NRC RAI Letter No. PTN-RAI-LTR-037

SRP Section: 02.05.02 - Vibratory Ground Motion

Question for Geosciences and Geotechnical Engineering Branch 1 (RGS1)

NRC RAI Number: 02.05.02-2 (eRAI 5896)

FSAR Subsection 2.5.2.4.5 describes new ground motion prediction equations (GMPEs) that the applicant developed for Caribbean region seismic sources. The basis of the new GMPEs is a scientific study conducted by Motazedian and Atkinson (2005) in the Puerto Rico area. In accordance with NUREG-0800, Standard Review Plan, Chapter 2.5.2, "Vibratory Ground Motion," and Regulatory Guide (RG) 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion":

a. Please explain why ground motion prediction models developed by Motazedian and Atkinson (2005) for the Puerto Rico region, which is primarily a subduction zone, provide an adequate basis for the larger Caribbean region, especially for the region between Cuba and Florida.

b. Please provide the complete Senior Seismic Hazard Analysis Committee (SSHAC) documentation for the Level 2 study conducted to develop the Caribbean GMPEs for the staff to specifically evaluate the makeup of the Technical Integrator (TI) team, the peer review panel, how the experts' opinions were integrated into the development of the final GMPE, whether any conflicting opinions among the experts were dealt with, and how the final GMPEs represent the consensus of the informed community.

c. Please provide copies of the following supporting calculations: Report #: 25409-000-K0C-0000-00009, Report#: 25409-000-K0C-0000-00024, Report #: 25409-000-K0C-0000-00034 to enable the staff to evaluate the technical details of the final GMPEs.

d. In order for the staff to be able to compare the new Caribbean GMPEs with the 2004/2006 EPRI mid-continent GMPEs, please provide plots showing both ground motion models for earthquake magnitudes of 6.0, 7.0, and 8.0 in the distance range of 200 km to 1000 km at all seven frequencies defined in the EPRI 2004 and 2006 GMPEs.

e. Discuss evidence, if any, that seismic source scaling varies regionally and/or between source types in the Caribbean. For example, is there any evidence that stress parameter varies systematically between the northern Hispaniola sources, the Caribbean plate-boundary transform fault sources, and the Cuba sources? If so, what are the implications for the attenuation models and hazard calculated at TPNPP?

FPL RESPONSE:

Part a: Please explain why ground motion prediction models developed by Motazedian and Atkinson (2005) for the Puerto Rico region, which is primarily a subduction zone, provide an adequate basis for the larger Caribbean region, especially for the region between Cuba and Florida.

The Motazedian and Atkinson (FSAR Reference 2.5.2-287) ground motion prediction equations (GMPEs) are not used directly to model attenuation of strong ground motion between Cuba (and the northern Caribbean) and southern Florida. Rather, after performing a literature review of possibly applicable GMPEs, the regional attenuation and source parameters developed by Motazedian and Atkinson from a Puerto Rico earthquakes dataset were selected as reasonable starting points from which to develop simulation-based ground motions for the estimation of a regional suite of GMPEs for use in the Turkey Point PSHA.

As noted in Garcia et al. (FSAR Reference 2.5.2-255), there are currently no calibrated GMPEs for Cuba and the surrounding region. Strong motion instruments have only recently been installed in 1998 and the amount of recorded empirical ground motion data from these instruments, which is operated by the Cuban agency (FSAR Reference 2.5.2-255), is limited or unavailable. In the absence of a local regionally based empirical GMPE, Garcia et al. (FSAR Reference 2.5.2-255) employed the use of other GMPEs from similar regions. Specifically the rock versions of the Dahle et al. [1995] and Ambraseys et al. [1996] relations were used for the rock seismic hazard assessment; the stiff soil version of the Ambraseys et al. [1996], the soil version of the Dahle et al. [1995], and the Motazedian and Atkinson relation (FSAR Reference 2.5.2-287) GMPE, which was developed for Puerto Rico for soft rock site conditions, were used for the soil hazard computation.

The Motazedian and Atkinson (FSAR Reference 2.5.2-287) study uses a dataset of approximately 300 earthquakes of magnitude 3.0-5.5 located on and around the island of Puerto Rico to develop regional ground motion attenuation and source parameters. Motazedian and Atkinson acknowledge that their ground motion dataset consisted of recorded ground motions from both crustal and subduction zone earthquakes and that the separation of the earthquakes used in their dataset into crustal and subduction events was not possible due to the limited data precision for Puerto Rico events.

To address this possible concern about the influence of using both subduction and crustal events to estimate the regional attenuation and source parameters, Motazedian and Atkinson (FSAR Reference 2.5.2-287) provide a comparison of their GMPE with representative GMPEs for central and eastern United States (FSAR Reference 2.5.2-210), California (Atkinson and Silva, 2000), and an empirically-based GMPE based on the global ground motion dataset for subduction zones (Atkinson and Boore, 2003). Motazedian and Atkinson conclude that, overall the Puerto Rico relations agree well with the stochastic relations for California and eastern North America and are quite different from those calculated by the global subduction relations. This comparison and noted results provide a technical justification for using the source and attenuation parameters from the Puerto Rico ground motion dataset (FSAR Reference 2.5.2-287) as the starting point for the development of applicable GMPEs for the Caribbean seismic sources.

In developing our Caribbean GMPEs, a number of sensitivity studies were performed, including some that considered a range of anelastic attenuation parameters in an attempt to capture uncertainty in the attenuation of ground motion over propagation paths that, in part, run through the Gulf Coast region crust between the northern Caribbean and southern Florida. Details of the development and validation of the resulting Caribbean GMPEs are presented below in the response to Part b.

Part b: **Please provide the complete Senior Seismic Hazard Analysis Committee (SSHAC) documentation for the Level 2 study conducted to develop the Caribbean GMPEs for the staff to specifically evaluate the makeup of the Technical Integrator (TI) team, the peer review panel, how the experts' opinions were integrated into the development of the final GMPE, whether any conflicting opinions among the experts were dealt with, and how the final GMPEs represent the consensus of the informed community.**

As noted above, only limited empirical strong motion attenuation information has been found for the Caribbean, and existing studies of earthquake hazard depend significantly on adoption of ground motion prediction equations (GMPEs) from other regions. No studies have been found modeling attenuation of strong ground motion between earthquakes in the Caribbean and sites in the CEUS so that no experts could be identified who could be characterized as a proponent, which NUREG/CR-6372 defines as "an expert who advocates a particular hypothesis or technical position" (FSAR Reference 2.5.2-318). The absence of a proponent or proponents made it difficult to categorize the level of the study per the SSHAC guidelines. However, what has been done in this regard is otherwise fully consistent with industry practice in general and the SSHAC guidelines in particular as will be more fully discussed in the ***SSHAC Study Summary*** section of this response.

Initial development of a suite of Caribbean GMPEs was performed by, what in SSHAC nomenclature would be called, the Technical Integration team of two Bechtel seismologists: Drs. Nick Gregor and Behrooz Tavakoli, both with significant experience in generating and evaluating GMPEs. Peer review was provided by a Technical Advisory Group (TAG) at several points throughout the GMPE development process. A resource expert, Dr. Dariush Motazedian of Carleton University, Ottawa, Canada, was also consulted during this time.

This response first summarizes in more detail the initial development of the Caribbean GMPEs, which included, with the participation, guidance, and acceptance of the TAG, an examination of the sensitivity of these GMPEs to alternative source and anelastic attenuation parameters. This response then goes on to discuss the subsequent further confirmation of the reasonableness and conservatism of these Caribbean GMPEs as obtained through both the performance of additional sensitivity studies and the solicitation of comments from a panel of additional recognized strong ground motion attenuation experts.

Initial GMPE Development Summary

A suite of GMPEs was developed with guidance from a Technical Advisory Group (TAG) whose members were:

- Dr. Robert Kennedy (RPK Structural Mechanics Consulting)
- Dr. William McCann (Earth Scientific Consultants)
- Mr. Donald Moore (Southern Nuclear Operating Company)
- Dr. J. Carl Stepp (Earthquake Hazards Solutions)
- Dr. Robert Youngs (Geomatrix Consultants, currently AMEC-Geomatrix)

Three TAG meetings and an additional TAG review after the third meeting provided a forum for the TAG members to review progress and to offer participatory peer review guidance on the development of the Caribbean GMPEs.

Initially a literature review was performed with the goal of retrieving acceptable GMPEs for the Cuba and Caribbean region as appropriate for use in the site PSHA. However, this literature review only retrieved one GMPE developed recently by Motazedian and Atkinson (FSAR Reference 2.5.2-287). In addition to the interaction with the TAG members, correspondence was conducted with Professor Motazedian during the initial development of the Caribbean GMPEs. These initial technical discussions were for the possible application of the published Motazedian and Atkinson (FSAR Reference 2.5.2-287) GMPE for the PSHA study. However, based on the limitations of this GMPE (e.g., incomplete suite of necessary spectral frequencies, limited application for distances greater than 500 km, and site-specific ground conditions of soft rock), it was determined that this published GMPE was not directly acceptable for use in the PSHA.

For the development of the GMPEs for the Cuba and Caribbean region, the regionally determined source and attenuation parameters from Motazedian and Atkinson (FSAR Reference 2.5.2-287) were used with a point-source stochastic ground motion methodology to develop a suite of nine GMPEs applicable for the large distance and large magnitude range needed for the PSHA.

At the suggestion of TAG members over the course of the three TAG meetings, alternative GMPE relationships were considered to examine the sensitivity of the initial GMPEs to alternative source and anelastic attenuation properties. Specifically, the effect on GMPE results of adopting a double corner (2C) seismic source model was examined, recognizing that the active northern Caribbean plate margin, the source of the fault seismic sources used for the PSHA, might be expected to act like a more active tectonic environment such as the western United States (WUS) rather than the less active tectonic environment of the central and eastern United States (CEUS). In addition, a Gulf Coast region anelastic attenuation factor (Q) model rather than the Puerto Rico region-specific Q model from Motazedian and Atkinson (FSAR Reference 2.5.2-287) was analyzed, recognizing that much of the propagation path from the Caribbean sources to the Turkey Point Units 6 & 7 site, especially the Cuban areal source, is through the Gulf Coast Region-like crust.

It was found that adoption of alternatives suggested by the TAG (i.e., different suite of regional attenuation and seismic source parameter values) led to ground motion values that were equal to (at large distances based on the anelastic attenuation rates) or lower than (based on the different magnitude scaling from the WUS- based double corner model) the suite of original nine new GMPE models adopted for the Cuba and Caribbean region. A

comparison of the weighted combination of the original nine GMPE models and the inclusion of these additional sensitivity models resulted in a slightly lower weighted mean GMPE curve over the magnitude and distance range needed for the PSHA. Therefore, their incorporation into the final PSHA results would have slightly lowered the already low hazards, and thus, the use of the original nine GMPE models was accepted by the TAG members because the inclusion of these additional GMPE models would be expected to lead to lower, and less conservative, ground motion results.

In a review of these results after the third and final TAG meeting, and in a comparison of initial GMPE models with the accepted EPRI 2004 (FSAR Reference 2.5.2-242) eastern US ground motion models, the TAG concluded that the results satisfactorily responded to their recommendations.

With satisfaction of all TAG recommendations, the original suite of nine GMPE models was concluded to be acceptable and was used for development of probabilistic seismic hazard analysis (PSHA) for the Turkey Point Units 6 & 7 FSAR. In response to this RAI, supplemental sensitivity studies have been performed and solicitation of additional expert comment has been made. The results of this additional work are presented below in the ***Supplemental Sensitivity Studies*** and ***SSHAC Study Summary*** sections, respectively.

Supplemental Sensitivity Studies

After the suite of nine GMPEs was developed, two additional sensitivity analyses were performed to further validate the technical assessment of the stochastic Caribbean GMPE models developed for Turkey Point Units 6 & 7. These analyses sought additional empirical data with which to compare the Caribbean GMPEs and examined the effect of alternate suites of GMPEs on the PSHA results at the site. The results of these two additional sensitivity studies are presented here.

The first supplemental sensitivity analysis compared the suite of nine GMPEs used in the Turkey Point Units 02.05.02-5

PSHA with empirical regional ground motion data recorded at broadband site locations in the Caribbean and Central America area and the southeastern and eastern United States and made publically available by the Incorporated Research Institutions for Seismology (IRIS). To assist in the technical evaluation of the current Caribbean GMPE models developed for the Turkey Point Units 6 & 7 FSAR a comparison of empirical ground motions from five regional earthquakes occurring since 2004 in the Gulf of Mexico and northern Caribbean region were analyzed. These earthquakes were selected based on a search of the IRIS database for the Caribbean region for moderate to large earthquakes that were recorded on seismic instruments in the southeastern United States, Gulf of Mexico, Central America, and Caribbean region. The intention was to select earthquakes from among those available that were likely to be most representative of earthquakes whose tectonic settings and locations might be expected to be like those of future earthquakes contributing to the overall PSHA at the site under the source model adopted. Specifically, these were non-subduction zone earthquakes in the northern Caribbean or Gulf of Mexico.

Regional broadband empirical data from selected Incorporated Research Institutions for Seismology (IRIS) stations were obtained, processed and compared to the suite of Caribbean GMPE models and the suite of EPRI 2004 and 2006 (FSAR References 2.5.2-

242 and 203) GMPE models for both the Mid-continent and Gulf Coast regional models. Based on these comparisons, a technical assessment can be made on the applicability of using the Caribbean GMPE for the Turkey Point Units 6 & 7 PSHA.

Note that the current PSHA results were developed using the suite of EPRI 2004 and 2006 (FSAR References 2.5.2-242 and 2.5.2-203) Mid-continent GMPE models for other non-Caribbean sources. In this comparison all of the GMPE curves are for the assumed CEUS hard rock site conditions with Vs = 2.83 km/sec, whereas the empirical IRIS data are initially for the individual, and largely unknown site conditions of each station that would generally be expected to be less than Vs = 2.83 km/sec. Based on simplified site response analysis it would be expected that an adjustment for the station-specific site conditions to the more stable CEUS hard rock site conditions would require a reduction factor in the observed empirical ground motion values, including for the shorter spectral frequencies of interest (e.g., 1 or 2.5 Hz).

To better quantify the effect of subsurface conditions at the various IRIS recording sites, available information on these conditions was gathered and used to develop estimates of site amplification correction factors to apply to the raw IRIS data in making comparisons of these data with the Caribbean GMPEs used in the Turkey Point PSHA, as well as with the alternative GMPEs. This subsurface information consisted of various types of data ranging from geologic descriptions and or pictures to subsurface shear-wave velocity information. For all cases, an estimate of the average shear-wave velocity in the top 30m (Vs30m) was made for each of the IRIS stations. Next given these estimated values, frequency-dependent site amplification factors were computed based on the site response model of Boore and Atkinson (2007) for a reference site condition of Vs30m=760 m/sec. The Vs30m=760 m/sec amplifications were further adjusted by applying published frequency-dependent amplification factors for the amplification of ground motions from a Vs30m=760 m/sec to a typical CEUS hard rock site conditions. These final site-specific amplification factors were developed using both the Frankel et al. (1996) (FSAR Reference 2.5.2-252) and Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) methodology. In addition to the site amplification corrections, a uniform and frequency independent free surface effect scale factor of 2.0 was applied for those IRIS instrument recordings which were located at some depth below the ground surface. There were two stations of this type: TEIG on the Yucatan Peninsula and, importantly, DWPF in central Florida.

The current deaggregation of seismic hazard at the Turkey Point Units 6 & 7 site from all sources, Cuban, Caribbean, and southeast United States, is shown in Figure 1 (FSAR Figure 2.5.2-226 and Figure 2.5.2-228) for longer period motions (for which the relative contribution of the larger, more distant Cuban and Caribbean sources would be expected to have their greatest relative contribution) and for the 10^{-4} and 10^{-5} mean annual frequency of exceedance probabilities used to develop design ground motions under current NRC regulatory guidance. The relative contribution for the higher frequency cases of 5 and 10 Hz (see FSAR Figures 2.5.2-227 and 2.5.2-229) from the more distant Caribbean sources is significantly less than the contribution from the closer local seismic sources. For this sensitivity analysis, the empirical ground motions for 1 and 2.5 Hz for each of the five regional earthquakes are compared to the Caribbean GMPEs.

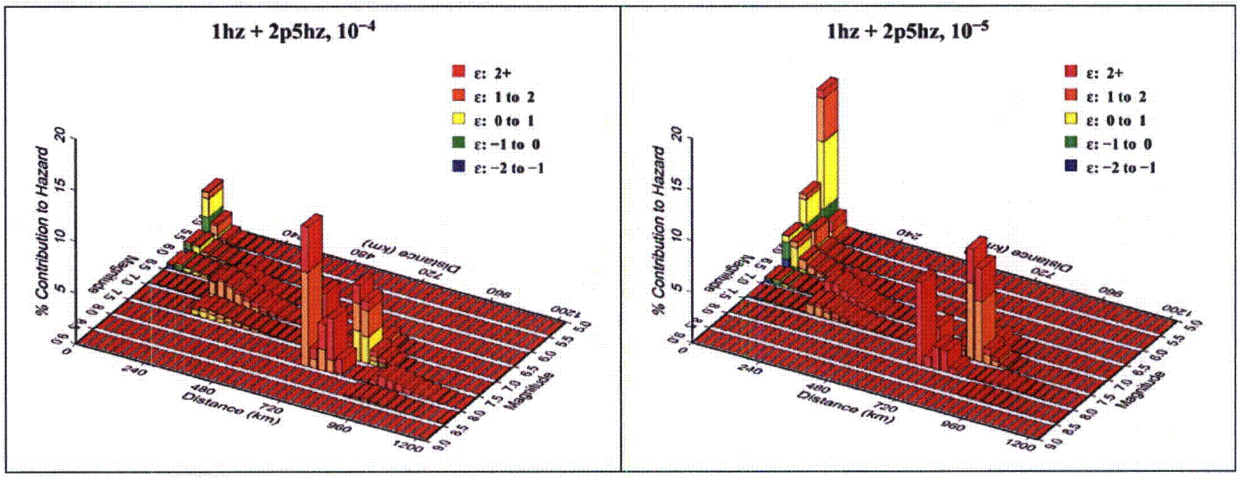

Figure 1. Magnitude and Distance Deaggregation for 1 and 2.5 Hz at 10^{-4} and 10^{-5} Annual Frequencies of Exceedance.

The five regional earthquakes that have been analyzed are:

- 12/14/2004 – Caribbean Sea Region (M_w6.8, 19.05 N, -81.52 W, hypocenter depth 12.0 km)
  Fault Plane 1 (Strike, Dip, Rake): 258.0, 84.0, -2.0; Fault Plane 2 (Strike, Dip, Rake): 349.0, 88.0, -174.0. The fault plane solution implies almost pure strike-slip motion on a nearly vertically dipping fault.
- 09/10/2006 – Gulf of Mexico (M_w5.9, 26.32 N, -86.84 W, hypocenter depth 29.6 km)
  Fault Plane 1 (Strike, Dip, Rake): 324.0, 28.0, 117.0; Fault Plane 2 (Strike, Dip, Rake): 114.0, 65.0, 77.0. The fault plane solution implies composite strike-slip and reverse-slip motion on a moderately steeply dipping fault.
- 02/04/2007 – Cuba Region (M_w6.2, 19.49 N, -78.34 W, hypocenter depth 12.0 km)
  Fault Plane 1 (Strike, Dip, Rake): 257.0, 76.0, -9.0; Fault Plane 2 (Strike, Dip, Rake): 349.0, 81.0, -166.0. The fault plane solution implies almost pure strike-slip motion with a small normal component on a steeply dipping fault.
- 05/28/2009 – North of Honduras (M_w7.3, 16.50 N, -87.17 W, hypocenter depth 12.0 km)
  Fault Plane 1 (Strike, Dip, Rake): 63.0, 60.0, -7.0; Fault Plane 2 (Strike, Dip, Rake): 156.0, 84.0, -150.0. The fault plane solution implies predominantly strike-slip with a smaller normal component on a moderately to steeply dipping fault.
- 01/12/2010 – Haiti (M_w7.0, 18.61 N, -72.62 W, hypocenter depth 12.0 km)
  Fault Plane 1 (Strike, Dip, Rake): 250.0, 71.0, 22.0; Fault Plane 2 (Strike, Dip, Rake): 152.0, 69.0, 159.0. The fault plane solution implies composite strike-slip with a moderate reverse component on a steeply dipping fault.

Note that, based on the hypocentral location and geographical location relative to tectonic plate boundary, none are associated with any regional subduction zones, four are associated with the northern boundary of the Caribbean plate, while the remaining Gulf of Mexico earthquake is within the region that may be characterized as Gulf Coast Region-like crust (see, for example, Electric Power Research Institute, 2013, Figure 1.3-1). Based on

this simplified tectonic classification for the events considered, the Gulf of Mexico earthquake would be the most representative event for earthquakes originating in the island of Cuba whereas the other four events would be a better representation of the events associated with the more distant northern Caribbean tectonic plate boundary seismic sources located south of the island of Cuba and extending both to the east and west of the Island.

For each event, a standard time history processing methodology was applied with the final results being a dataset of acceleration time histories and their acceleration response spectra for a spectral damping of 5%. More specifically, the time history processing methodology consisted of the following steps:

- Removal of the mean from time series.
- Removal of any linear trend from time series.
- Application of a Hanning window to taper start and end of the record.
- Removal of the instrument response which results in a displacement time series.
- Application of a 4-pole Butterworth high pass filter with a filter corner of 0.1Hz.
- Removal of the mean from the resulting time series.
- Removal of any linear trend from the resulting time series.
- Differentiation of the displacement time series to obtain velocity and acceleration time series.
- Calculation of the 5% damped response spectrum from the time series.

The geometric mean of the two horizontal components was computed and comparison plots for the 1 and 2.5 Hz spectral frequencies were generated showing the empirical data and the suite of GMPE models (i.e., both of the EPRI, 2004 (FSAR Reference 2.5.2-242), GMPE models and the Caribbean GMPE models). Both the raw IRIS spectral accelerations and these data corrected to estimates of equivalent hard rock site condition spectral accelerations (as discussed above) are compared.

Both the individual GMPE curves and the weighted mean GMPE curve for a given GMPE set are shown in the comparison plots for each spectral frequency and earthquake. For the EPRI, 2004 (FSAR Reference 2.5.2-242), GMPE model, only Clusters 1, 2, and 3 were considered because no model comparable to an EPRI 2004 (FSAR Reference 2.5.2-242) Cluster 4 model was included in the Caribbean GMPE suite. Sensitivity analysis focusing on low frequency ground motions from large magnitude earthquakes (the motions most likely to include significant contributions to the total PSHA results from Caribbean sources) show that inclusion of the EPRI 2004 (FSAR Reference 2.5.2-242) Cluster 4 GMPE with the GMPEs of Clusters 1, 2, and 3 would have lowered the weighted means of both the Midcontinent and Gulf Coast models, making the comparison of the Caribbean GMPEs more conservative relative to these two alternative EPRI, 2004, GMPE models (FSAR Reference 2.5.2-242).

Caribbean Sea Region (M_w6.8), 12/14/2004:

This event occurred in the Caribbean Sea region and its epicenter is shown in Figure 2a along with the Turkey Point Units 6 & 7 site location, and the location of the IRIS stations whose recorded data for this earthquake were analyzed. Based on the observed station distribution, the IRIS station DWPF located in central Florida has the most applicable

source to site path for this comparison. The GMPE curves and empirical data are shown in Figures 2b and 2c for the 1 and 2.5 Hz spectral frequencies. The data point from the DWPF station is highlighted as a solid blue symbol. The circle symbols are for the raw recorded IRIS data with no adjustment based on the difference in site conditions from the CEUS hard rock site conditions. The square and diamond symbols are the IRIS data adjusted using the two different amplification factors for CEUS hard rock site conditions and the free surface factor of 2 for TEIG and DWPF IRIS instruments not located on the ground surface. Overall the empirical data falls below the median Caribbean GMPE curve (heavy red line) and has values that are in the lower distribution range of Caribbean curves. In addition, the observation from the DWPF station is lower than the entire range of the Caribbean GMPE curves.

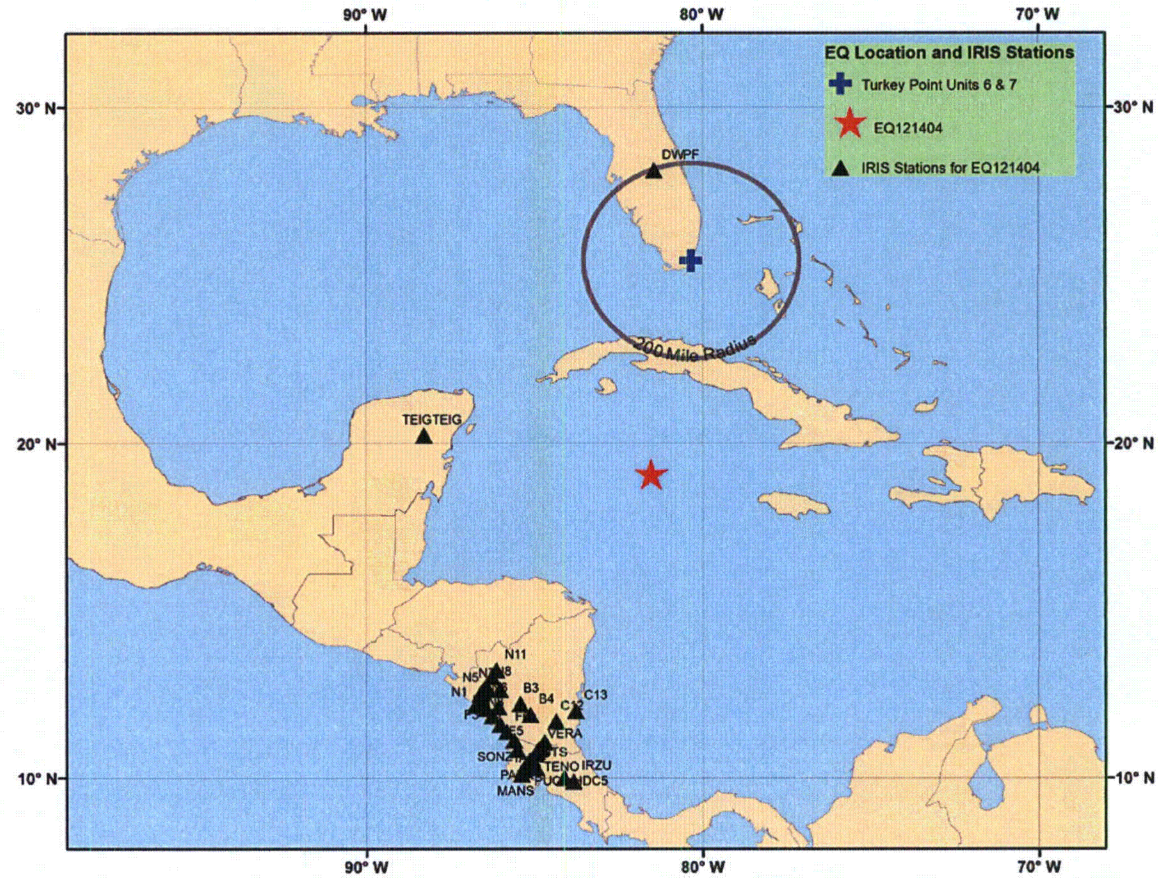

Figure 2a. Map showing the earthquake location for the 12/14/2004 Caribbean Sea Region earthquake (M_w6.8), the IRIS station locations used in the analysis (shown as black triangles in this and similar subsequent figures), and Turkey Point Units 6 & 7 site location.

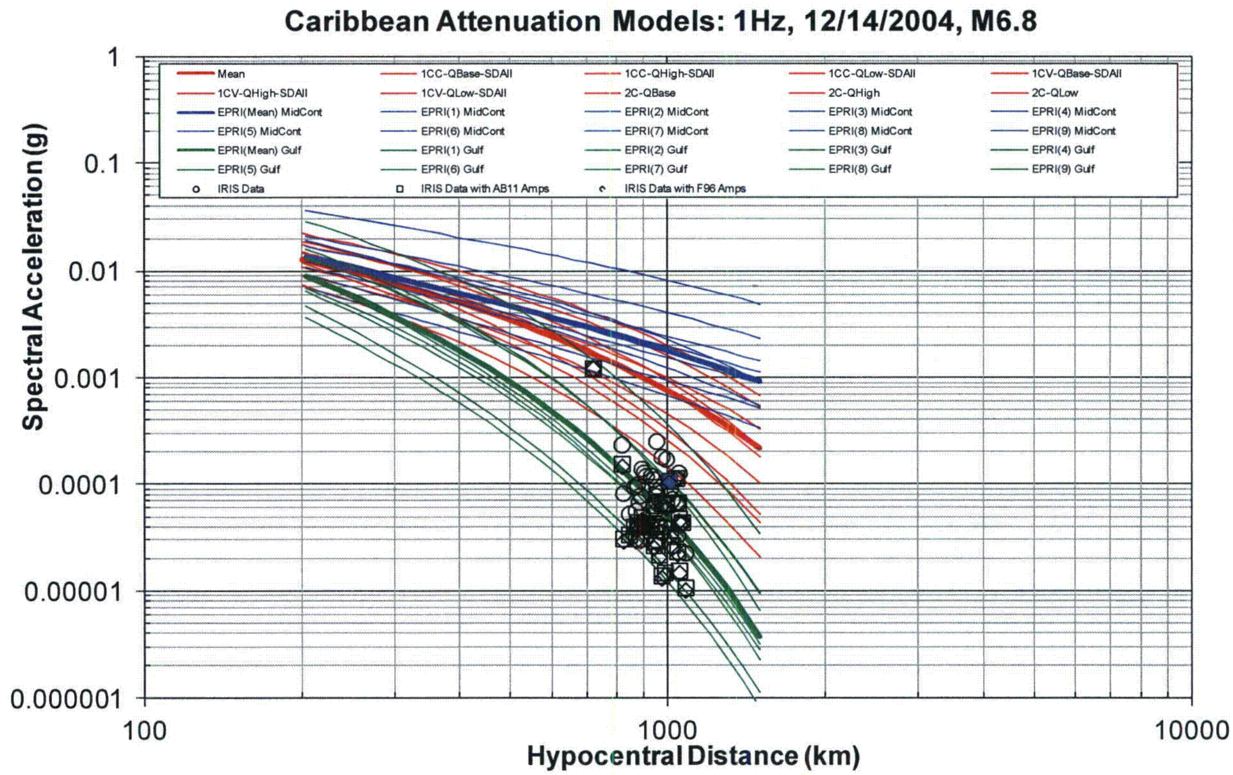

Figure 2b. Comparison of Caribbean (red), EPRI (2004) (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 2.5.2-252) amplification factor corrections (open diamonds) for a spectral frequency of 1 Hz.

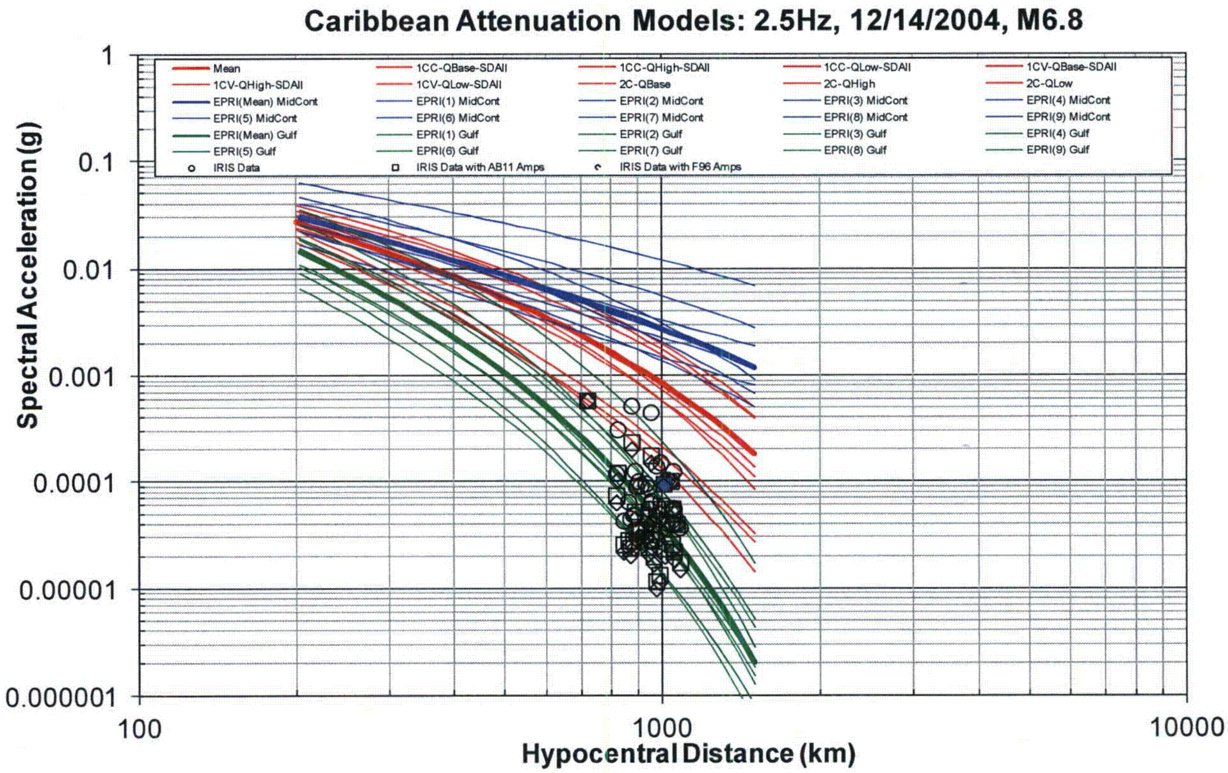

Figure 2c. Comparison of Caribbean (red), EPRI 2004 (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (FSAR Reference 2.5.2- 252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

Gulf of Mexico (M_w5.9), 09/10/2006:

This event occurred in the Gulf of Mexico and its epicenter is shown in Figure 3a along with the Turkey Point Units 6 & 7 site location, and the location of the IRIS stations whose recorded data for this earthquake were analyzed. Based on the observed station distribution, the IRIS station DWPF located in central Florida has the most applicable source to site path for this comparison. The stations in the central United States have a less applicable travel path azimuth and may show different attenuation properties based on these different tectonic travel paths. Out of the five earthquakes considered in this analysis, this event has the most consistent crustal structure between the earthquake and the Turkey Point Units 6&7 site and can be considered as the best representative event for events occurring in the island of Cuba and being observed in Southern Florida.

The GMPE curves and empirical data are shown in Figures 3b and 3c for the 1 and 2.5 Hz spectral frequencies. The data point from the DWPF station is highlighted as solid blue symbols (circle is the uncorrected data and the square and diamond symbol are for the adjusted CEUS hard rock site condition data including the free surface factor). In general

the empirical observations fall within the range of the Caribbean GMPE curves with the single exception of station LRAL (i.e., at a distance of about 750 km) for 2.5 Hz for which the unadjusted empirical data exceeds the highest Caribbean GMPE curve. For this station and frequency, however, the CEUS hard rock adjusted ground motions fall within the range of Caribbean GMPE models which are defined for CEUS hard rock site conditions. It can also be concluded from the comparison plots in Figures 3b and 3c, that the distribution of the current Caribbean GMPE curves adequately captures the range of the empirical data. In addition, the observation from the DWPF station is in the lower range of the Caribbean GMPE curves.

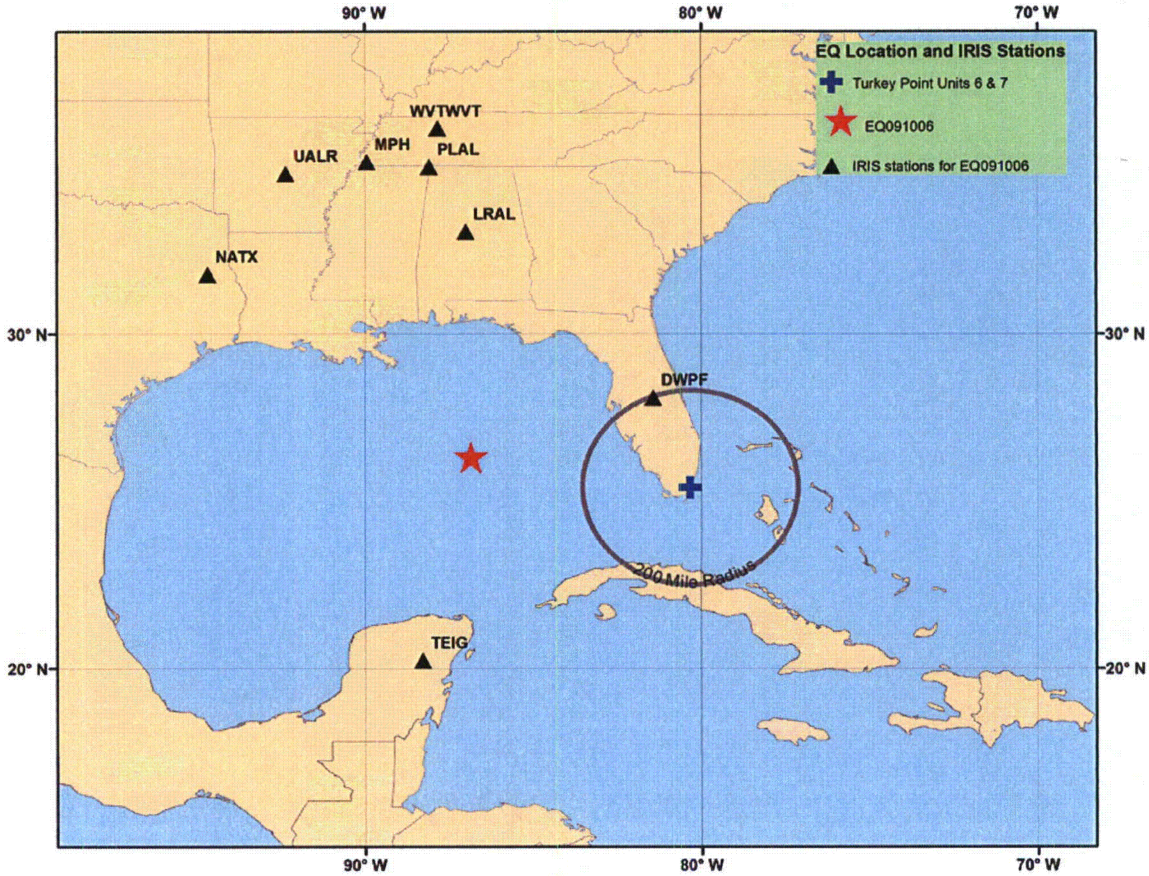

Figure 3a. Map showing the earthquake location for the 09/10/2006 Gulf of Mexico earthquake (M_w5.9), the IRIS station locations used in the analysis and Turkey Point Units 6 & 7 site location.

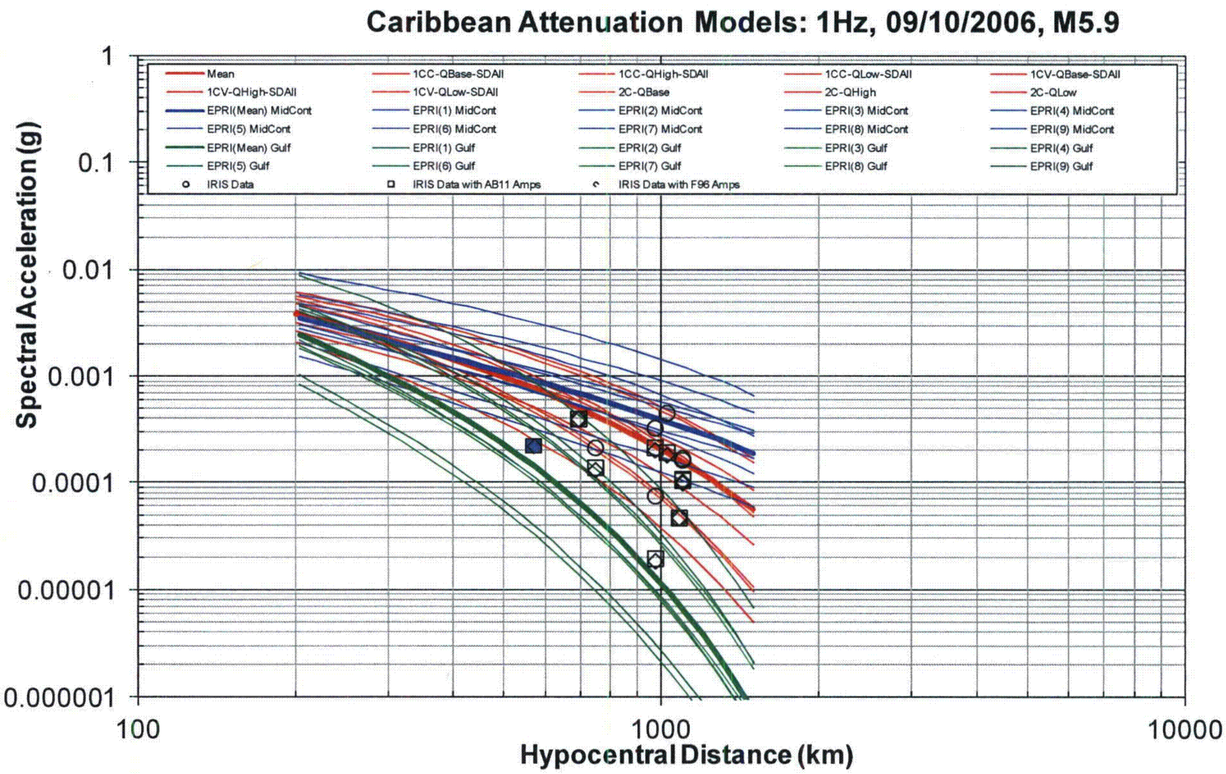

Figure 3b. Comparison of Caribbean (red), EPRI (2004) (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (FSAR Reference 2.5.2-252) amplification factor corrections (open diamonds) for a spectral frequency of 1 Hz.

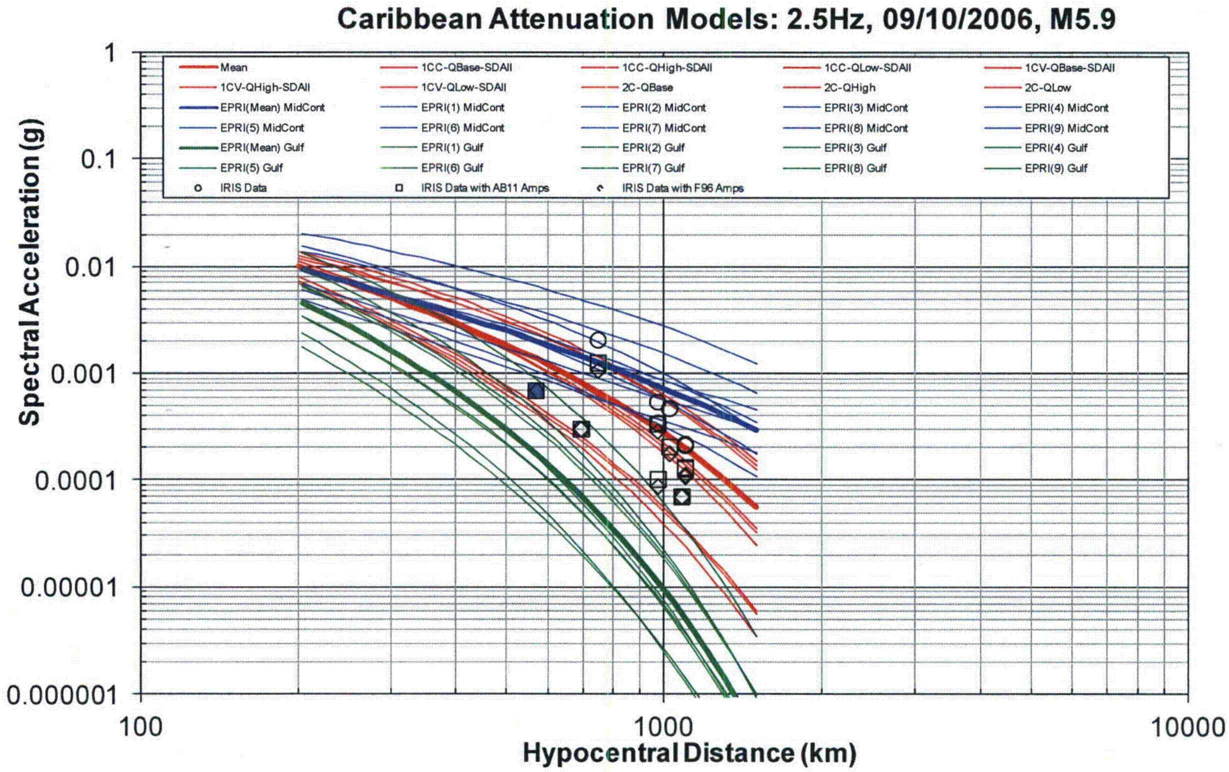

Figure 3c. Comparison of Caribbean (red), EPRI (2004) (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (FSAR Reference 2.5.2-252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

<u>Cuba Region (M_w6.2), 02/04/2007:</u>

This event occurred south of the island of Cuba and its epicenter is shown in Figure 4a along with the Turkey Point Units 6 & 7 site location, and the location of the IRIS stations whose recorded data for this earthquake were analyzed. Only three IRIS stations were analyzed from this earthquake and their station locations are shown in Figure 4a. Based on the observed station distribution, the IRIS station DWPF located in central Florida has the most applicable source to site path for this comparison. The GMPE curves and empirical data are shown in Figures 4b and 4c for the 1 and 2.5 Hz spectral frequencies. The data point from the DWPF station is highlighted as solid blue symbols. The uncorrected recorded motion is the blue circle symbol and the blue square and diamond symbols are the adjusted ground motion values including the free surface factor. Overall the empirical data fall below the median Caribbean GMPE curve (heavy red line) and have values which are in the lower distribution range of Caribbean GMPE curves. In addition, the observation from the DWPF station is similar to the lowest Caribbean GMPE curve or lower.

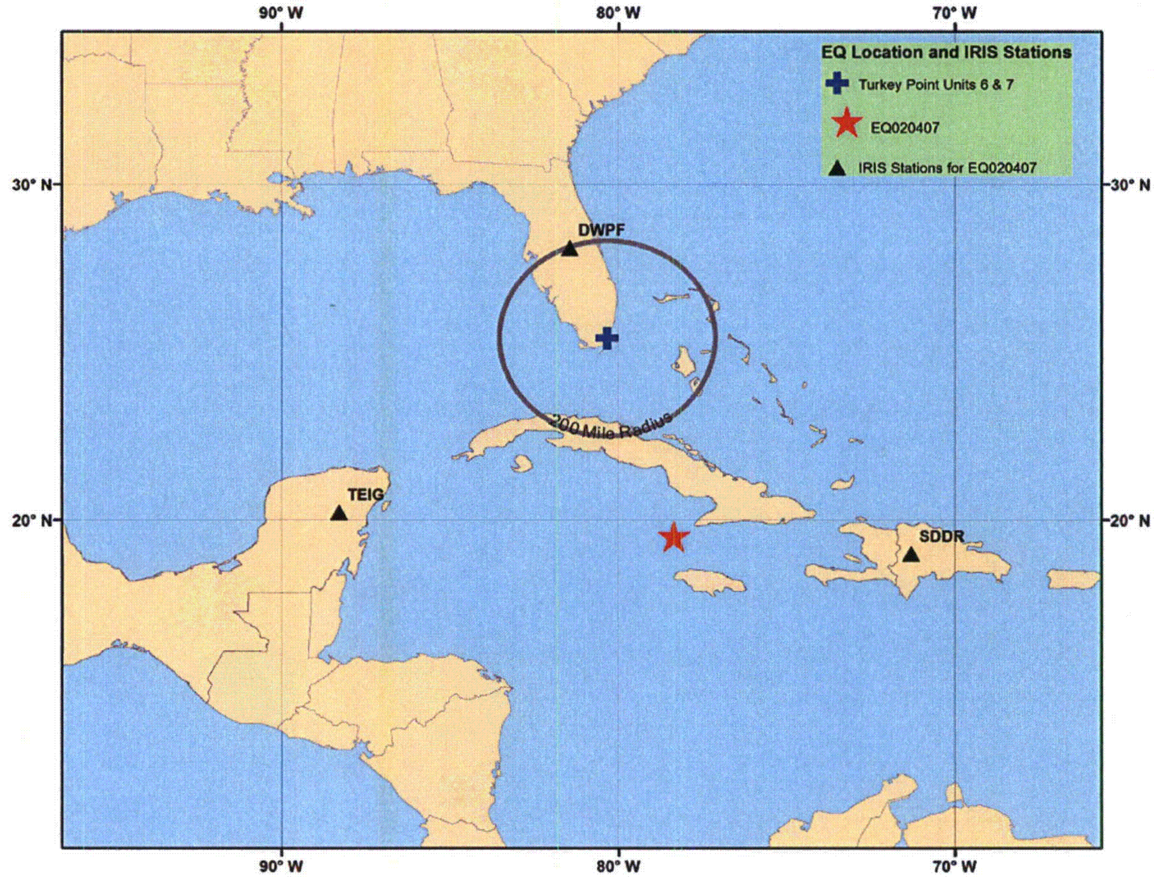

Figure 4a. Map showing the earthquake location for the 02/04/2007 Cuba Region earthquake (M_w6.2), the IRIS station locations used in the analysis and Turkey Point Units 6 & 7 site location.

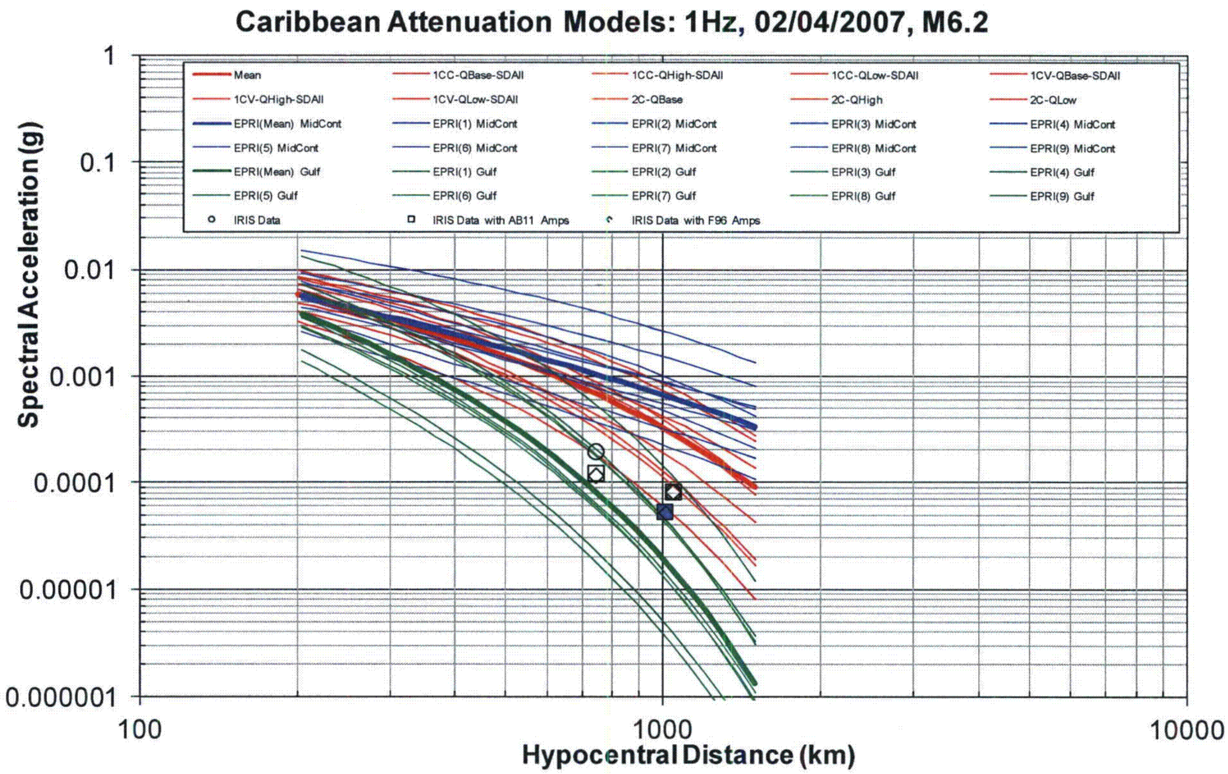

Figure 4b. Comparison of Caribbean (red), EPRI (2004) (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (FSAR Reference 2.5.2-252), amplification factor corrections (open diamonds) for a spectral frequency of 1 Hz.

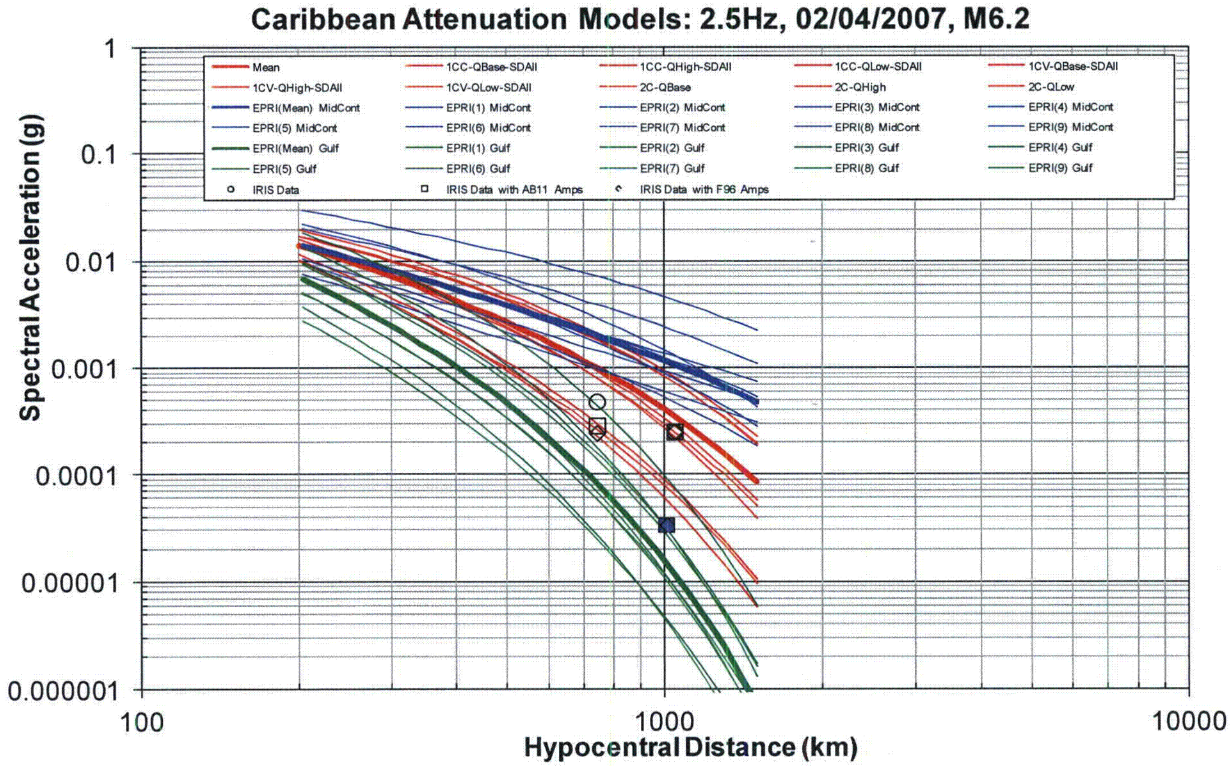

Figure 4c. Comparison of Caribbean (red), EPRI (2004) (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (FSAR Reference 2.5.2-252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

North of Honduras (M_w7.3), 05/28/2009:

This event occurred north of Honduras in Central America and is the largest earthquake in the suite of five events analyzed in this sensitivity study. The location of its epicenter is shown in Figure 5a along with the Turkey Point Units 6 & 7 site location, and the location of the three IRIS stations that were analyzed. Based on the azimuths from the earthquake to the three IRIS stations, none of the associated seismic ray travel paths are ideal for this comparison study. The GMPE curves and empirical data are shown in Figures 5b and 5c for the 1 and 2.5 Hz spectral frequencies. The comparisons provided in the figures indicate that the empirical data from this earthquake are lower than any of the Caribbean GMPE curves.

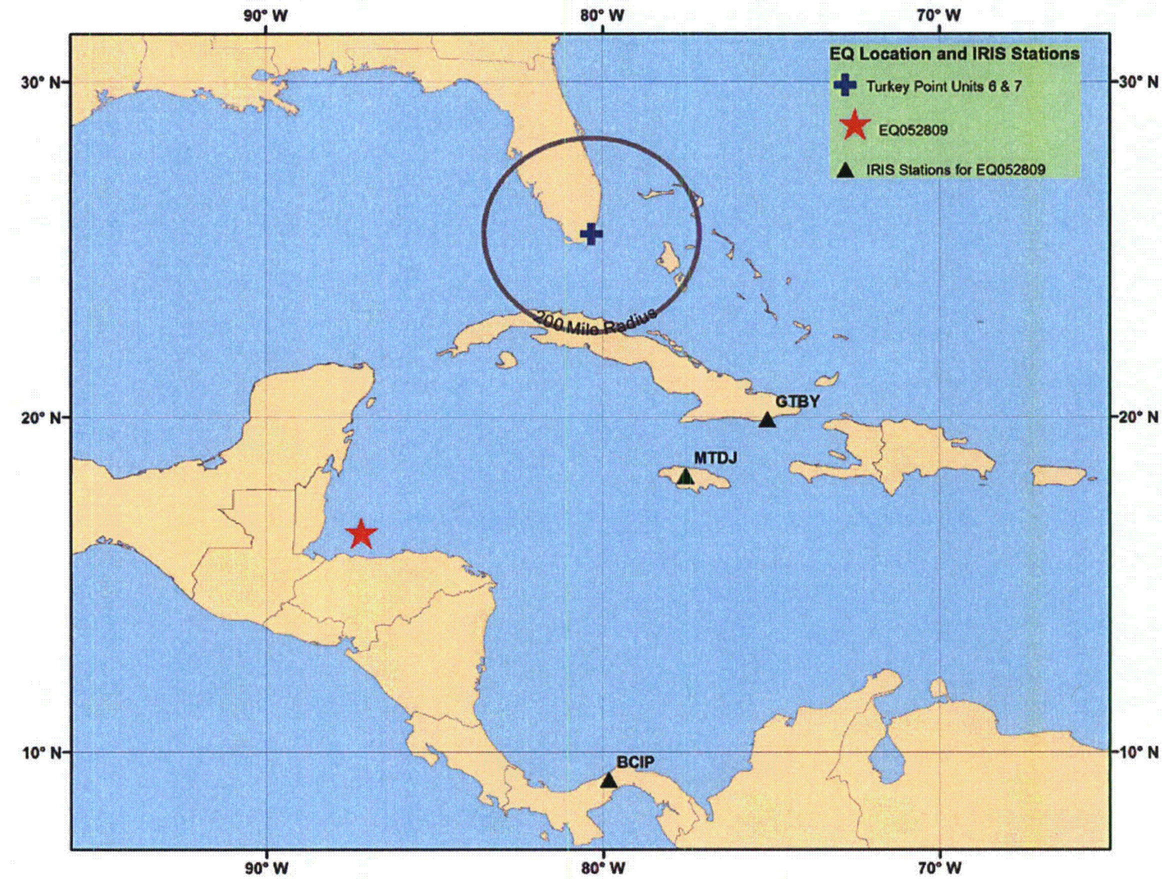

Figure 5a. Map showing the earthquake location for the 05/28/2009 North of Honduras earthquake (M_w7.3), the IRIS station locations used in the analysis and Turkey Point Units 6 & 7 site location.

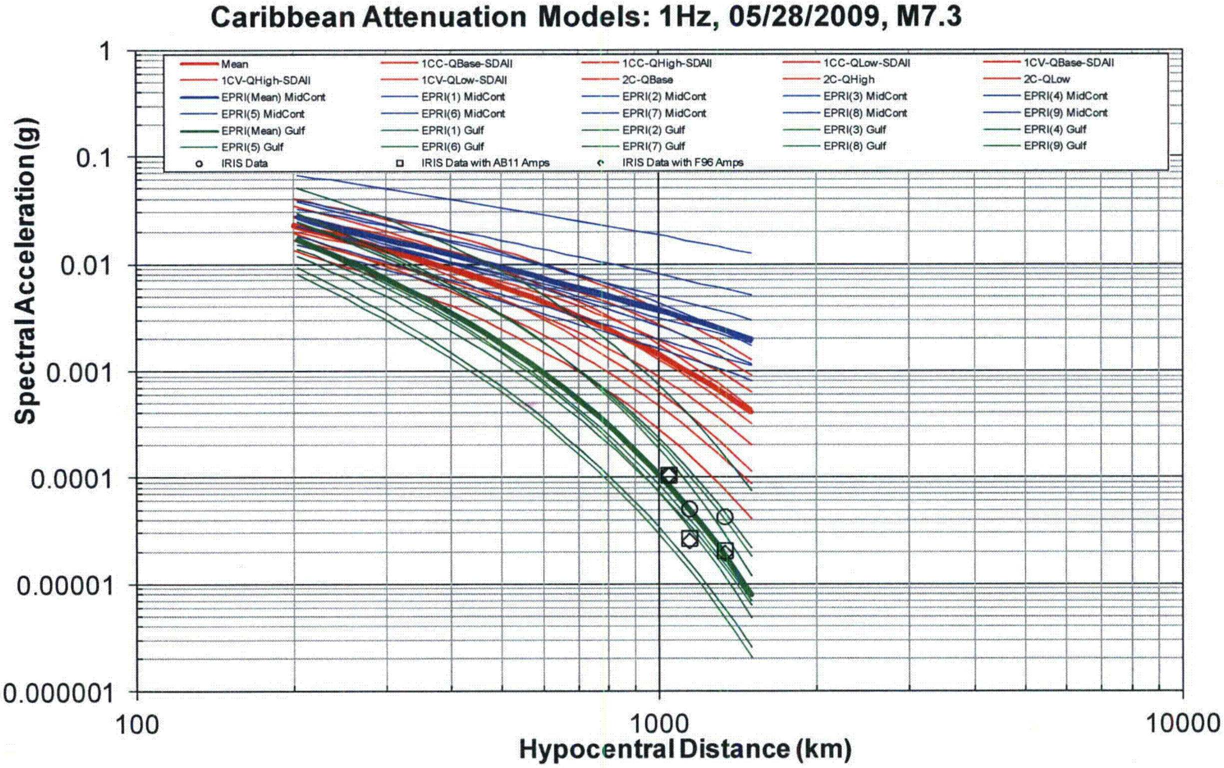

Figure 5b. Comparison of Caribbean (red), EPRI (2004) (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (FSAR Reference 2.5.2-252) amplification factor corrections (open diamonds) for a spectra frequency of 1.

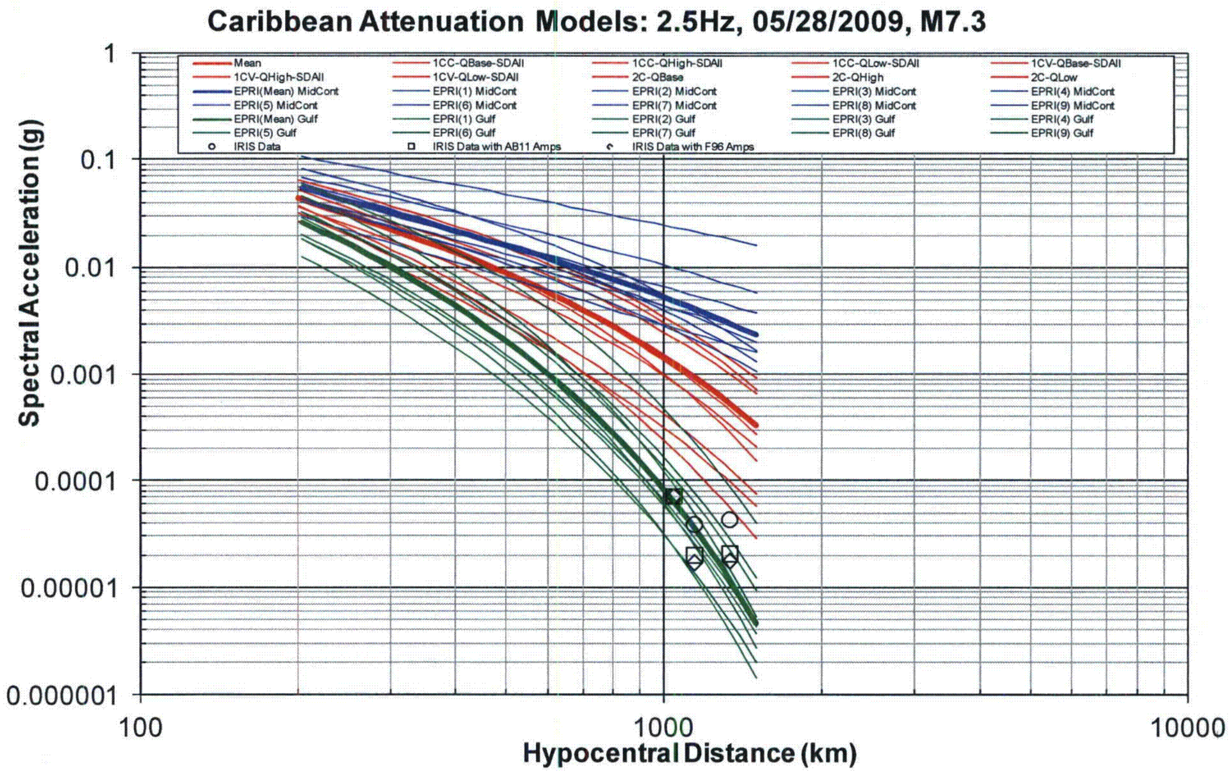

Figure 5c. Comparison of Caribbean (red), EPRI (2004) (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (FSAR Reference 2.5.2-252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

<u>Haiti (M_w7.0), 01/12/2010:</u>

The Haiti earthquake is the most recent event in this suite of five earthquakes analyzed. The epicentral location and the suite of IRIS stations analyzed are shown in Figure 6a. Note that the data from the DWPF were not available for this earthquake. For the SDV station, only one single horizontal component was available and thus was not included in the comparison which was based on the geometric mean of two horizontal component ground motions. The large distance and undesirable azimuthal direction away from Southern Florida for this station from this earthquake provides an additional justification for not including this station in the comparison. The GMPE curves and empirical data are shown in Figures 6b and 6c for the 1 and 2.5 Hz spectral frequencies. Overall the empirical data fall in the lower range or lower than the Caribbean GMPE curves.

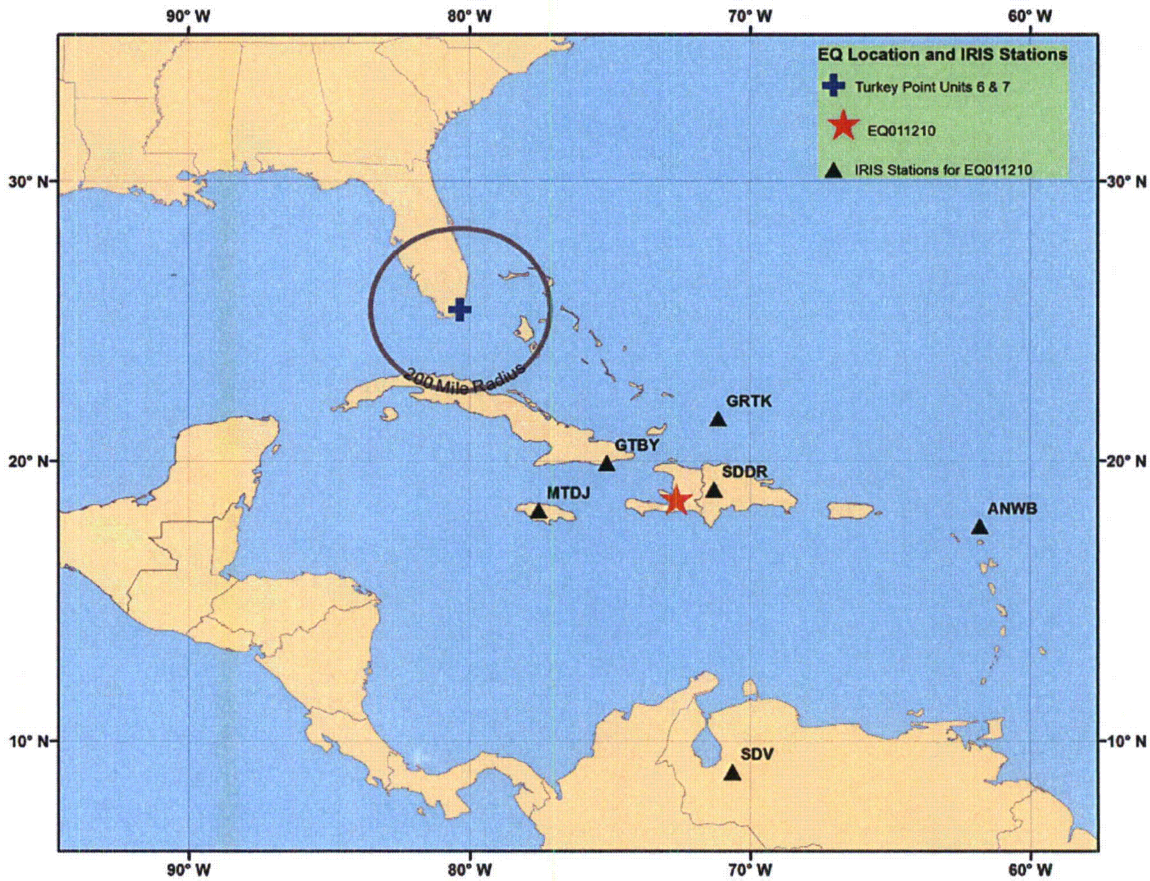

Figure 6a. Map showing the earthquake location for the 01/12/2010 Haiti earthquake (M_w7.0), the IRIS station locations used in the analysis and Turkey Point Units 6 & 7 site location.

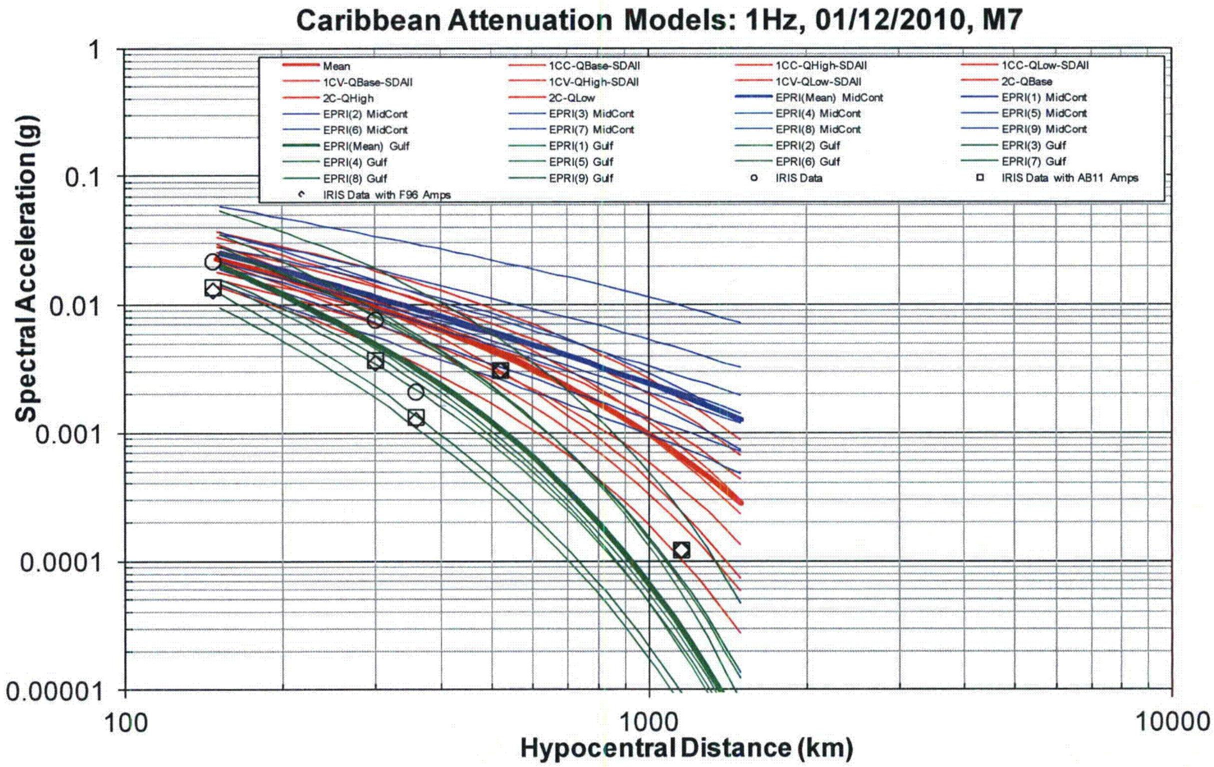

Figure 6b. Comparison of Caribbean (red), EPRI (2004) (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (FSAR Reference 2.5.2-252) amplification factor corrections (open diamonds) for a spectral frequency of 1 Hz.

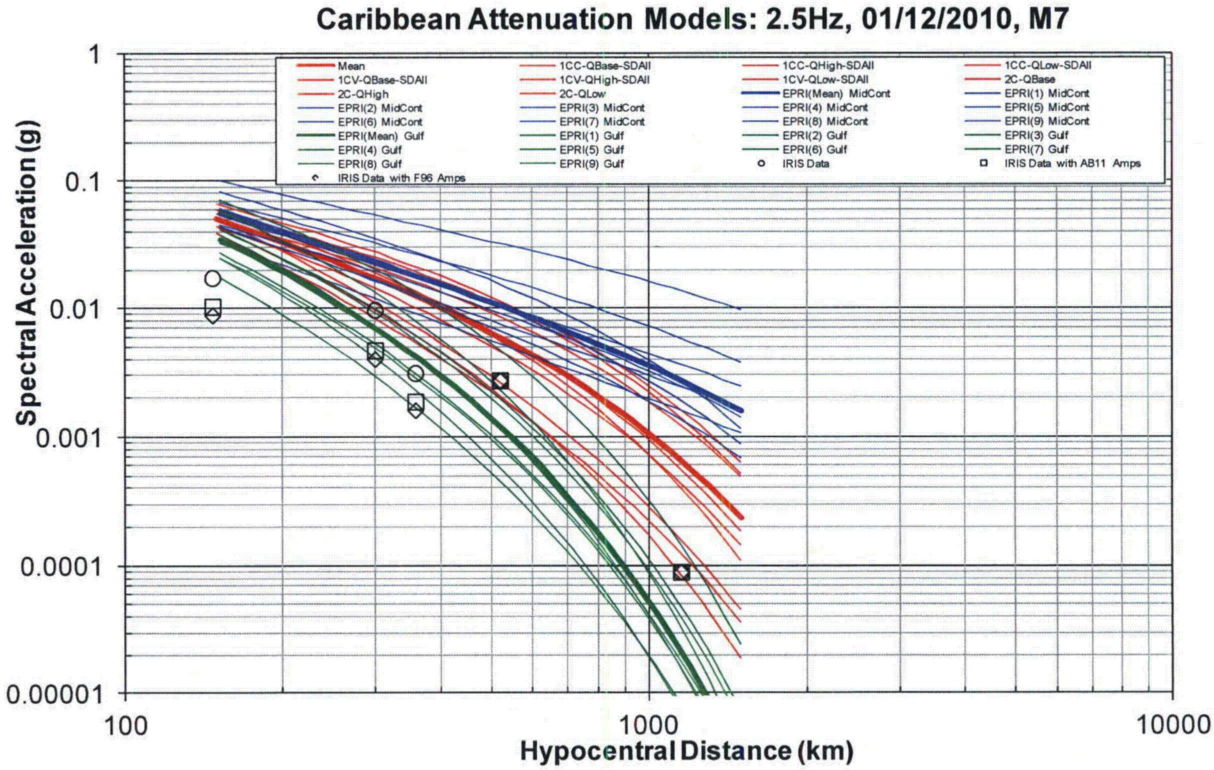

Figure 6c. Comparison of Caribbean (red), EPRI (2004) (FSAR Reference 2.5.2-242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (FSAR Reference 2.5.2-359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (FSAR Reference 2.5.2-252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

Based on this first supplemental sensitivity analysis, it is concluded that the suite of Caribbean GMPE models used in the current PSHA predicts larger ground motions on average than the observed empirical data from these five earthquakes for the spectral frequencies of 1 and 2.5 Hz. In looking at the comparison results from the Gulf of Mexico earthquake, which can be taken as the best tectonic representative event from the five earthquakes for earthquakes occurring in the island of Cuba being observed in Southern Florida, the comparison indicates that the Caribbean GMPE and the empirical data are similar with the empirical data being slightly lower. For the more complex tectonics and crustal structure observed for events located south, east, and west of the island and Cuba, the data comparison indicates that the Caribbean GMPE is predicting larger ground motions than the empirical data. In addition, given the subset of data from just those stations that have a more appropriate source to seismic ray path, this conclusion can be extended to state that the use of the Caribbean GMPE models should provide conservative (i.e., higher) ground motion predictions compared to the observed empirical data from the region.

The second supplemental sensitivity determined the sensitivity of the ground motion response spectrum (GMRS) at the Turkey Point Units 6 & 7 site to the GMPEs used for the Caribbean seismic sources, which include the Cuba areal source plus nine fault sources at the North American-Caribbean plate boundary. Five sets of seismic hazard calculations for five different GMPE suites were used to develop the corresponding GMRS. The GMPEs used for Caribbean seismic sources are: those of the base case which is (1) the Caribbean GMPE models developed for Turkey Point Units 6 & 7 (FSAR Subsection 2.5.2.4.5.2), (2) EPRI 2004 and 2006 Mid-continent region (FSAR References 2.5.2-242 and 2.5.2-203) equations, (3) EPRI Mid-continent region "mod1" (FSAR References 2.5.2-242 and 2.5.2-203) equations, (4) EPRI Gulf region (FSAR References 2.5.2-242 and 2.5.2-203) equations, and (5) EPRI Gulf region "mod 1" (FSAR References 2.5.2-242 and 2.5.2-203) equations. The modification of the EPRI GMPEs for both the Mid-continent and Gulf Coast cases was examined to see the effect of excluding the EPRI GMPE that predicts anomalously higher ground motions for large distance, such as those from the contributing Cuba and Caribbean sources. All seismic hazard calculations were made for hard rock site conditions and include the other non-Caribbean sources in the PSHA. Thus, the observed differences are based solely on the use of different GMPE models for the Caribbean seismic sources. For each five cases, ground motion values were estimated from the mean hazard curves for the seven standard spectral frequencies. Site specific horizontal GMRS are plotted in Figure 7 and are developed using the site amplification factors from the FSAR. In general, the GMRS results using the EPRI Gulf Coast GMPEs are equal to or lower than the results using the Caribbean GMPE (i.e., indicated as Base Case in Figure 7). For the EPRI Mid-continent GMPE, the opposite result is concluded in which the GMRS values exceed the GMRS values using the Caribbean GMPE models. However, based on the previous additional sensitivity, the EPRI Mid-continent models predict higher ground motions than the empirical ground motions and as such may not be applicable for the modeling of ground motion attenuation for seismic sources in this Caribbean region and the Turkey Point Units 6 & 7 site location in southern Florida. In addition, the tectonic structure and potential attenuation of ground motions for Caribbean sources might be more consistent with the EPRI Gulf Coast GMPE models based on the southern region of Florida being located in the Gulf Coast tectonic region of the eastern United States, especially for events that would occur in the island of Cuba and the Gulf of Mexico. For events occurring further south of the island of Cuba, the tectonic regime and subsequent seismic ray travel paths and associated attenuation are more complex based on the more complex tectonic environment located south, east, and west of the island of Cuba and may not be as consistent with the Gulf Coast GMPE. However, based on the results of the first sensitivity analysis the empirical data indicates that the Caribbean GMPE is conservative in its estimation of ground motions and based on the results shown in Figure 7, the use of the EPRI Gulf Coast GMPE for the PSHA gives similar or lower GMRS values

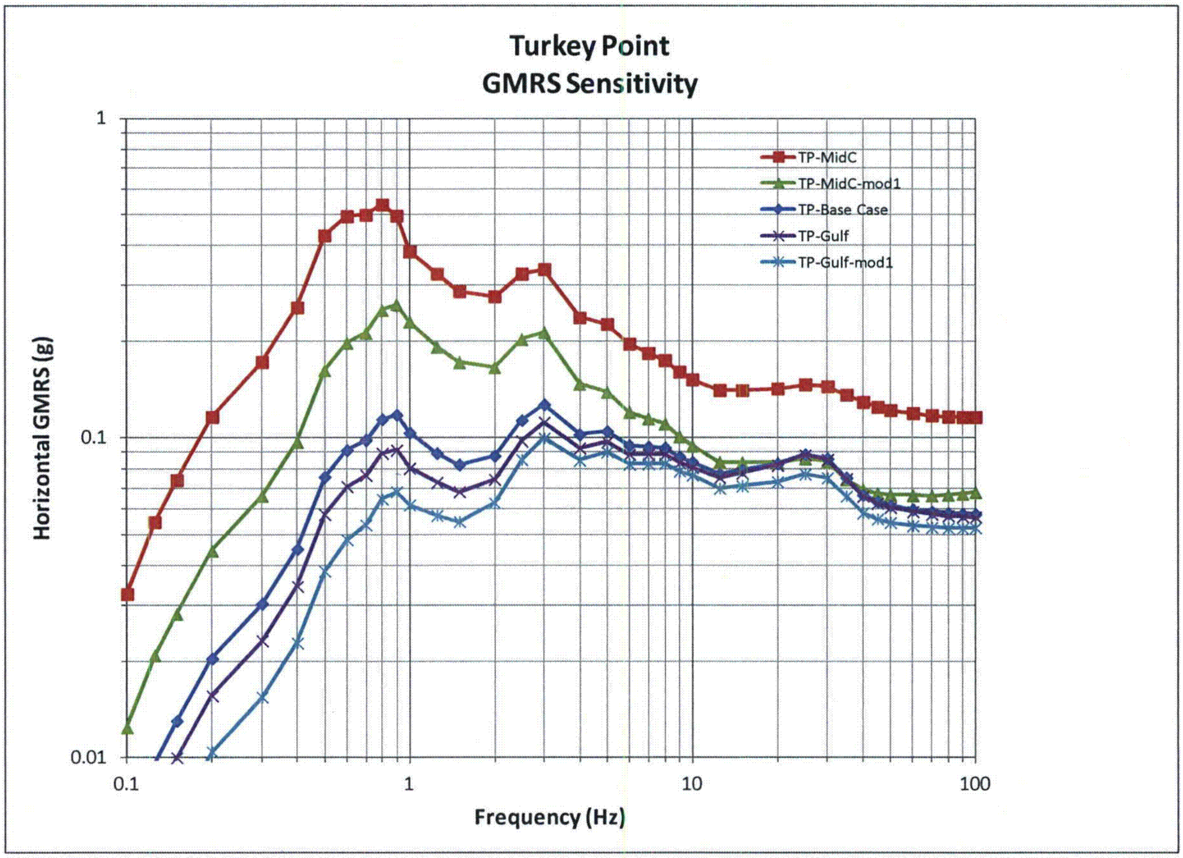

Figure 7. Horizontal GMRS for Caribbean sources for five GMPE suites for the Turkey Point Units 6 & 7 site.

These two supplemental sensitivity analyses indicate that the suite of GMPEs used for the Turkey Point Units 6 & 7 FSAR to characterize contributions to hazard at the site from Caribbean earthquakes, and the resulting GMRS at the site from these earthquakes, are conservative.

SSHAC Study Summary

The GMPE development reflects the uniquely challenging situation that exists with regard to the seismic characterization of Cuba and the adjacent Northern Caribbean region plate boundary in that, for this region, empirical ground motion data is limited or unavailable, there are currently no calibrated GMPEs predicting ground motions in southern Florida arising from earthquakes in Cuba or the Northern Caribbean, and there are no experts identified who can be characterized as proponents as defined in SSHAC (1997) (FSAR Reference 2.5.2-318).

SSHAC (1997) (FSAR Reference 2.5.2-318) characterizes a Level 2 study as one in which the TI reviews the literature and then interacts with proponents and resource experts to identify issues and interpretations and, on the basis of these interactions, "estimates community distribution," i.e., develops "a representation…of the diversity of interpretations and their uncertainties" (see Table 3-1 and Sections 3.1.3.5 and 3.2.1 of SSHAC [1997]).

SSHAC (1997) (FSAR Reference 2.5.2-318) also acknowledges (in Section 3.1.3.3) that the "choice of the level of [study] is often driven by...the amount of resources available for the study."

The process described in the ***Initial GMPE Development Summary*** above is generally consistent with a Level 2 study as described in SSHAC (1997) (FSAR Reference 2.5.2-318), where it states (in Section 3.2.1): "...the TI would communicate with the authors of published studies and other local experts who have expertise in the region or in regional ground motions...to hear and understand the technical positions taken by various proponents of particular hypotheses....In effect, the TI is...attempting to provide an overall assessment that would represent the informed scientific community's view of the subject, if the community were to make such an assessment."

Section 3.2.1 of SSHAC (1997) (FSAR Reference 2.5.2-318) goes on to state that a "key aspect of the TI approach is the use of peer review to assure that the process followed was adequate and to ensure that the results provide a reasonable representation of the diversity of views of the technical community." As again discussed above in the ***Initial GMPE Development Summary*** section of this response, the members of the Turkey Point Units 6 & 7 Technical Advisory Group (TAG) acted as participatory peer reviewers for the study, with the proposed GMPE development methodology and resultant outcomes reviewed with the TAG in three meetings and an additional TAG review after the third meeting. The TAG provided both technical and process reviews, and the methodology applied and the results obtained in developing initial GMPEs for the Caribbean seismic sources were ultimately endorsed by the TAG members, i.e., the TAG members provided, "an affirmation that the particular project [met their] standards of quality, thoroughness, and validity," as is expected per Section 3.1.3.5 of the SSHAC Report.

The challenge which the Bechtel TI team still faced in fully conforming to the expectations for a SSHAC Level 2 study as set forth in SSHAC (1997) (FSAR Reference 2.5.2-318) was that the team found "various proponents" do not exist and that there is no available "informed scientific community" having direct expertise in appropriate GMPEs in the region at issue. While Professor Motazedian was consulted as a resource expert, he could not be considered a proponent as characterized in SSHAC (1997) (FSAR Reference 2.5.2-318), and Professor Motazedian confirmed there are no other researchers who could be considered proponents for the purposes of a SSHAC study as there is no one, including Professor Motazedian, who has published a relationship for the attenuation of motion between Caribbean earthquake sources and the southeastern US.

Because no proponents could be identified, an additional effort was made in response to this RAI to engage ground motion experts who have otherwise developed and evaluated ground motion predictions equations more generally. A total of six such ground motion experts agreed to participate in the SSHAC study. These six experts were:

- Dr. Norman Abrahamson (Consultant)
- Dr. Yousef Bozorgnia (University of California, Berkeley, Pacific Earthquake Engineering Research Center)
- Dr. Kenneth Campbell (EQECAT)
- Dr. Shahram Pezeshk (University of Memphis)
- Dr. Paul Somerville (URS Corporation)
- Dr. Robert Youngs (AMEC-Geomatrix)

It should be noted that Dr. Robert Youngs also served as part of the TAG committee for Turkey Point Units 6 & 7.

The TI team of Drs. Gregor and Tavakoli developed a background technical summary note and questionnaire for distribution to the six ground motion experts. This technical note and questionnaire are contained in Enclosure A of this response.

The summary note and questionnaire asked seven specific questions of the experts dealing with the Caribbean GMPE models used in the PSHA. The actual responses from the experts are contained in Enclosure A. Presented here are the excerpted and/or summarized experts' responses for each of the seven questions as interpreted by the TI team. Note that sentences and responses given in quotes below are taken directly from the expert's response.

Question 1: Are the newly developed Caribbean GMPEs acceptable for modeling ground motions in the Caribbean region for the project site located in Southern Florida for the PSHA study?	
Dr. N. Abrahamson	Based on the comparison with the IRIS empirical data, any concerns about the model or uncertainty parameters is secondary. Based on the comparison with the empirical data, the model appears to be predicting higher ground motions.
Dr. Y. Bozorgnia	"Based on the review of the materials submitted by Bechtel, the newly developed GMPEs are acceptable, and the process of developing the GMPEs is rational and logical."
Dr. K. Campbell	"Yes, it is my opinion that the newly developed Caribbean GMPEs are generally acceptable, albeit possibly conservative at very large distances, for modeling ground motions in the Caribbean region for a site located in Southern Florida for the PSHA study..."
Dr. S. Pezeshk	"My general comment is that the newly developed Caribbean GMPEs are acceptable and possibly conservative for modeling ground motions in the Caribbean region…."
Dr. P. Somerville	"From a regulatory viewpoint I expect that they are acceptable because they are conservative when compared to the data…."
Dr. R. Youngs	"The models developed from simulation appear to be reasonable. The comparisons with recorded motions indicate that they may slightly over estimate ground motions, which is OK."

Question 2: Are the selected input parameters acceptable for their use?	
Dr. N. Abrahamson	This question is not as significant based on the comparison of the empirical data to the GMPE models.
Dr. Y. Bozorgnia	"Yes, especially considering the work of Motazedian and Atkinson (2005) (Reference Q2-1). Also, using Kappa=0.006 sec for the reference rock is consistent with the latest preliminary findings of NGA-East project."
Dr. K. Campbell	"Yes, I am not aware of any other parameters that might be more acceptable for use in deriving a GMPE for the Caribbean region..."
Dr. S. Pezeshk	The comparison of the empirical data with the Gulf of Mexico earthquake indicates that the parameters are acceptable for the capturing of the recorded ground motion data.
Dr. P. Somerville	"Not relevant, see Comment on Q5 below."
Dr. R. Youngs	A comparison should be made between the Chen and Atkinson (2002) (Reference Q2-2) amplification functions and those used to develop the CEUS models to confirm their consistency.

Q2-1 FSAR Reference 2.5.2-287
Q2-2 FSAR Reference 2.5.2-343

Question 3: Is the recommended sigma value (i.e., 0.645 natural log units) acceptable?	
Dr. N. Abrahamson	This question is not as significant based on the comparison of the empirical data to the GMPE models.
Dr. Y. Bozorgnia	"... On average sense, this number is a reasonable number; however, the standard deviation of GMPEs can be a function of frequency...."
Dr. K. Campbell	"Yes, I believe that the recommended sigma value of 0.645 natural log units (0.28 common log units) is acceptable as long as sufficient epistemic uncertainty is captured in the model."
Dr. S. Pezeshk	"...In response to question 3, the aleatory uncertainty with an average value of 0.645 in natural log units is reasonable to capture the uncertainties in input seismological parameters discussed above for all frequencies in the Caribbean region."
Dr. P. Somerville -	"Yes"
Dr. R. Youngs	"There does not appear to be a strong basis for the 0.645 and it is intended for use in Puerto Rico. A more preferable model with a stronger basis may be the EPRI (2006) (Reference Q3-1) model for CENA or some simplification of that model, perhaps using the final NGA (2008) (Reference Q3-2) results."

Q3-1 FSAR Reference 2.5.2-203
Q3-2 "NGA (2008)" refers to a suite of five ground motion models: Abrahamson and Silva; Boore and Atkinson; Campbell and Bozorgnia; Chiou and Youngs; and Idriss – all published in 2008 in a special issue of the journal Earthquake Spectra.

Question 4: Is the recommended weighting based on the EPRI (2004) class weights acceptable?	
Dr. N. Abrahamson	This question is not as significant based on the comparison of the empirical data to the GMPE models.
Dr. Y. Bozorgnia	"The explanation on the assigned weights in Table 3 is reasonable."
Dr. K. Campbell	"Yes, the weighting scheme based on class weights seems reasonable ..."
Dr. S. Pezeshk	"The recommended weighting based on the EPRI (2004) (Reference Q4-1) class weights is reasonable and acceptable."
Dr. P. Somerville	"Not relevant, see Comment on Q5 below."
Dr. R. Youngs	"Yes, roughly equal weights for 1 versus 2 corners is reasonable."

Q4-1 FSAR Reference 2.5.2-242

Question 5: Are there any other GMPE models which should be considered for the PSHA contribution from Caribbean sources?	
Dr. N. Abrahamson	No response.
Dr. Y. Bozorgnia	"Based on the sensitivity analysis of five regional events reported in the Bechtel report, it seems that EPRI Gulf Coast GMPEs are more appropriate..."
Dr. K. Campbell	Recommendation that the Gulf Coast EPRI (2004) (Reference Q6-1) be used to capture the epistemic uncertainty in ground motion models based on the empirical data comparison with the Gulf of Mexico earthquake. In addition, it is not recommended to use the Mid-Continent EPRI (2004) (Reference Q6-1) model for Caribbean sources.
Dr. S. Pezeshk	Based on the importance of the Q model in controlling the ground motions especially at large distances, the Caribbean GMPEs are between the Mid-Continent and Gulf Coast models. The comparison with the empirical data indicates that the Caribbean GMPE models are closer to the Gulf Coast GMPEs than the Mid-Continent GMPEs from the EPRI (2004) study.
Dr. P. Somerville	"The Gulf Coast region GMPE is more appropriate; see Comment on Q5 below."
Dr. R. Youngs	"I do not see any reason to consider the EPRI (2004) models to be more appropriate than the Caribbean model developed for the Turkey Point study. The comparisons with data shown in the figures confirm that."

Q5-1 "NGA (2008)" refers to a suite of five ground motion models: Abrahamson and Silva; Boore and Atkinson; Campbell and Bozorgnia; Chiou and Youngs; and Idriss – all published in 2008 in a special issue of the journal Earthquake Spectra.

Q5-2 FSAR Reference 2.5.2-287

Q5-3 FSAR Reference 2.5.2-359

Question 6: Is either the Mid-Continent or Gulf Coast region GMPE from EPRI (2004) more appropriate for use in the evaluation of the contribution to PSHA at a site in southern Florida from Caribbean seismic sources?	
Dr. N. Abrahamson	No response.
Dr. Y. Bozorgnia	"Based on the sensitivity analysis of five regional events reported in the Bechtel report, it seems that EPRI Gulf Coast GMPEs are more appropriate..."
Dr. K. Campbell	Recommendation that the Gulf Coast EPRI (2004) (Reference Q6-1) be used to capture the epistemic uncertainty in ground motion models based on the empirical data comparison with the Gulf of Mexico earthquake. In addition, it is not recommended to use the Mid-Continent EPRI (2004) (Reference Q6-1) model for Caribbean sources.
Dr. S. Pezeshk	Based on the importance of the Q model in controlling the ground motions especially at large distances, the Caribbean GMPEs are between the Mid-Continent and Gulf Coast models. The comparison with the empirical data indicates that the Caribbean GMPE models are closer to the Gulf Coast GMPEs than the Mid-Continent GMPEs from the EPRI (2004) (Reference Q6-1) study.
Dr. P. Somerville	"The Gulf Coast region GMPE is more appropriate; see Comment on Q5 below."
Dr. R. Youngs	"I do not see any reason to consider the EPRI (2004) (Reference Q6-1) models to be more appropriate than the Caribbean model developed for the Turkey Point study. The comparisons with data shown in the figures confirm that."

Q6-1 FSAR Reference 2.5.2-242

Question 7: Do you have any other comments?	
Dr. N. Abrahamson	None.
Dr. Y. Bozorgnia	For the sensitivity analysis with the IRIS data, the correction/adjustment of the empirical data for a consistent Vs=2.83km/sec should be performed. In addition, residual plots should be computed along with the event terms and their uncertainty.
Dr. K. Campbell	The applicability of the regional parameters from the MA (2005) (Reference Q7-1) study for distances beyond 500 km must be adequately captured in the epistemic uncertainty. Presumably this is captured in the epistemic uncertainty in the Q model. In addition, any potential updates to the MA (2005) (Reference Q7-1) and or more recent datasets and studies should be investigated. The terms GMPE and attenuation models should be differentiated with the term attenuation being used to describe actual attenuation properties such as Q and geometrical spreading. The assumption that based on a simplified site response analysis that the adjustments for the station-specific site conditions to the more stable CEUS hard rock site conditions would result in the reduction of the observed empirical ground motions might be true for relatively low frequencies, however, it may not be true for relatively high frequencies where a very small kappa at the project site might result in higher ground motions. The deaggregation histograms shows the Caribbean sources are important contributors to the seismic hazard at low structural and exceedance frequencies. What do the results show for the higher structural frequencies?
Dr. S. Pezeshk	The shear-wave velocity at the source is noted as 3.6 km/sec for the Caribbean study; however, the amplification factors taken from Chen and Atkinson (2002) (Reference Q7-2) were developed for a shear-wave velocity of 3.8 km/sec. Thus the amplification factors used in the analysis should be adjusted for this difference in the shear-wave velocity. An explanation on how the values listed in Table 2 is needed. If there are records available from intermediate magnitude events recorded between Cuba and southern Florida, they should be added to the empirical data comparison analysis. The focal mechanism and depths for the events considered should be included.
Dr. P. Somerville	None.
Dr. R. Youngs	(a) "The presentation of the comparisons on Figures 1-7 makes it very difficult to distinguish among the various relationships. It would perhaps be more useful to compare the median models of the EPRI (2004) (Reference Q7-3) clusters with the three base case Caribbean relationships. (b) It is not stated why the EPRI (2004) (Reference Q7-3) Cluster 4 model is not included in the comparisons. It is appropriate for large magnitude earthquakes, which are the type of earthquakes from the Caribbean sources that contribute to the hazard at Turkey Point. (c) Some description of the site conditions at the Florida DWPF stations should be included. This station has the appropriate path for Caribbean earthquakes recorded in Florida, but what about site conditions or expected amplification from hard rock?"

Q7-1 FSAR Reference 2.5.2-287
Q7-2 FSAR Reference 2.5.2-343
Q7-3 FSAR Reference 2.5.2-242

In reviewing and summarizing the responses from the experts it is concluded that the use of the Caribbean GMPE models in the PSHA is acceptable. As noted by the six experts, based on the comparison between the Caribbean GMPE model and the empirical IRIS data, these GMPE models may be conservative in their estimation of ground motions in the region. In addition the assignment of an aleatory uncertainty value of 0.645 in natural log units was acceptable based on the consensus of the six experts.

As part of the expert's responses to the questionnaire, additional comments and requests were presented by each expert (e.g., see the responses to Question 7). Specific elements of ground motion sensitivity analyses, such as the lack of any site condition information for the IRIS stations, any necessary adjustments for potentially different site amplification factors, a frequency-dependent and/or a different sigma model, comparisons with other GMPE models, or the development of a new empirically-calibrated GMPE model, were noted by the experts. These, and each of the additional comments made by the subject matter experts, are addressed below.

Dr. Y. Bozorgnia points out, "For the sensitivity analysis with the IRIS data, the correction/adjustment of the empirical data for a consistent Vs=2.83km/sec should be performed. In addition, residual plots should be computed along with the event terms and their uncertainty." Similarly Dr. Youngs says, "Some description of the site conditions at the Florida DWPF stations should be included. This station has the appropriate path for Caribbean earthquakes recorded in Florida, but what about site conditions or expected amplification from hard rock?" To address these comments we have now sought all available information on the subsurface conditions at each of the IRIS stations contribution empirical data against which the Caribbean GMPEs can be measured, and used this information to estimate correction factors at each station to scale the measured spectral accelerations to their hard rock equivalents. These scale factors have now been incorporated in the comparison plots presented above in this response. Residual plots were considered but it was determined that there was not enough data to make them meaningful.

Dr. Young's comment is a special case of Dr. Bozorgnia's. The IRIS station DWPF data are corrected and this data point has been highlighted on plots for which this datum is available.

Dr. K. Campbell points out in his response to Question 5 of the expert elicitation, "None of the earthquakes used to compare recorded ground motions with the Caribbean GMPEs developed in this study appeared to be subduction earthquakes. However, most recordings from subduction earthquakes represent continental travel paths and, at large distances, paths in the backarc region, which have been shown to show greater attenuation than paths in the forearc region. Therefore, subduction GMPEs are not appropriate for the primarily oceanic travel paths to the southern Florida site. To show that this is the case, it would be beneficial to compare predictions from the current set of empirical subduction GMPEs with the Caribbean GMPEs developed in this study for large earthquakes at distances of relevance to the southern Florida site to show that these subduction GMPEs would predict smaller ground motions. However, if they don't, then they should be considered for predicting ground motions from subduction sources."

For the probabilistic seismic hazard analysis (PSHA) performed for Turkey Point Units 6 & 7 site, a total of 10 seismic sources were considered for the Caribbean region. Of these 10 sources the two Northern Hispaniola sources (i.e., western and eastern) are identified as being associated with the tectonic subduction zone in the region. Based on the comparison plots given in the Motazedian and Atkinson study (2005) and the large distance from the Turkey Point Units 6 & 7 site to these individual subduction seismic sources, the use of an empirically derived GMPE for the subduction seismic source zones would lead to lower ground motions than the use of GMPEs based on the Motazedian and Atkinson (2005) source and attenuation scaling. Thus the PSHA results are understood to have higher ground motion results than if a subduction GMPE was used for those specific Caribbean subduction fault sources. Other potential sources along the North American – Caribbean plate boundary are too far away to contribute significantly to the PSHA relative to the closer sources considered.

Dr. K. Campbell points out in his response to Question 7 of the expert elicitation, "The terms GMPE and attenuation models should be differentiated with the term attenuation being used to describe actual attenuation properties such as Q and geometrical spreading."

To address Dr. Campbell's concern to differentiate the terms "GMPE" and "attenuation models" from the term "attenuation" when being used to describe actual attenuation properties such as Q and geometrical spreading the FSAR will be revised to make this distinction clear.

Dr. K. Campbell further points out in his response to Question 7 of the expert elicitation, "The assumption that, based on a simplified site response analysis, the adjustments for the station-specific site conditions to the more stable CEUS hard rock site conditions would result in the reduction of the observed empirical ground motions might be true for relatively low frequencies, however, it may not be true for relatively high frequencies where a very small kappa at the project site might result in higher ground motions."

In consideration of this comment it is noted that a first order scalar adjustment has now been applied to the empirical IRIS ground motion as described above to scale the observed empirical ground motions values based on an estimated station specific Vs30m value to a more consistent hard rock ground condition. These scalar adjustments are based on the site response model contained within the Boore and Atkinson (2007) (FSAR Reference 2.5.2-360) GMPE model for an adjustment to an average Vs30m value of 760m/sec. For the additional scalar adjustment from Vs30m of 760m/sec to CEUS hard rock site conditions with an average Vs30m of 2.8km/sec two sets of amplification factors are applied: Frankel et al. (1996) (FSAR Reference 2.5.2-252) and Atkinson and Boore (2011) (FSAR Reference 2.5.2-359). The results of these scalar adjustments of the empirical IRIS data lead to "hard rock" values that are less than or equal to the uncorrected empirical values.

Beyond that, note that the Caribbean GMPE model used for the Turkey Point Units 6 & 7 PSHA was developed for an assigned kappa value of 0.006 sec to be consistent with the other EPRI (2004, 2006) (FSAR References 2.5.2-242 and 203) GMPEs used in the PSHA for CEUS hard rock site conditions. It is recognized that there is the potential for a site specific kappa value lower than this assigned value at the comparable hard rock horizon for the FPL site and that this might lead to higher ground motion values, especially in the high frequency range. However, the potential also exists for a higher site-specific kappa value

which would lead to lower high frequency ground motion estimates. There are currently no estimates of a hard rock horizon site-specific kappa value for the FPL project site. And given the limited site classification and subsurface foundation information available for the IRIS recording stations, no attempt has been made to further adjust amplification factors to account for any site-specific kappa values for the empirical IRIS data.

The comparison of the empirical IRIS data with the EPRI (2004, 2006) (FSAR References 2.5.2-242 and 203) and the Caribbean GMPE models, (all of which assume a kappa of 0.006 sec) for frequencies of 10 Hz and less are the most important for the Turkey Point 6 &7 PSHA because for higher frequencies, which could potentially be more influenced by different kappa values, the contribution to the total hazard from these distant Caribbean sources is not significant relative to the local and regional sources around the project site location. For these reasons adoption of a kappa of 0.006 sec is believed to be reasonable.

Dr. K. Campbell points out in his response to Question 7 of the expert elicitation, "The deaggregation histograms (provided as part of the expert elicitation questionnaire) shows the Caribbean sources are important contributors to the seismic hazard at low structural and exceedance frequencies. What do the results show for the higher structural frequencies?"

The Turkey Point Units 6 & 7 FSAR (to which Dr. Campbell had no access at the time of his review of the Caribbean GMPEs) states "The current deaggregation of seismic hazard at the Turkey Point Units 6 & 7 site from all sources, Cuban, Caribbean, and southeast United States, is shown in Figures 2.5.2-226 and 2.5.2-228 for longer period motions (for which the relative contribution of the larger, more distant Cuban and Caribbean sources would be expected to have their greatest relative contribution) and for the 10^{-4} and 10^{-5} mean annual frequency of exceedance probabilities used to develop design ground motions under current NRC regulatory guidance. The relative contribution for the higher frequency cases of 5 and 10 Hz (FSAR Figures 2.5.2-227 and 2.5.2-229) from the more distant Caribbean sources is significantly reduced relative to the closer local seismic sources. For this sensitivity comparison, the empirical ground motions for 1 and 2.5 Hz are presented for each of the five regional earthquakes and ground motion prediction equations."

Dr. S. Pezeshk recommends in his response to Question 5 of the expert elicitation, "The Q-factor relations in the Caribbean region and the WUS region show that areas of active tectonics have higher attenuation of seismic waves than the stable continental regions such as the CEUS region. Therefore, I would recommend that the shallow crustal ground-motion attenuation relations in WUS (NGA 2008)[1] as well as the ground-motion model of MA05, which was developed for Puerto Rico, are also plotted to provide a better estimation of ground motions in the Caribbean region for comparison. The intermediate earthquakes (Mw 5-6), in particular near the north of Cuba can be added to the actual data plots (see USGS and IRIS datasets) to better understand the variability of ground motions between the Cuba and the FPL project site."

As far as we have been able to find there are no records of the type envisioned by Dr. Pezeshk (magnitude 5-6 in Cuba and recorded in the SEUS) to follow up on his suggestion.

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[1] "NGA (2008)" refers to a suite of five ground motion models: Abrahamson and Silva; Boore and Atkinson; Campbell and Bozorgnia; Chiou and Youngs; and Idriss – all published in 2008 in a special issue of the journal Earthquake Spectra.

Similarly, Dr. R. Youngs in his response to Question 5 says: "The USGS uses WNA GMPEs for modeling ground motions in Puerto Rico. It may be useful to compare the predictions from the NGA models adjusted to CEUS hard rock conditions using published factors (e.g. Atkinson and Boore, BSSA 2011) (FSAR Reference 2.5.2-359) with the developed models at least for distances of about 200 evaluate whether they predict higher or lower ground motions."

For low frequencies (0.5 and 1.0Hz) the mean curve from the Caribbean and NGA West (2008) model, after correction for hard rock conditions using the Atkinson and Boore factors, are similar to the NGA West (2008) mean curve, being slightly lower over the distance range of 150 - 200 km for magnitudes 6, 7, and 8. For frequencies greater than 1 Hz, the mean curve from the NGA West (2008) model is lower than the mean curve from the Caribbean models. At the highest frequencies (e.g., PGA) this mean curve from the NGA West (2008) models predicts ground motion values that are approximately equal to the lowest individual curve from the suite of Caribbean GMPE models.

Dr. S. Pezeshk notes in his response to Question 7 of the expert elicitation, "The shear-wave velocity at the source is noted as 3.6 km/sec for the Caribbean study; however, the amplification factors taken from Chen and Atkinson (2002) (FSAR Reference 2.5.2-343) were developed for a shear-wave velocity of 3.8 km/sec. Thus the amplification factors used in the analysis should be adjusted for this difference in the shear-wave velocity."

Similarly, in response to the Question 2, Dr. R. Youngs says: "A comparison should be made between the Chen and Atkinson (2002) (FSAR Reference 2.5.2-343) amplification functions and those used to develop the CEUS models to confirm their consistency

As correctly stated, the Chen and Atkinson (2002) (FSAR Reference 2.5.2-343) site amplification factors were used for the development of the Caribbean GMPE models. These site amplification factors, however, are based on empirical data from recordings in Eastern North America (ENA) for typical hard rock site conditions. In addition, the site amplification factors provided in the Chen and Atkinson (2002) (FSAR Reference 2.5.2-343) study are based on the empirical ratio of horizontal to vertical components of earthquakes with magnitude between 2.5 and 7.5 (i.e., H/V spectral ratios). Table 3 of Chen and Atkinson (2002) (FSAR Reference 2.5.2-343) does assign a typical source shear-wave velocity of 3.8 km/sec for ENA, but this value is not used for the development of the reported site amplification factors listed later in their paper. In the Chen and Atkinson (2002) (FSAR Reference 2.5.2-343) study, the source shear-wave velocity of 3.8 km/sec is used for the analysis of magnitude estimates.

Several different estimates of source shear-wave velocity values can be found in the literature for typical CEUS site profiles. These values tend to range between 3.5 and 3.8 km/sec. As an example several specific values of source shear-wave velocity and their references are listed below. Note that this is not a complete set of estimated source shear-wave velocity values but rather a sampling to show the range of values:

- Chen and Atkinson (2002) (FSAR Reference 2.5.2-343) 3.8 km/sec
- Atkinson and Boore (2011) (FSAR Reference 2.5.2-359 3.7 km/sec
- Frankel et al. (1996) (FSAR Reference 2.5.2-252) 3.6 km/sec
- Boore and Joyner (1997) 3.6 km/sec
- Motazedian and Atkinson (2005) (FSAR Reference 2.5.2-287) 3.6 km/sec
- EPRI (2012) 3.52 km/sec

For the Caribbean GMPE development an assigned source shear-wave velocity of 3.6 km/sec was used based on the Motazedian and Atkinson (2005) (FSAR Reference 2.5.2-287) modeling results. Based on the listed values and noted range for typical CEUS site condition, the value of 3.6 km/sec is within the range of adopted values. In addition, since the empirically based site amplification factors used for the Caribbean GMPEs from the Chen and Atkinson (2002) study (FSAR Reference 2.5.2-343) are not based on their listed source shear-wave velocity of 3.8 km/sec, no adjustment would necessarily be needed for the site amplification factors.

Thus, the response to the question posed by Dr. Pezeshk would be that the use of the Chen and Atkinson (2002) (FSAR Reference 2.5.2-343) empirical site amplification factors is not inconsistent with the use of a source shear-wave velocity of 3.6 km/sec as opposed to the assigned value of 3.8 km/sec given in the Chen and Atkinson (2002) (FSAR Reference 2.5.2-343) study for the analysis of magnitude estimates. It should also be noted that in the development of the Caribbean GMPE models for the project site, large epistemic uncertainties were applied to other input parameters for the stochastic modeling of the ground motions and the expected influence on site amplification factors and resulting ground motions from using a source shear-wave velocity of 3.6 km/sec or 3.8 km/sec would be expected to be well encompassed within the current range of alternative Caribbean GMPEs. This answers the fundamental concern posed by Drs. Pezeshk and Youngs.

A sensitivity analysis was performed to investigate the quantitative effect of this alternative shear-wave velocity on the amplification factor. Based on the sensitivity analysis a change in the source shear-wave velocity from 3.6 km/sec to 3.8 km/sec for a generic CEUS hard rock site profile (Boore and Joyner, 1997) would be expected to increase the site amplification factors by about 3% over all frequencies. Although this result indicates that a higher source shear-wave velocity of 3.8 km/sec would lead to slightly higher site amplification factors over all frequencies, the development of the ground motions used in the development of the Caribbean GMPE which used a shear-wave velocity of 3.6 km/sec involved additional equations and input parameters. Specifically for the stochastic ground-motion simulation approach the Fourier amplitude spectrum of the ground motions is a function of the source shear-wave velocity in a number of ways in addition to any amplification factor influence. This dependence is for not only the constant term but also for the spectral model of radiated waves from the source (e.g., frequency-dependent Brune source model) and the anelastic Q-model term. For the constant term, the cube of the source shear-wave velocity is in the denominator of the equation and has a more significant impact on the resulting ground motions then the dependence from the other terms. Given this recognition of the complete functional dependence of the source shear-wave velocity parameter, increasing this value from 3.6 km/sec to a larger value of 3.8 km/sec would be expected to lead to an overall reduction in the stochastic ground-motion simulation values.

Dr. S. Pezeshk notes in his response to Question 7 of the expert elicitation, "An explanation on how the values listed in Table 2 is needed," where Table 2 in this context is Table 2 of Enclosure A of this response, "SSHAC CARIBBEAN GMPE QUESTIONAIRE." In additional discussion of the values in this table it is noted that for the 1CV single corner source model the magnitude dependent stress parameter values used for the simulations are listed in this table and that this magnitude dependent scaling on the stress parameters was taken from Silva et al. (2003). This magnitude-dependent stress parameter scaling is constant for magnitudes less than 5.5 and greater than 8.5. The reduction factors on the stress parameter from the Silva et al. (2003) reference are:

- Stress parameter for magnitudes less than 5.5 is equal to value for magnitude 5.5
- Stress parameter at magnitude 6.5 = 75% Stress parameter at magnitude 5.5
- Stress parameter at magnitude 7.5 = 75% Stress parameter at magnitude 6.5
- Stress parameter at magnitude 8.5 = 78% Stress parameter at magnitude 7.5
- Stress parameter for magnitudes greater than 8.5 is equal to value for magnitude 8.5

For the application to the range in magnitude values used in the calculation of the Caribbean GMPEs, a linear interpolation of the reduction factor as a function of magnitude was estimated given the scaling noted above. These interpolated scale factors were then applied to the base stress parameter value of 130 bars to develop the variable stress parameters listed in the table and used in the analysis. Rounding differences on the order of 1 or 2 bars are not significant and the values listed in the table are the specific values used in the analysis. Note that the same factor of 2 is applied for the Low and High stress parameter models.

Dr. S. Pezeshk notes in his response to Question 2 of the expert elicitation, "Note that the focal mechanism and the depth of actual earthquakes in the Caribbean region are significant, especially for their use to validate the Caribbean GMPEs. This information should be addressed in the report." And again in his response to Question 7 of the expert elicitation, "The focal mechanism and depth of the actual earthquakes should be addressed in the report."

This information has been added to this response and addressed in the context of the implications of both the depths and fault plane solutions for the five earthquakes with the best empirical IRIS data to the Caribbean GMPE comparisons.

Dr. R. Youngs points out in his response to Question 7 of the expert elicitation, "The presentation of the comparisons on Figures 1-7 makes it very difficult to distinguish among the various relationships. It would perhaps be more useful to compare the median models of the EPRI (2004) (FSAR Reference 2.5.2-252) clusters with the three base case Caribbean relationships." Figures 1-7 in this context are Figures 1-7 of Enclosure 1 of this response, "SSHAC CARIBBEAN GMPE QUESTIONAIRE."

Figure 8 below is the equivalent of Figure 1b of Enclosure A of this response modified as suggested.

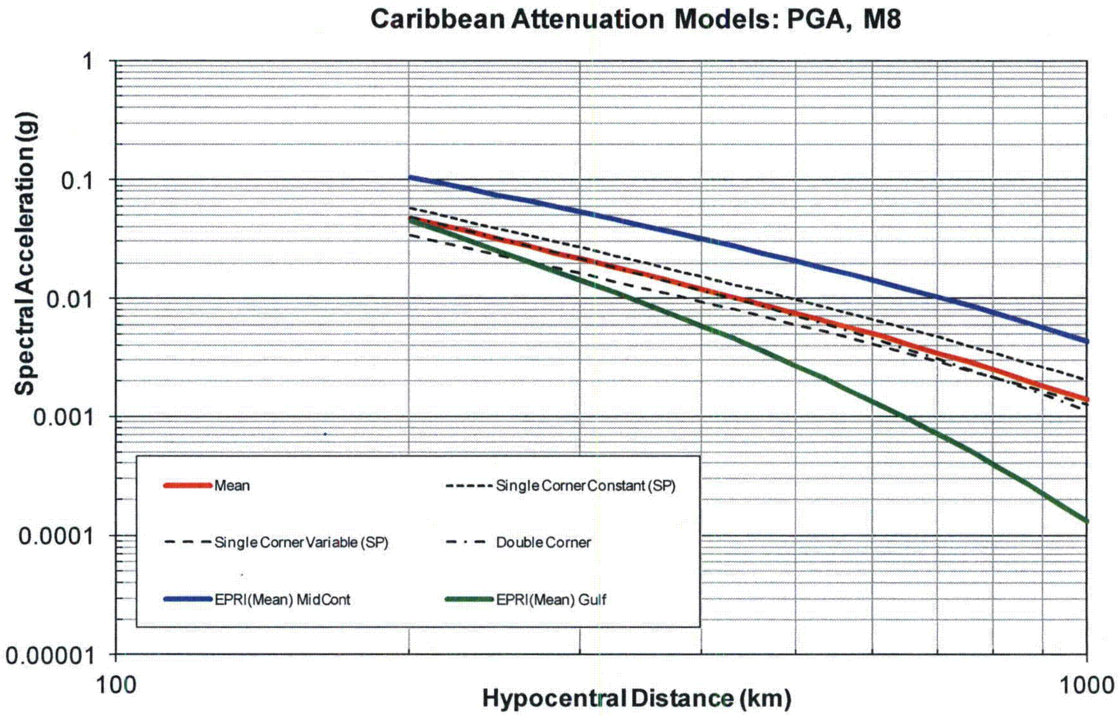


Figure 8. Magnitude 8 mean GMPE curves for PGA for the Caribbean (red curves), Mid-Continent (blue curves), and Gulf Coast (green curves) region GMPE models.

Since Dr. Young's suggestion applies to a modification of the expert solicitation questionnaire, since no additional solicitation of expert opinion is anticipated at this time that might possibly benefit from adding the simplified plots to this response, and since the original plots allowed the experts to perform their evaluations of the Caribbean GMPEs, the remaining thirteen equivalent plots of Figures 1-7 of the expert solicitation questionnaire are not appended to this response. It is noted, however, that similar simplified comparison plots of the EPRI (2004) (FSAR Reference 2.5.2-242) Mid-Continent and our Caribbean GMPEs for the seven spectral ordinates of the PSHA are presented in response below to Part d.

Dr. R. Youngs points out in his response to Question 7 of the expert elicitation, "It is not stated why the EPRI (2004) (FSAR Reference 2.5.2-242) Cluster 4 model is not included in the comparisons. It is appropriate for large magnitude earthquakes, which are the type of earthquakes from the Caribbean sources that contribute to the hazard at Turkey Point."

The response has been supplemented above to clarify this omission. That is, for the EPRI, 2004 (FSAR Reference 2.5.2-242) GMPE model, only Clusters 1, 2, and 3 were considered because no model comparable to an EPRI 2004 Cluster 4 model was included in the Caribbean GMPE suite. Sensitivity analysis focusing on low frequency ground motions from large magnitude earthquakes (the motions most likely to include significant contributions to the total PSHA results from Caribbean sources) show that inclusion of the EPRI 2004 Cluster 4 GMPE with the GMPEs of Clusters 1, 2, and 3 would have lowered the weighted means of both the Midcontinent and Gulf Coast models, making the comparison of the

Caribbean GMPEs more conservative relative to these two alternative EPRI, 2004, (FSAR Reference 2.5.2-242) GMPE models.

In consideration of the suite of responses from the experts, the TI team concluded that the consensus of the experts was that the Caribbean GMPE models were acceptable for use in the PSHA for Turkey Point Units 6 & 7 site, even as the IRIS empirical data suggest some conservatism.

When asked about the applicability of the EPRI Mid-continent or Gulf Coast models, the consensus of the six experts was that the Gulf Coast GMPE models are closer to the empirical data than the Mid-continent suite. However, this did not indicate that the EPRI Gulf Coast models are preferable over the Caribbean GMPE models. Based on this conclusion with regards to the two EPRI ground motion models and the current sensitivity studies which showed that the use of the EPRI Gulf Coast GMPE in the PSHA resulted in lower GMRS ground motions, it is concluded that the use of the Caribbean GMPE models is conservative in the estimation of the GMRS ground motions for the Turkey Point Units 6 & 7 site.

Based on the polling and summary of the responses from the six experts the ultimate use of the specific Caribbean GMPEs in the PSHA for the Turkey Point Units 6 & 7 site location for seismic sources in the Cuba and Caribbean region falls within the range of the informed technical community and actually may produce slightly larger ground motions than would be estimated from the center, body, and range of the informed technical community. The experts' opinions support the development of the final Caribbean GMPEs. There were no conflicting opinions among the experts regarding the suitability of the final Caribbean GMPEs for use in the PSHA analysis for the Turkey Point Units 6 & 7 FSAR.

Part c: Please provide copies of the following supporting calculations: Report #: 25409-000-K0C-0000-00009, Report#: 25409-000-K0C-0000-00024, Report #: 25409-000-K0C-0000-00034 to enable the staff to evaluate the technical details of the final GMPEs.

The requested calculations are available for inspection in the Reading Room.

As a result of additional studies conducted for this RAI, new calculations were performed to document GMPE curve plots from the EPRI (2004) (FSAR Reference 2.5.2-242) and Caribbean GMPEs, provide a comparison of IRIS empirical data with GMPE models for the Caribbean region, and to evaluate the sensitivity of GMRS at the Turkey Point site to five sets of GMPEs used for Caribbean sources. These calculations will also be made available for inspection in the Reading Room.

Part d: In order for the staff to be able to compare the new Caribbean GMPEs with the 2004/2006 EPRI mid-continent GMPEs, please provide plots showing both ground motion models for earthquake magnitudes of 6.0, 7.0, and 8.0 in the distance range of 200 km to 1000 km at all seven frequencies defined in the EPRI 2004 and 2006 GMPEs.

Mean GMPE curve plots are provided for the EPRI Mid-continent (FSAR References 2.5.2-242 and 2.5.2-203) and Caribbean ground motion prediction equations (GMPEs) in Figures 8 – 14 for the seven defined frequencies. Note that EPRI (FSAR Reference 2.5.2-203) is

only a recommendation for the associated aleatory uncertainty and therefore does not impact the comparison plots of the weighted mean GMPE curve. The plotted mean GMPE curve is the weighted mean of the individual median GMPE curves as defined in EPRI (FSAR Reference 2.5.2-242) and for the Caribbean GMPE models. These GMPE plots are provided for three specific moment magnitude (M_w) values: 6, 7, and 8 for distances between 200km and 1,000km. Note that the EPRI (FSAR Reference 2.5.2-242) GMPE model is defined as a function of epicentral distance, whereas the Caribbean GMPE model is defined as a function of hypocentral distance. For these comparison plots, the GMPE curves are plotted as a function of epicentral distance and for the Caribbean GMPE curves an assumed hypocentral depth of 8 km was used.

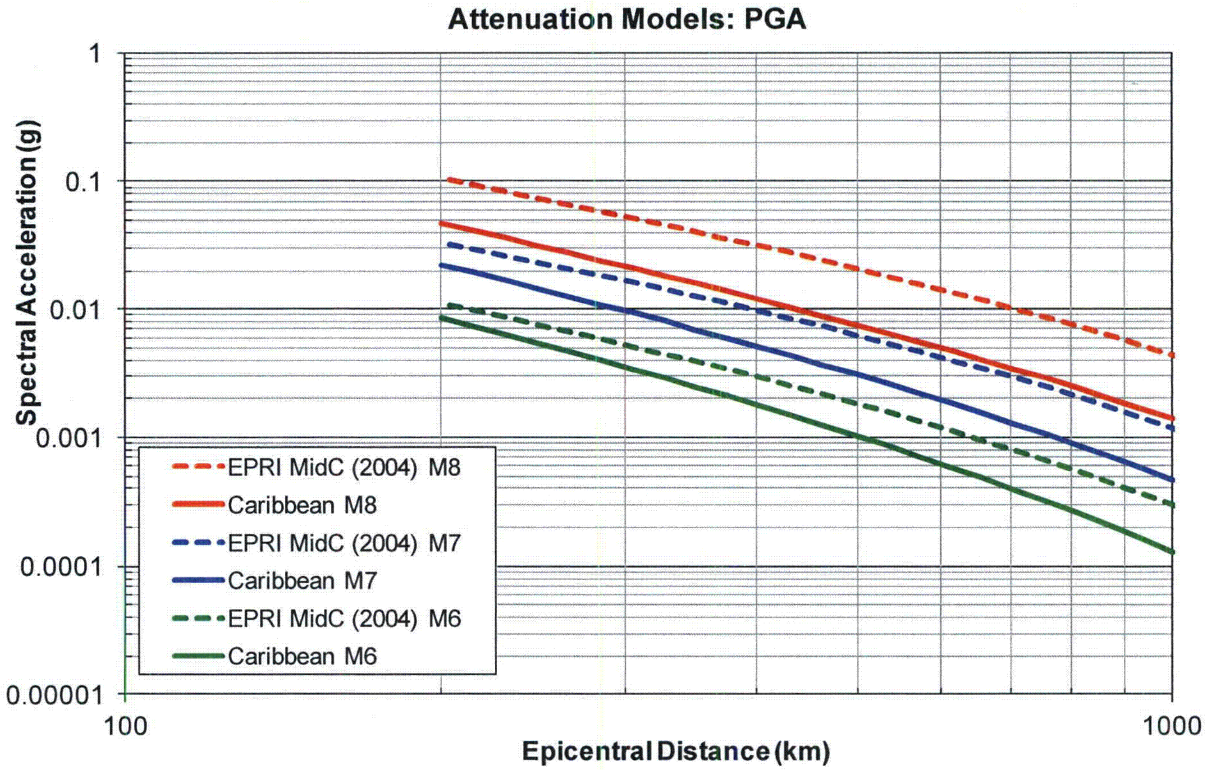


Figure 8. Comparison of EPRI Mid-continent (FSAR Reference 2.5.2-242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for PGA.

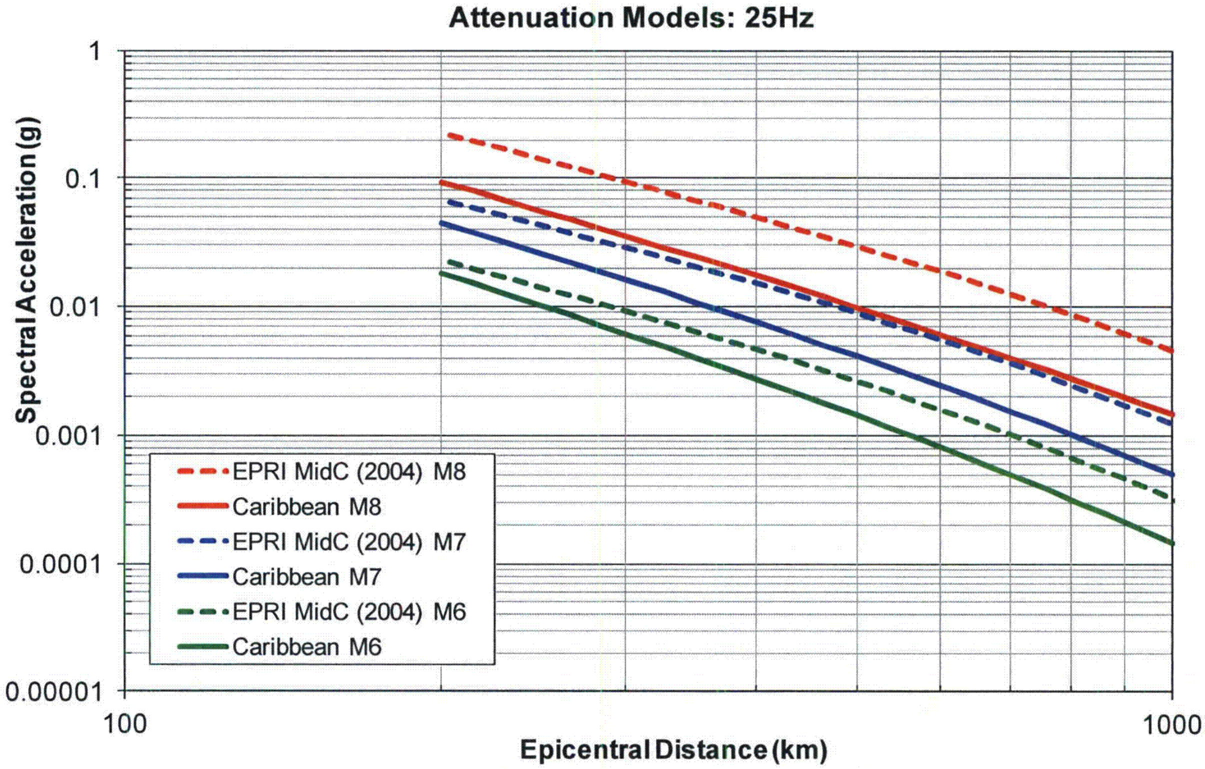


Figure 9. Comparison of EPRI Mid-continent (FSAR Reference 242) mean (dashed lines) and Caribbean mean (solid lines) attenuation curves for magnitudes 6, 7, and 8 for 25 Hz.

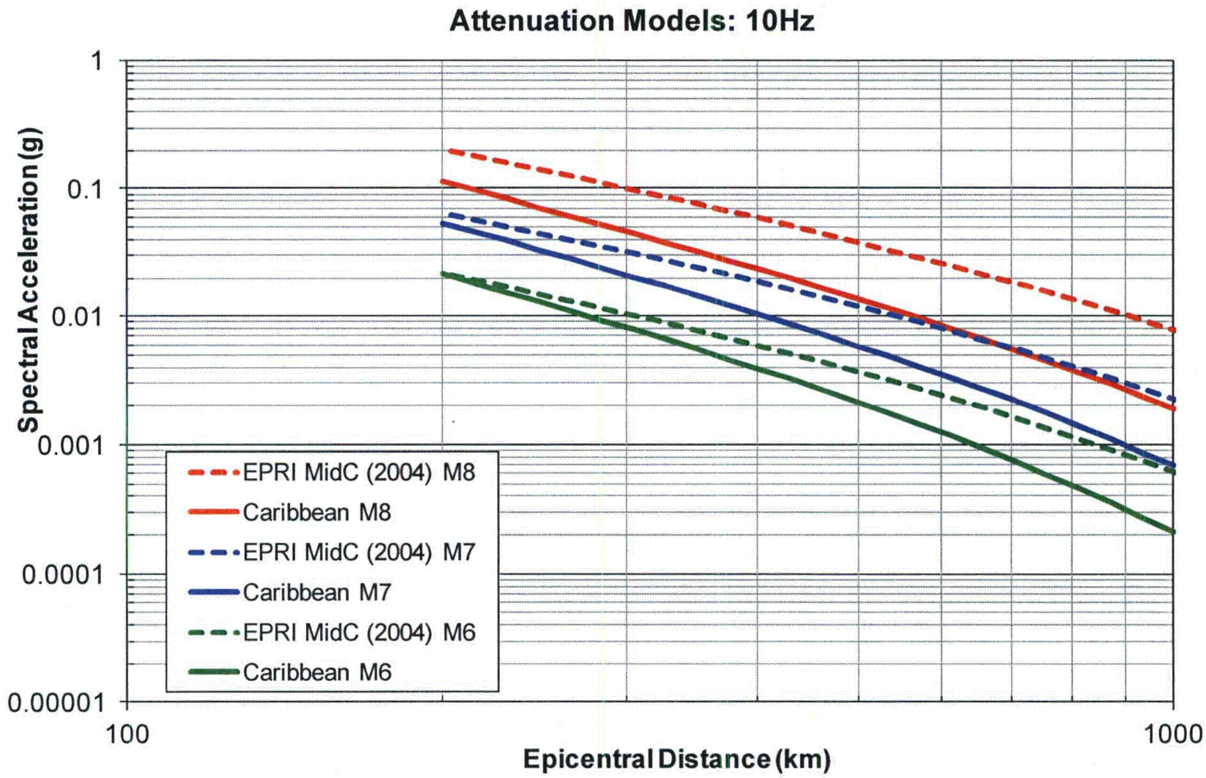


Figure 10. Comparison of EPRI Mid-continent (FSAR Reference 2.5.2-242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 10 Hz.

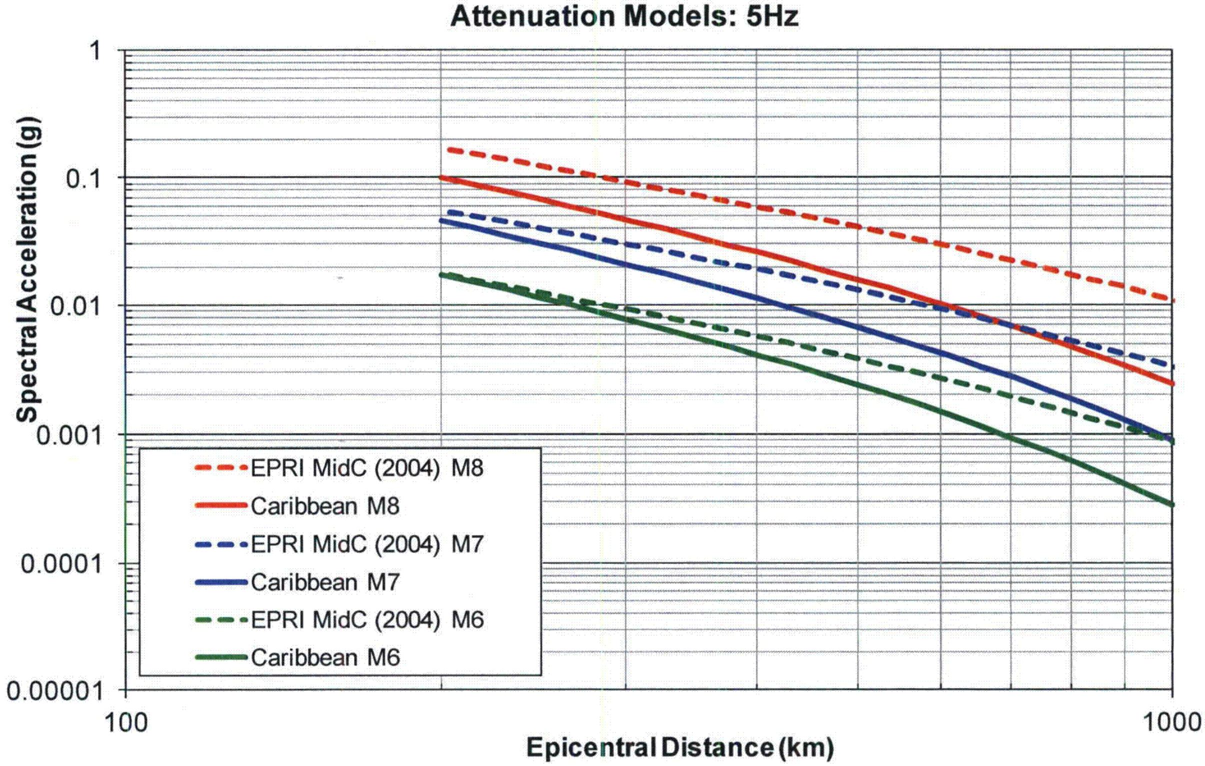


Figure 11. Comparison of EPRI Mid-continent (FSAR Reference 2.5.2-242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 5 Hz.

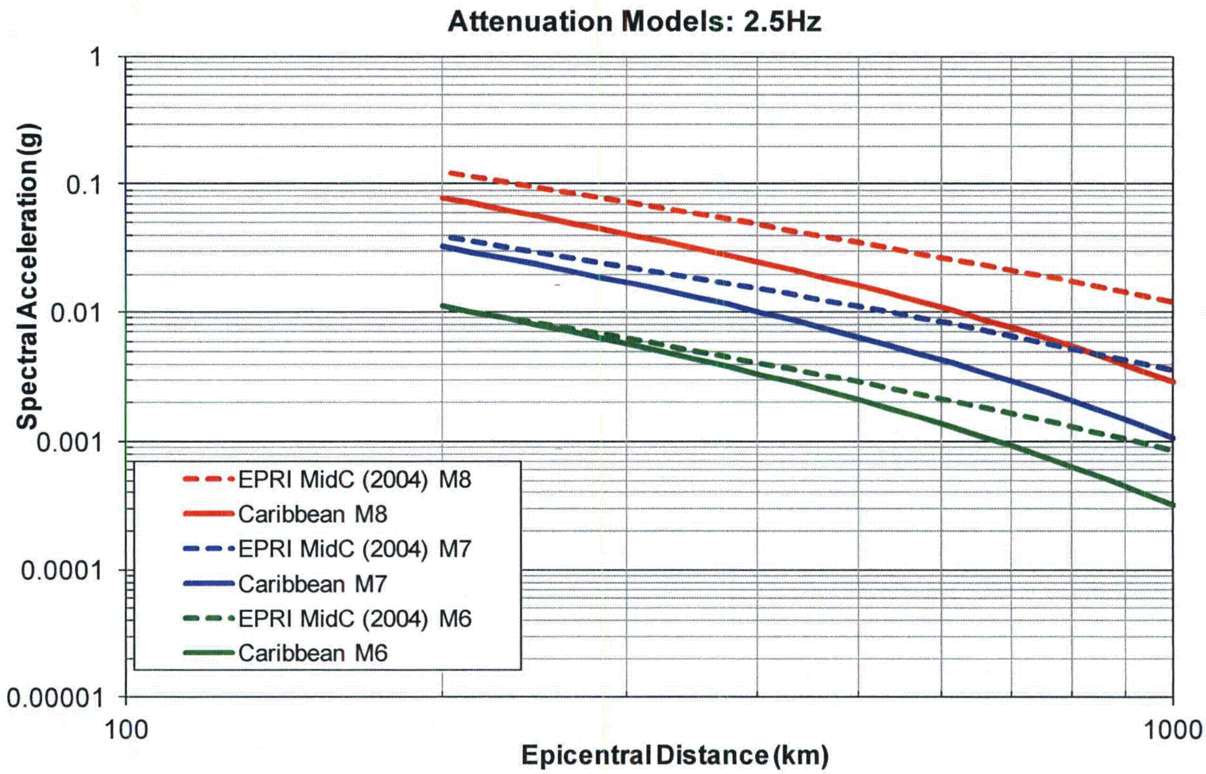


Figure 12. Comparison of EPRI Mid-continent (FSAR Reference 2.5.2-242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 2.5 Hz.

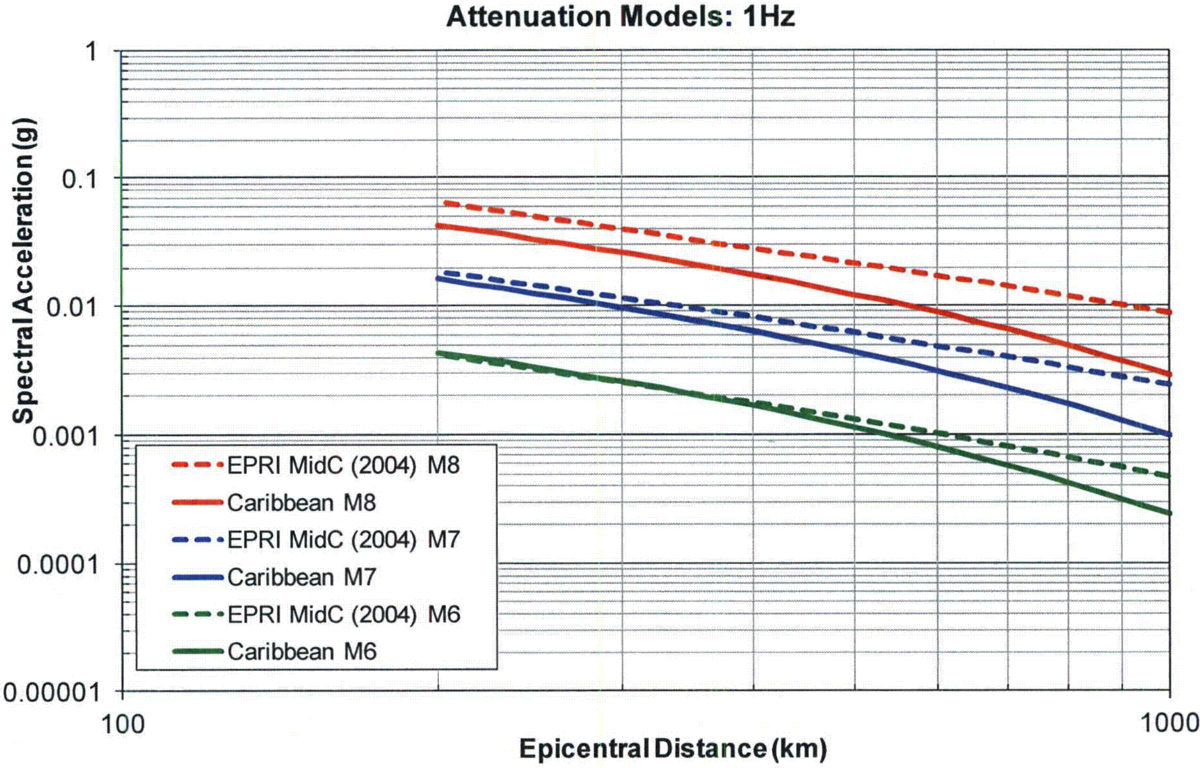


Figure 13. Comparison of EPRI Mid-continent (FSAR Reference 2.5.2-242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 1 Hz.

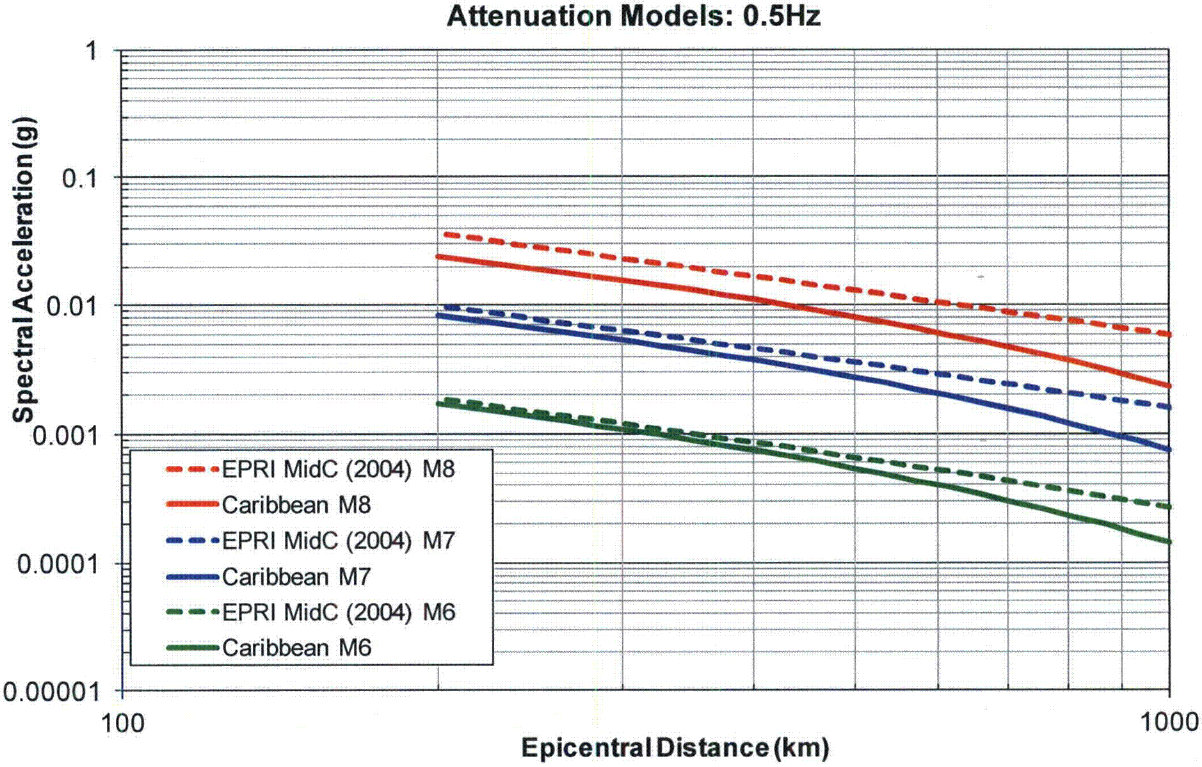


Figure 14. Comparison of EPRI Mid-continent (FSAR Reference 2.5.2-242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 0.5 Hz.

Part e: Discuss evidence, if any, that seismic source scaling varies regionally and/or between source types in the Caribbean. For example, is there any evidence that stress parameter varies systematically between the northern Hispaniola sources, the Caribbean plate-boundary transform fault sources, and the Cuba sources? If so, what are the implications for the attenuation models and hazard calculated at TPNPP?

Based on the relatively moderate to high levels of observed seismicity in the Caribbean region, the investigation into any potential seismic source variation on either a local or regional scale could, in theory, be studied. However, based on the limited seismic networks in the region, only one such study was discovered in the literature. This study by Motazedian and Atkinson (FSAR Reference 2.5.2-287) studied a dataset of ground motion recordings in and around the island of Puerto Rico to develop a seismic source model including the stress parameter for the region. As noted by Motazedian and Atkinson (FSAR Reference 2.5.2-287), this ground motion dataset contains both crustal and subduction earthquakes but could not be subdivided based on the earthquake type. No studies were found during a literature review that specifically addresses any potential stress parameter variation between earthquakes associated with the northern Hispaniola, Caribbean plate-boundary transform faults, and Cuba sources.

Motazedian and Atkinson (FSAR Reference 2.5.2-287) compared their GMPE model based on the Puerto Rico data and associated stress parameter with ground motion prediction equations (GMPEs) for the central and eastern United States (CEUS), California, and subduction ground motion models. Note that the CEUS and California models are based on a similar stochastic ground motion methodology that was used by Motazedian and Atkinson (FSAR Reference 2.5.2-287) whereas the subduction model is based on empirical data. Their conclusion was that the Puerto Rico based model is similar to the CEUS and California models and based on their GMPE curve plots, their model predicts significantly larger (i.e., larger by factors of 5 – 10 or greater) ground motions than the empirically-based subduction GMPE.

Tectonically, the larger Caribbean region consists of both crustal faults and subduction zones. As noted in Motazedian and Atkinson (FSAR Reference 2.5.2-287), their dataset most likely contained ground motions from both types of earthquakes. However, for the PSHA, the seismic sources around the island of Puerto Rico were not modeled based on their significantly large distance from the site. Garcia et al. (2012) present a regional tectonic characterization of the Caribbean region based on Flinn-Engdahl geographical regions. For the immediate region around Cuba and southern Florida, the tectonics are classified as being active regions without subduction tectonics. Subduction zone tectonics are noted for the eastern side of the island of Hispaniola and further east to the island of Puerto Rico.

For the probabilistic seismic hazard analysis (PSHA) performed for Turkey Point Units 6 & 7 site, a total of 10 seismic sources were considered for the Caribbean region. Of these 10 sources the two Northern Hispaniola sources (i.e., western and eastern) are identified as being associated with the tectonic subduction zone in the region. Based on the comparison plots given in the Motazedian and Atkinson study (FSAR Reference 2.5.2-287) and the large distance from the Turkey Point Units 6 & 7 site to these individual subduction seismic sources, the use of an empirically derived GMPE for the subduction seismic source zones would lead to lower ground motions than the use of GMPEs based on the Motazedian and Atkinson (FSAR Reference 2.5.2-287) source and attenuation scaling. Thus the PSHA results are understood to have higher ground motion results than if a subduction GMPE was used for those specific Caribbean subduction fault sources.

This response is PLANT SPECIFIC.

References:

Abrahamson, N.A., and Silva, W, (2008). Summary of the Abrahamson & Silva NGA Ground-Motion Relations, Earthquake Spectra. 24, 67-97.

Ambraseys, N. N., Simpson, K. A., and Bommer, J. J. (1996) "Prediction of horizontal response spectra in Europe," Earthquake Engineering and Structural Dynamics, 25, 371–400.

Atkinson, G.M., and Boore, D.M., (2011), Modifications to existing ground-motion prediction equations in light of new data, Bulletin of the Seismological Society of America 101 (3), 1121-1135.

Atkinson, G., Boore, D. (2003) "Empirical Ground Motion Relation for Subduction Zone Earthquakes and their Application to Cascadia and other regions," Bulletin of the Seismological Society of America, v. 93, no. 4, pp. 1703-1729.

Atkinson, G., Silva, W. (2000) "Stochastic Modeling of California Ground Motions," Bulletin of the Seismological Society of America, v. 90, no. 2, pp. 255-274.

Boore, D. and G. Atkinson (2007). Boore-Atkinson NGA Ground Motion Relations for the Geometric Mean Horizontal Component of Peak and Spectral Ground Motion Parameters. Pacific Earthquake Engineering Research Center, PEER Report 2007/01, University of California, Berkeley, May 2007, 234 p.

Boore, D.M. and G.M. Atkinson (2008). Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-Damped PSA at Spectral Periods between 0.01s and 10.0s, Earthquake Spectra. 24, 99-138.

Boore, D. M., and W. B. Joyner (1997). Site amplifications for generic rock sites, Bull. Seism. Soc. Am. 87, pp. 327-341.

Campbell, K.W., and Bozorgnia, Y. (2008). NGA Ground Motion Model for the Geometric Mean Horizontal Component of PGA, PGV, PGD and 5% Damped Linear Elastic Response Spectra for Periods Ranging from 0.01 to 10 s, Earthquake Spectra. 24, 139-171.

Chiou, B.S-J and Youngs, R.R. (2008). An NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra, Earthquake Spectra. 24, 173-215.

Dahle, A., Climent, A., Taylor, W., Bungum, H., Santos, P., Ciudad Real, M., Linholm, C., Strauch, W., and Segura, F. (1995) "New spectral strong motion attenuation models for Central America," Proceedings of the Fifth International Conference on Seismic Zonation, (Nice, France), vol. II, pp. 1005–1012.

Electric Power Research Institute (2012). "Seismic Evaluation Guidance, Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic," EPRI Report 1025287, November 2012.

Electric Power Research Institute (2013) "EPRI (2004, 2006) Ground-Motion Model (GMM) Review Project, Final Report."

Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E.V., Dickman, N., Hanson, S., and Hopper, M., (1996), National seismic-hazard maps; documentation: U.S. Geological Survey Open-File Report 96-532, 110 p.

Garcia, D., D.J. Wald, and M.G. Hearne (2012). "A Global Earthquake Discrimination Scheme to Optimize Ground-Motion Prediction Equation Selection," Bulletin of the Seismological Society of America, v. 102, no. 1, pp. 185-203.

Idriss, I.M. (2008). An NGA Empirical Model for Estimating the Horizontal Spectral Values Generated By Shallow Crustal Earthquakes, Earthquake Spectra. 24, 217-242.

Nuclear Regulatory Commission (2007). "Regulatory Guide 1.208 – A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion", U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

Senior Seismic Hazard Analysis Committee [SSHAC] (1997). "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts," NUREG/CR- 6372, Lawrence Livermore National Laboratory, UCRL-ID-122160.

Silva, W., N. Gregor, and R. Darragh (2003). "Development of Regional Hard Rock Attenuation Relations for Central and Eastern North America, Mid-Continent and Gulf Coast Areas," Pacific Engineering, http://www.pacificengineering.org/, dated August 13, 2003.

ASSOCIATED COLA REVISIONS:

The text in FSAR Subsection 2.5.2.4.5.2 will be revised as follows in a future update of the FSAR:

2.5.2.4.5.2 New ~~Attenuation~~**GMPE** Models for the Cuba and Caribbean Region

The incorporation of additional seismic sources developed for the Caribbean region in the PSHA requires applicable ground motion ~~attenuation~~**prediction equation (GMPE)** models. Although much of the Caribbean has experienced large, damaging earthquakes, there are very few recorded strong ground motion data from the region, and this has prevented the development of a regional empirical ~~ground motion~~**GMPE, specifically one for** attenuation ~~relationship~~**of ground motion between sources in the northern Caribbean and the Turkey Point Units 6 & 7 site location in southern Florida**. Moreover, the use of ~~ground motion prediction equations (GMPE's)~~**GMPEs** from other regions, such as the EPRI 2004 (Reference 242) GMPE's, cannot be uncritically adopted for PSHA analysis because of the observed differences in crustal properties between the CEUS and Caribbean.

~~One study of strong ground motion attenuation was found.~~**No studies have been found modeling attenuation of strong ground motion between earthquakes in the Caribbean and sites in the CEUS so that no experts could be identified who could be characterized as a proponent, which SSHAC (Reference 318) defines as "an expert who advocates a particular hypothesis or technical position." The absence of a proponent or proponents made it difficult to categorize the level of the study per the SSHAC guidelines. However, what has been done in this regard is otherwise fully consistent with industry practice in general and the SSHAC guidelines in particular.**

Initial development of a suite of specific GMPEs was performed by, what in SSHAC nomenclature would be called, the Technical Integration team of two Bechtel seismologists: Drs. Nick Gregor and Behrooz Tavakoli, both with significant experience in generating and evaluating GMPEs. Peer review was provided by a Technical Advisory Group (TAG) at several points throughout the GMPE development process. A resource expert, Dr. Dariush Motazedian of Carleton University, Ottawa, Canada, was also consulted during this time.

The GMPE development reflects the uniquely challenging situation that exists with regard to the seismic characterization of Cuba and the adjacent Northern Caribbean region in that, for this region, empirical ground motion data is limited or unavailable, there are currently no calibrated GMPEs predicting ground motions in southern Florida arising from earthquakes in Cuba or the Northern Caribbean, and there are no experts identified that can be characterized as proponents as defined in SSHAC (Reference 318).

SSHAC (Reference 318) characterizes a Level 2 study as one in which the TI reviews the literature and then interacts with proponents and resource experts to identify issues and interpretations and, on the basis of these interactions, "estimates community distribution," i.e., develops "a representation...of the diversity of interpretations and their uncertainties" (see Table 3-1 and Sections 3.1.3.5 and 3.2.1 of SSHAC [Reference 318]). SSHAC (Reference 318) also acknowledges (in Section 3.1.3.3) that the "choice of the level of [study] is often driven by...the amount of resources available for the study."

Initially a literature review was performed with the goal of retrieving acceptable GMPEs for the Cuba and Caribbean region. However, this literature review only retrieved one GMPE developed recently by Motazedian and Atkinson (Reference 287). In addition to the interaction with the TAG members, correspondence was conducted with Professor Motazedian during the initial development of the Caribbean GMPEs. These initial technical discussions were for the possible application of the published Motazedian and Atkinson (Reference 287) GMPE for the PSHA study. However, based on the limitations of this GMPE (e.g., incomplete suite of necessary spectral frequencies, limited application for distances greater than 500 km, and site-specific ground conditions of soft rock), it was determined that this published GMPE was not directly acceptable for use in the PSHA.

The process described is generally consistent with a Level 2 study as described in SSHAC (Reference 318) where it states (in section 3.2.1): "...the TI would communicate with the authors of published studies and other local experts who have expertise in the region or in regional ground motions...to hear and understand the technical positions taken by various proponents of particular hypotheses....In effect, the TI is...attempting to provide an overall assessment that would represent the informed scientific community's view of the subject, if the community were to make such an assessment."

Motazedian and Atkinson (Reference 287) analyzed a dataset of approximately 300 earthquakes recorded by stations in Puerto Rico. This dataset spanned the Mw range of 3 to 5.5 and distances from about 20 km to 500 km. **They acknowledge that their ground motion dataset consisted of recorded ground motions from both crustal and subduction zone earthquakes and that the separation of the earthquakes used in their dataset into crustal and subduction events was not possible because of the limited station coverage for the region.** Based on these data, Motazedian and Atkinson developed a set of regional anelastic attenuation and source parameters. Finally, Motazedian and Atkinson used these regional parameters within a stochastic simulation process to create an artificial dataset for larger earthquakes at near distances to fit a GMPE to these generated data.

To address this possible concern about the influence of using both subduction and crustal events to estimate the regional attenuation and source parameters, Motazedian and Atkinson (Reference 287) provide a comparison of their GMPE with representative GMPEs for the CEUS (Reference 210), California (Reference 357), and an empirically-based GMPE based on the global ground motion dataset for subduction zones (Reference 358). They conclude that, overall the Puerto Rico relations agree well with the stochastic relations for California and eastern North America and are quite different from those calculated by the global subduction

relations. This comparison and noted results provide a technical justification for using the source and attenuation parameters from the Puerto Rico ground motion dataset (Reference 287) as the starting point for the development of applicable GMPEs for the Caribbean seismic sources.

The Motazedian and Atkinson (Reference 287) study focused on ~~GMPE's~~GMPEs most useful for the evaluation of PSHA results for Puerto Rico. For the purposes of an evaluation of potential contributions to PSHA at the Turkey Point **Units 6 & 7** site from Caribbean earthquakes, GMPE results from somewhat larger and significantly more distant earthquakes are needed.

Beginning with the suite of regional ~~an elastic~~**anelastic** attenuation and source parameters of Motazedian and Atkinson, and following the stochastic simulation methodology, region-specific ~~attenuation~~**GMPE** models for the Cuba and Caribbean region were developed. Ground motions were estimated for seven spectral frequencies on hard rock for earthquakes with magnitudes between Mw 4.75 and 8.75 and for a distance range of 150 to 2000 kilometers.

To account for the expected uncertainty associated with the application of regional attenuation and source parameters estimated from earthquakes in and around Puerto Rico and their application to other regions within the Caribbean (e.g., Cuba), the stress parameter of the source and the anelastic attenuation models from Motazedian and Atkinson (Reference 287) were varied in the stochastic ground motion simulation analysis. The regional attenuation and source parameters from the Motazedian and Atkinson (Reference 287) study and the specific values used for the development of the suite of applicable ~~attenuation~~**GMPE** models are listed in Table 2.5.2-231. The variation of the stress parameter was ~~based~~**defined** to be normally distributed with a standard deviation (sigma value) of 0.7 (in natural log units) given in **the** EPRI 1993 study (Reference 244). The variation of the regional anelastic attenuation constant term was based on an assumed sigma value of 0.4 (in natural log units) given in the 2003 Silva et al.~~,~~ study (Reference 342). In addition, three separate seismic source models were used in the analysis: single corner with constant stress parameter (1CC model), single corner with magnitude dependent stress parameter (1CV model), and double corner source (2C model) based on the analysis of CEUS ground motion data. These three seismic source models are part of the larger set of source models that are included in the 2004 EPRI (Reference 242) ground motion models.

A linear regression was performed on the simulated datasets to estimate the regression coefficients for the Caribbean regional GMPEs for use in the PSHA. A nonlinear GMPE functional form and regression, generally needed to successfully predict saturation of strong ground motion at small distances, were not required because of the large minimum distance of 150 kilometers separating Caribbean earthquakes from the Turkey Point **Units 6 & 7** site. An aleatory sigma value of 0.645 (in natural log units) was selected following the Motazedian and Atkinson study (Reference 287) and was assigned to each Caribbean ~~attenuation~~**GMPE** model for use in the PSHA for all frequencies.

To capture the epistemic uncertainty in ground motion models in the hazard analysis, a number of GMPEs from the different seismic source models ~~was~~were included along with model-dependent weights. The weights for these new ~~attenuation~~**GMPE** models were assessed based on the family class weights used in the 2004 EPRI ground motion model

study and the family class (that is, 1CC, 1CV, or 2C) of the seismic source model (Reference 242). Figure 2.5.2-255 shows the suite of Caribbean PGA ~~attenuation~~**GMPE** curves for a magnitude Mw 7 earthquake over the applicable distance range of 150 - 2000 kilometers. Within a given seismic source model type (e.g., single corner constant stress parameter), the difference between the ~~attenuation~~**GMPE** models based on the low, base, and high stress parameter values resulted in a constant scaling of the ~~attenuation~~**GMPE** curves. This scalar variation was captured by combining the datasets from these stress parameter values for the regression analysis leading to a combined suite of nine ground motion ~~attenuation~~**GMPE** models (i.e., heavy lines) that were adopted for use in the PSHA with the Caribbean seismic sources. As a check, the complete suite of ~~attenuation~~**GMPE** curves is shown in Figure 2.5.2-255 and the resulting nine adopted ~~attenuation~~**GMPE** curves span the general range of values from the complete suite of curves. Figures 2.5.2-256 and 2.5.2-257 plot the ~~ground motion attenuation~~**GMPE** curves for the periods of 0.1 and 1.0 seconds, respectively.

~~Finally~~**At the suggestion of TAG members over the course of the three TAG meetings,** a sensitivity analysis was performed to examine the effect on epistemic uncertainty of alternative ~~attenuation relationships~~**GMPE**s for use in the PSHA. The alternative relationships considered adopted a double corner (2C) seismic source model, such as might be expected to occur in a more active tectonic environment such as the western United States (WUS) rather than the double corner seismic source model of the less active tectonic environment of the CEUS, and a Gulf Coast region lower amplitude but higher (less rapidly attenuating) anelastic attenuation factor (Q) model rather than the Puerto Rico region-specific (higher amplitude but more rapidly attenuating) Q model from Motazedian and Atkinson (Reference 287) recognizing that much of the propagation path from the Caribbean sources to the Turkey Point **Units 6 & 7** site is through the Gulf Coast crust. It was found that adoption of these alternatives (i.e., different suite of regional attenuation and seismic source parameter values) led to ~~GMPE~~**ground motion** values that were equal to (at large distances based on the anelastic attenuation rates) or lower than (based on the different magnitude scaling from the WUS-based double corner model) ~~than~~the suite of original nine new ~~ground motion attenuation~~**GMPE** models adopted for the Cuba and Caribbean region. A comparison of the weighted combination of the original nine GMPE models and the inclusion of these additional sensitivity models ~~results~~**resulted** in a slightly lower weighted mean ~~attenuation~~**GMPE** curve over the magnitude and distance range needed for the PSHA. ~~Thus~~Therefore, their incorporation into the final PSHA results would have slightly lowered the already low hazards**,** and **thus**, the use of the original nine GMPE models was accepted **by the TAG members because the inclusion of these additional GMPE models would be expected to lead to lower, and less conservative, ground motion results.**

After the suite of GMPEs was developed, two additional sensitivity analyses were performed to further validate the technical assessment of the stochastic Caribbean GMPE models developed for Turkey Point Units 6 & 7. These analyses sought additional empirical data with which to compare the GMPEs for Turkey Point Units 6 & 7 and examined the effect of alternate suites of GMPEs on the PSHA results at the site. The results of these two additional sensitivity studies are presented here.

The first supplemental sensitivity analysis compared the suite of GMPEs used in the Turkey Point Units 6 & 7 PSHA with empirical regional ground motion data. To assist in the technical evaluation of the current Caribbean GMPE models developed for the for the Turkey Point Units 6 & 7 FSAR a comparison of empirical ground motions from five regional earthquakes occurring since 2004 in the Gulf of Mexico and northern Caribbean region were analyzed. These earthquakes were selected from among those available as being most representative of earthquakes whose tectonic settings and locations might be expected to be like those of future earthquakes contributing to the overall PSHA at the site under the source model adopted. Specifically, these were shallow crustal earthquakes in the northern Caribbean or Gulf of Mexico.

Regional broadband empirical data from selected Incorporated Research Institutions for Seismology (IRIS) stations were obtained, processed and compared to the suite of Caribbean GMPE models and the suite of EPRI (References 242 and 203) GMPE models for both the Mid-continent and Gulf Coast regional models. Based on these comparisons, a technical assessment can be made on the applicability of using the Caribbean GMPE for the Turkey Point Units 6 & 7 PSHA.

Note that the current PSHA results were developed using the suite of EPRI (References 242 and 203) Mid-continent GMPE models for other non-Caribbean sources. In this comparison all of the GMPE curves are for the assumed CEUS hard rock site conditions with Vs = 2.83 km/sec, whereas the empirical IRIS data are for the individual unknown site conditions of each station which is expected to be less than Vs = 2.83 km/sec. Based on simplified site response analysis, it was computed that adjustment factors for the station specific site conditions to the more stable CEUS hard rock site conditions required a reduction factor in the observed empirical ground motion values, especially for the longer spectral frequencies of interest (e.g., 1 or 2.5 Hz).

The current deaggregation of seismic hazard at the Turkey Point Units 6 & 7 site from all sources, Cuban, Caribbean, and southeast United States, is shown in Figures 2.5.2-226 and 2.5.2-228 for longer period motions (for which the relative contribution of the larger, more distant Cuban and Caribbean sources would be expected to have their greatest relative contribution) and for the 10^{-4} and 10^{-5} mean annual frequency of occurrence probabilities used to develop design ground motions under current NRC regulatory guidance. The relative contribution for the higher frequency cases of 5 and 10 Hz (Figures 2.5.2-227 and 2.5.2-229) from the more distant Caribbean sources is significantly reduced relative to the closer local seismic sources. For this sensitivity comparison, the empirical ground motions for 1 and 2.5 Hz are presented for each of the five regional earthquakes and ground motion prediction equations.

For each event, acceleration response spectra for a spectral damping of 5 percent at each station were computed. The geometric mean of the two horizontal components was computed and amplitudes for the 1 and 2.5 Hz spectral frequencies were generated and compared to the suite of GMPE models (i.e., both of the EPRI, 2004 GMPE models (Reference 242) and the Caribbean GMPE models).

Note that, based on the hypocentral location and geographical location relative to tectonic plate boundary, all five of these earthquakes are considered to be shallow crustal events and are not associated with any regional subduction zones. For each event, a standard time history processing methodology was applied with the final results being a dataset of the acceleration response spectra for a spectral damping of 5 percent at each station. The geometric mean of the two horizontal components was computed and comparison plots for the 1 and 2.5 Hz spectral frequencies were generated showing the empirical data (both as recorded and adjusted for a consistent CEUS hard rock site conditions) and the suite of GMPE models (i.e., both of the EPRI, 2004 GMPE models (Reference 242) and the Caribbean GMPE models). Both the individual GMPE curves and the weighted mean GMPE curve for a given set are shown in the comparison plots for each spectral frequency and earthquake.

These five events were as follows:

- **December 14, 2004 – Caribbean Sea Region (M_w6.8, 19.05 N, -81.52 W, hypocenter depth 12.0 km), Fault Plane 1 (Strike, Dip, Rake): 258.0, 84.0, -2.0; Fault Plane 2 (Strike, Dip, Rake): 349.0, 88.0, -174.0. The fault plane solution implies almost pure strike-slip motion on a nearly vertically dipping fault.**

  This event occurred in the Caribbean Sea region and its epicenter is shown in Figure 2.5.2-258a along with the Turkey Point Units 6 & 7 site location, and the location of the IRIS stations that recorded this earthquake and were analyzed. Based on the observed station distribution, the IRIS station DWPF located in central Florida has the most applicable source to site path for this comparison. The GMPE curves and empirical data are shown in Figures 2.5.2-258b and 2.5.2-258c for the 1 and 2.5 Hz spectral frequencies. The data point from the DWPF station is highlighted as a solid blue symbol. Overall the empirical data both as recorded and with the site condition correct factors applied falls below the median Caribbean GMPE curve (heavy red line) and has values which are in the lower distribution range of Caribbean GMPE curves.

- **September 10, 2006 – Gulf of Mexico (M_w5.9, 26.32 N, -86.84 W, hypocenter depth 29.6 km), Fault Plane 1 (Strike, Dip, Rake): 324.0, 28.0, 117.0; Fault Plane 2 (Strike, Dip, Rake): 114.0, 65.0, 77.0. The fault plane solution implies composite strike-slip and reverse-slip motion on a moderately steeply dipping fault.**

  This event occurred in the Gulf of Mexico and its epicenter is shown in Figure 2.5.2-259a along with the Turkey Point Units 6 & 7 site location, and the location of the IRIS stations that recorded this earthquake and analyzed. Based on the observed station distribution, the IRIS station DWPF located in central Florida has the most applicable source to site path for this comparison. Out of the five earthquakes considered in this analysis, this event has the most consistent tectonic structure between the earthquake and the Turkey Point Units 6&7 site and can be considered as the best representative event for events occurring in and around the island of Cuba and being observed in Southern Florida. The distribution of stations in the central United States have a less applicable travel path azimuth and may show different attenuation properties based on these different tectonic travel paths. The GMPE curves and empirical data are shown in Figures 2.5.2-259b and 2.5.2-259c for the 1 and 2.5 Hz spectral frequencies.

The data point from the DWPF station is highlighted as a solid blue symbol. In general the empirical observations fall within the range of the Caribbean GMPE curves with the single exception of station LRAL (i.e., at a distance of about 750 km) for 2.5 Hz in which the unadjusted empirical data exceeds the highest Caribbean GMPE curve. For this station and frequency, however, the CEUS hard rock adjusted ground motions fall within the range of Caribbean GMPE models which are defined for CEUS hard rock site conditions. It can also be concluded from the comparison plots in Figures 2.5.2-259b and 2.5.2-259c, that the distribution of the current Caribbean GMPE curves adequately captures the range of the empirical data. In addition, the observation from the DWPF station is in the lower range of the Caribbean GMPE curves.

- **February 4, 2007 – Cuba Region (M_w6.2, 19.49 N, -78.34 W, hypocenter depth 12.0 km), Fault Plane 1 (Strike, Dip, Rake): 257.0, 76.0, -9.0; Fault Plane 2 (Strike, Dip, Rake): 349.0, 81.0, -166.0. The fault plane solution implies almost pure strike-slip motion with a small normal component on a steeply dipping fault.**

  This event occurred south of the island of Cuba and its epicenter is shown in Figure 2.5.2-260a along with the Turkey Point Units 6 & 7 site location, and the location of the IRIS stations that recorded this earthquake were analyzed. Only three IRIS stations were analyzed from this earthquake and their station locations are shown in Figure 2.5.2-260a. Based on the observed station distribution, the IRIS station DWPF located in central Florida has the most applicable source to site path for this comparison. The GMPE curves and empirical data are shown in Figures 2.5.2-260b and 2.5.2-260c for the 1 and 2.5 Hz spectral frequencies. The data point from the DWPF station is highlighted as a solid blue symbol. Overall the empirical data falls below the median Caribbean GMPE curve (heavy red line) and has values which are in the lower distribution range of Caribbean GMPE curves. In addition, the observation from the DWPF station is similar to the lowest Caribbean GMPE curve or lower.

- **May 28, 2009 – North of Honduras (M_w7.3, 16.50 N, -87.17 W, hypocenter depth 12.0 km), Fault Plane 1 (Strike, Dip, Rake): 63.0, 60.0, -7.0; Fault Plane 2 (Strike, Dip, Rake): 156.0, 84.0, -150.0. The fault plane solution implies predominantly strike-slip with a smaller normal component on a moderately to steeply dipping fault.**

  This event occurred north of Honduras in Central America and is the largest earthquake in the suite of five events analyzed in this sensitivity study. The location of its epicenter is shown in Figure 2.5.2-261a along with the Turkey Point Units 6 & 7 site location, and the location of the three IRIS stations that were analyzed. Based on the azimuths from the earthquake to the three IRIS stations, none of the associated seismic ray travel paths are ideal for this comparison study. The GMPE curves and empirical data are shown in Figures 2.5.2-261b and 2.5.2-261c for the 1 and 2.5 Hz spectral frequencies. The comparisons provided in the figures indicate that the empirical data from this earthquake are lower than any of the Caribbean GMPE curves.

- **January 12, 2010 – Haiti (M_w7.0, 18.61 N, -72.62 W, hypocenter depth 12.0 km), Fault Plane 1 (Strike, Dip, Rake): 250.0, 71.0, 22.0; Fault Plane 2 (Strike, Dip, Rake): 152.0, 69.0, 159.0. The fault plane solution implies composite strike-slip with a moderate reverse component on a steeply dipping fault.**

  The Haiti earthquake is the most recent event in this suite of five earthquakes analyzed. The epicentral location and the suite of IRIS stations analyzed are shown in Figure 2.5.2-262a. Note that the data from the DWPF was not available for this earthquake. For the SDV station, only one single horizontal component was available and thus was not included in the comparison which was based on the geometric mean of two horizontal component ground motions. The large distance and undesirable azimuthal direction away from Southern Florida for this station from this earthquake provides an additional justification for not including this station in the comparison. The GMPE curves and empirical data are shown in Figures 2.5.2-262b and 2.5.2-262c for the 1 and 2.5 Hz spectral frequencies. The data point from the OTAV station is highlighted as a solid blue circle. Overall the empirical data falls in the lower range or lower than the Caribbean GMPE curves.

The results of these comparisons demonstrated that the suite of Caribbean GMPE models used in the current PSHA predicts larger ground motions on average than the observed empirical data from these five earthquakes for the spectral frequencies of 1 and 2.5 Hz, especially when considering the adjustment to a common CEUS hard rock site condition. In addition, for the subset of data from just those stations that have a more appropriate source to site travel paths in particular this conclusion can be extended to state that the use of the Caribbean GMPE models should provide conservative (i.e., higher) ground motion predictions compared to the available empirical data from the region.

The second supplemental sensitivity determined the sensitivity of the GMRS at the Turkey Point Units 6 & 7 site to the GMPEs used for the Caribbean seismic sources, which include the Cuba areal source plus nine fault sources. Five sets of seismic hazard calculations for five different GMPE suites were used to develop the corresponding GMRS. The GMPEs used for Caribbean seismic sources are: those of the base case which is (1) the Caribbean GMPE models developed for Turkey Point Units 6 & 7 (Subsection 2.5.2.4.5.2), (2) EPRI Mid-continent region (References 242 and 203) equations, (3) EPRI Mid-continent region "mod1" (References 242 and 203) equations, (4) EPRI Gulf region (References 242 and 203) equations, and (5) EPRI Gulf region "mod 1" (References 242 and 203) equations. The modification of the EPRI GMPEs for both the Mid-continent and Gulf Coast cases was to exclude the GMPE which predicts significantly higher ground motions for large distance, such as those from the contributing Cuba and Caribbean sources. All seismic hazard calculations were made for the hard rock site conditions and include the other non-Caribbean sources in the PSHA. Thus the observed differences are based solely on the use of different GMPE models for the Caribbean seismic sources. For each of the five cases, ground motion values were estimated from the mean hazard curves for the seven standard spectral frequencies. Site specific horizontal GMRS are plotted in Figure 2.5.2-263 and are developed using the site amplification factors. In general, the GMRS results using the EPRI Gulf Coast GMPEs are equal to or lower than the

results using the Caribbean GMPE (i.e., indicated as Base Case in Figure 2.5.2-263). For the EPRI Mid-continent GMPE, the opposite result is concluded in which the GMRS values exceed the GMRS values using the Caribbean GMPE models, however, based on the previous additional sensitivity, the EPRI Mid-continent models predicts higher ground motions than the empirical ground motions and as such may not be applicable for the modeling of ground motion attenuation for seismic sources in this Caribbean region and the Turkey Point Units 6 & 7 site location in southern Florida. In addition the tectonic structure and potential attenuation of ground motions for Caribbean sources might be more consistent with the EPRI Gulf Coast GMPE models based on the southern region of Florida being located in the Gulf Coast tectonic region of the eastern United States, especially for events that would occur in and around the island of Cuba and the Gulf of Mexico. For events occurring further south of the island of Cuba, the tectonic regime and subsequent seismic ray travel paths and associated attenuation may be more complex based on the more complex tectonic environment located south of the island of Cuba and may not be as consistent with the Gulf Coast GMPE. However, based on the results of the first sensitivity analysis, the empirical data indicates that the Caribbean GMPE is conservative in its estimation of ground motions and based on the results shown in Figure 2.5.2-263, the use of the EPRI Gulf Coast GMPE for the PSHA gives similar or lower GMRS values.

These two supplemental sensitivity analyses indicate that the suite of GMPEs used to characterize contributions to hazard at the site from Caribbean earthquakes, and the resulting GMRS at the site from these earthquakes, are conservative.

Next, six ground motion attenuation experts were asked to review and comment on both the methodology and results of the Caribbean GMPE models. These six experts were:

- **Dr. Norman Abrahamson (Consultant)**
- **Dr. Yousef Bozorgnia (University of California, Berkeley, PEER)**
- **Dr. Kenneth Campbell (EQECAT)**
- **Dr. Shahram Pezeshk (University of Memphis)**
- **Dr. Paul Somerville (URS Corporation)**
- **Dr. Robert Youngs (AMEC-Geomatrix)**

In reviewing and summarizing the responses from the experts it is concluded that the use of the Caribbean GMPE models in the PSHA is acceptable. As noted by the six experts, based on the comparison between the Caribbean GMPE model and the empirical IRIS data, these GMPE models may be conservative in their estimation of ground motions in the region. In addition the assignment of an aleatory uncertainty value of 0.645 in natural log units was acceptable based on the consensus of the six experts.

When asked about the applicability of the EPRI Mid-continent or Gulf Coast models, the consensus of the six experts was that the suite of Gulf Coast GMPE models is closer to the empirical data than the Mid-continent suite. However, this did not indicate that the EPRI Gulf Coast models are preferable over the Caribbean GMPE models.

Based on the polling and summary of the responses from the six experts, the ultimate use of the specific Caribbean GMPEs in the PSHA for the Turkey Point Units 6 & 7 site location for seismic sources in the Cuba and Caribbean region falls within the range of the informed technical community and actually may produce slightly larger ground motions than would be estimated from the center, body, and range of the informed technical community. The experts' opinions support the development of the final Caribbean GMPEs. There were no conflicting opinions among the experts regarding the suitability of the final Caribbean GMPEs for use in the PSHA analysis for Turkey Point Units 6 & 7.

Mean GMPE plots are provided for the EPRI Mid-continent (References 242 and 203) and Caribbean GMPEs in Figures 2.5.2-264 through 2.5.2-270 for the seven defined frequencies. Note that EPRI (Reference 203) is only a recommendation for the associated aleatory uncertainty and therefore does not impact the comparison plots of the weighted mean GMPE curve. The plotted mean GMPE curve is the weighted mean of the individual median GMPE curves as defined in EPRI 2004 (Reference 242) and for the Caribbean GMPE models. These GMPE plots are provided for three specific M_w values: 6, 7, and 8 for distances between 200 kilometers (124 miles) and 1,000 kilometers (621 miles). Note that the EPRI GMPE model (Reference 242) is defined as a function of epicentral distance, whereas the Caribbean GMPE model is defined as a function of hypocentral distance. For these comparison plots, the GMPE curves are plotted as a function of epicentral distance and for the Caribbean GMPE curves an assumed hypocentral depth of 8 kilometers (5 miles) was used.

The following references will be added to FSAR Subsection 2.5.2.7

357. Atkinson, G., Silva, W., "Stochastic Modeling of California Ground Motions," Bulletin of the Seismological Society of America, v. 90, no. 2, pp. 255 - 274, 2000.

358. Atkinson, G., Boore, D., "Empirical Ground Motion Relation for Subduction Zone Earthquakes and their Application to Cascadia and other regions," Bulletin of the Seismological Society of America, v. 93, no. 4, pp. 1703 - 1729, 2003.

359. Atkinson, G.M., and Boore, D.M., "Modifications to existing ground-motion prediction equations in light of new data," Bulletin of the Seismological Society of America v. 101, no. 3, pp. 1121-1135, 2011.

360. Boore, D. and G. Atkinson, "Boore-Atkinson NGA Ground Motion Relations for the Geometric Mean Horizontal Component of Peak and Spectral Ground Motion Parameters," Pacific Earthquake Engineering Research Center, PEER Report 2007/01, University of California, Berkeley, May 2007.

The following new figures will be added to FSAR Section 2.5.2:

Figure 2.5.2-258a

Map showing the earthquake location for the 12/14/2004 Caribbean Sea Region earthquake (M_w6.8), the IRIS station locations used in the analysis (shown as black triangles in this and similar subsequent figures), and Turkey Point Units 6 & 7 site location.

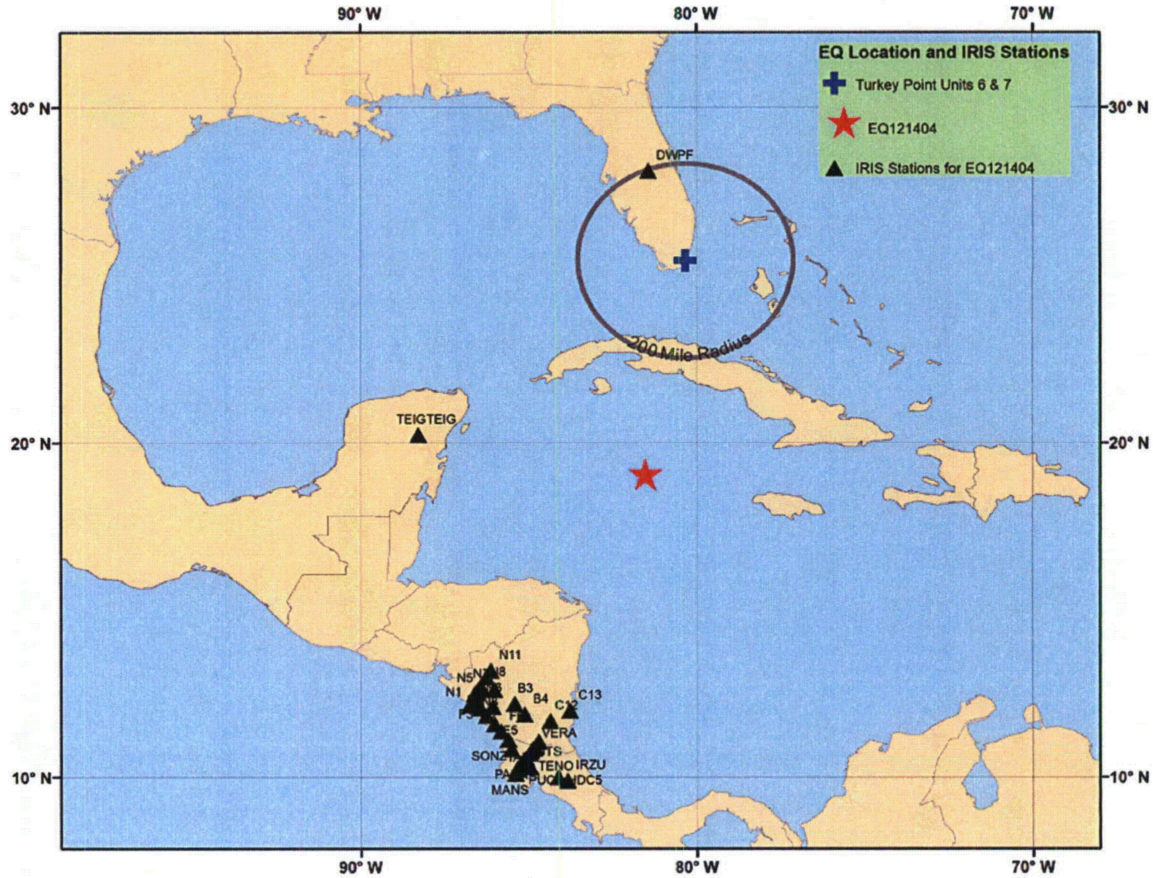


Figure 2.5.2-258b

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 1 Hz.

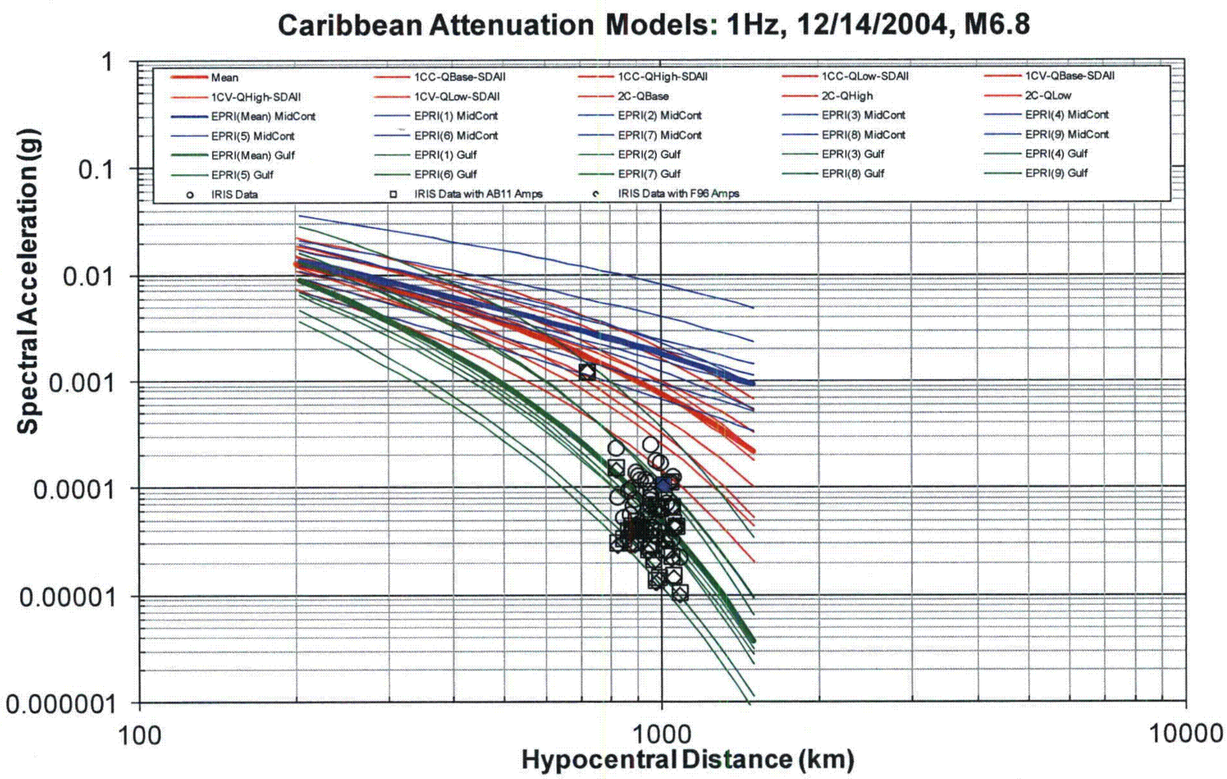


Figure 2.5.2-258c

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

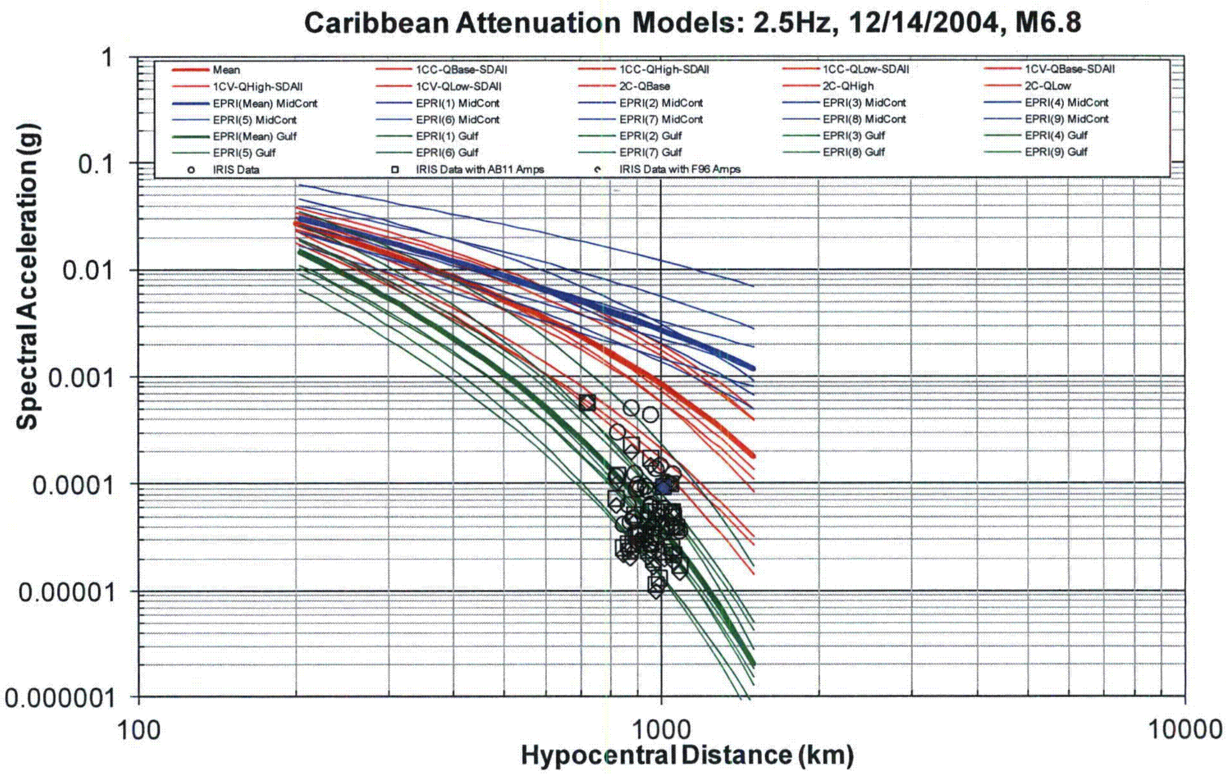


Figure 2.5.2-259a

Map showing the earthquake location for the 09/10/2006 Gulf of Mexico earthquake (M_w5.9), the IRIS station locations used in the analysis and Turkey Point Units 6 & 7 site location.

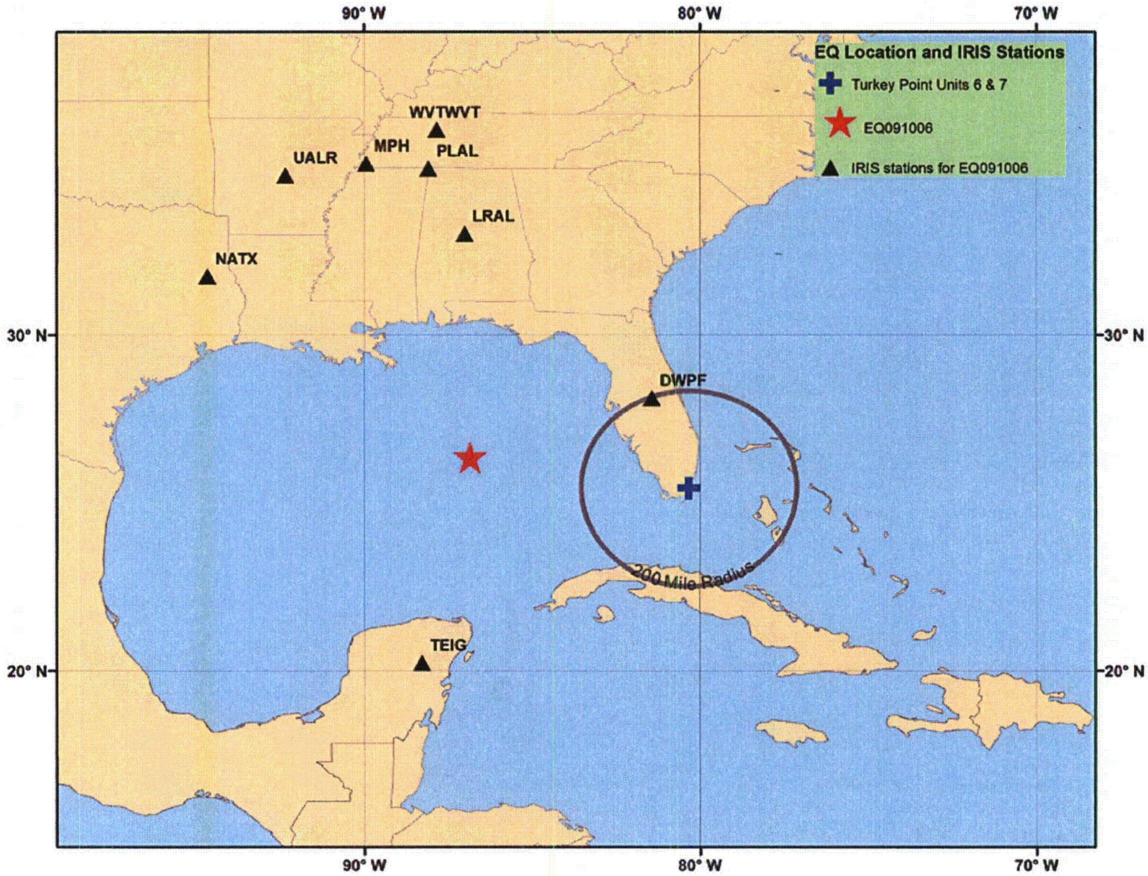


Figure 2.5.2-259b

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 1 Hz.

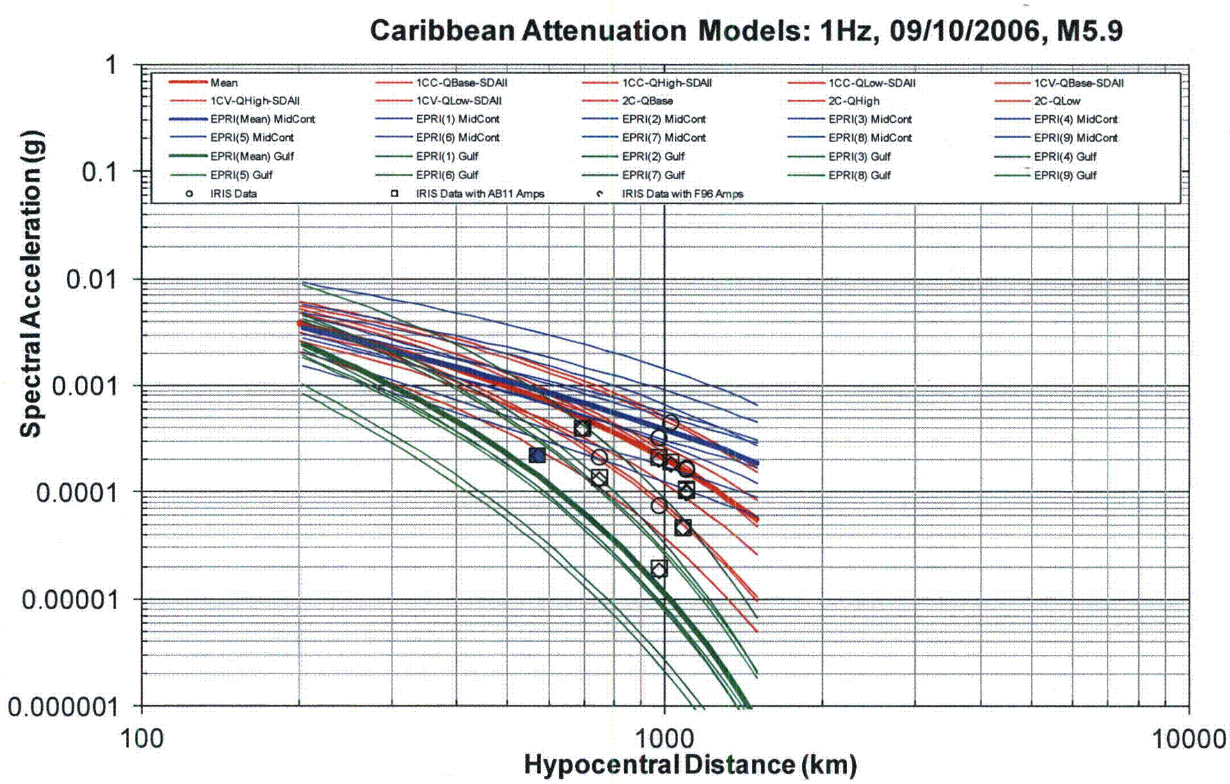


Figure 2.5.2-259c

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

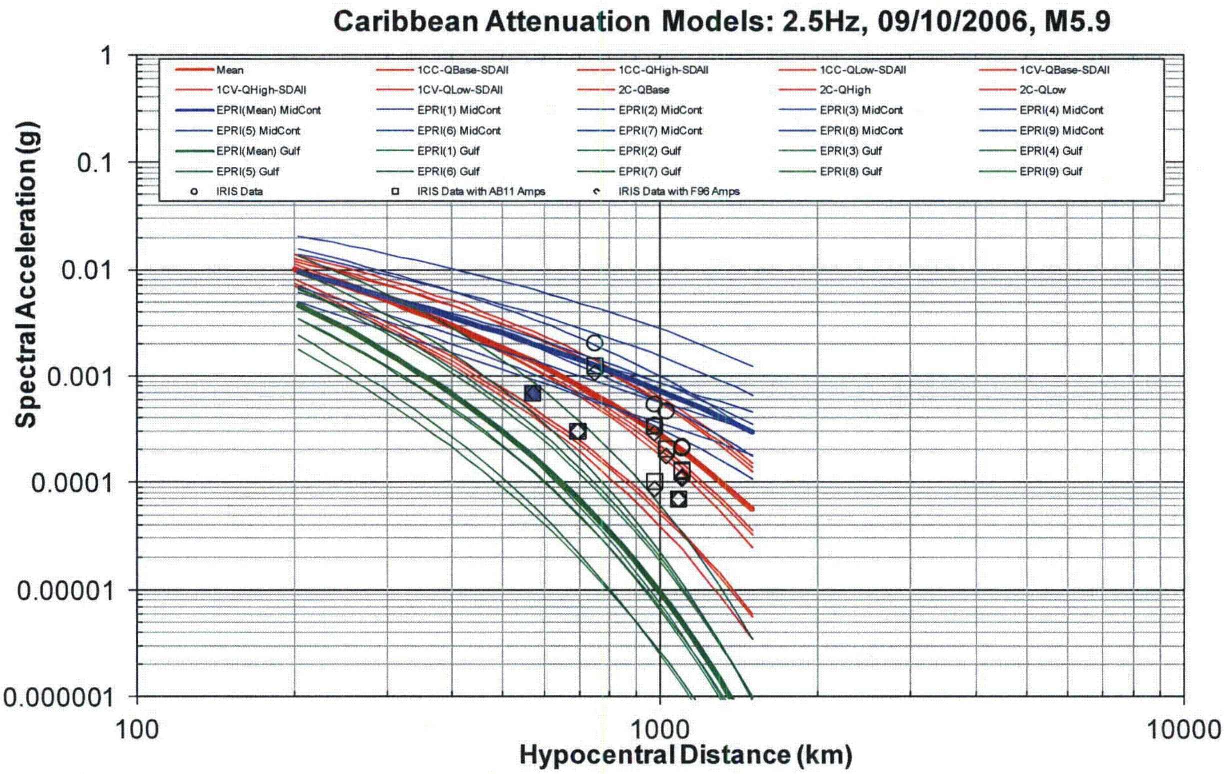


Figure 2.5.2-260a

Map showing the earthquake location for the 02/04/2007 Cuba Region earthquake (M_w6.2), the IRIS station locations used in the analysis and Turkey Point Units 6 & 7 site location

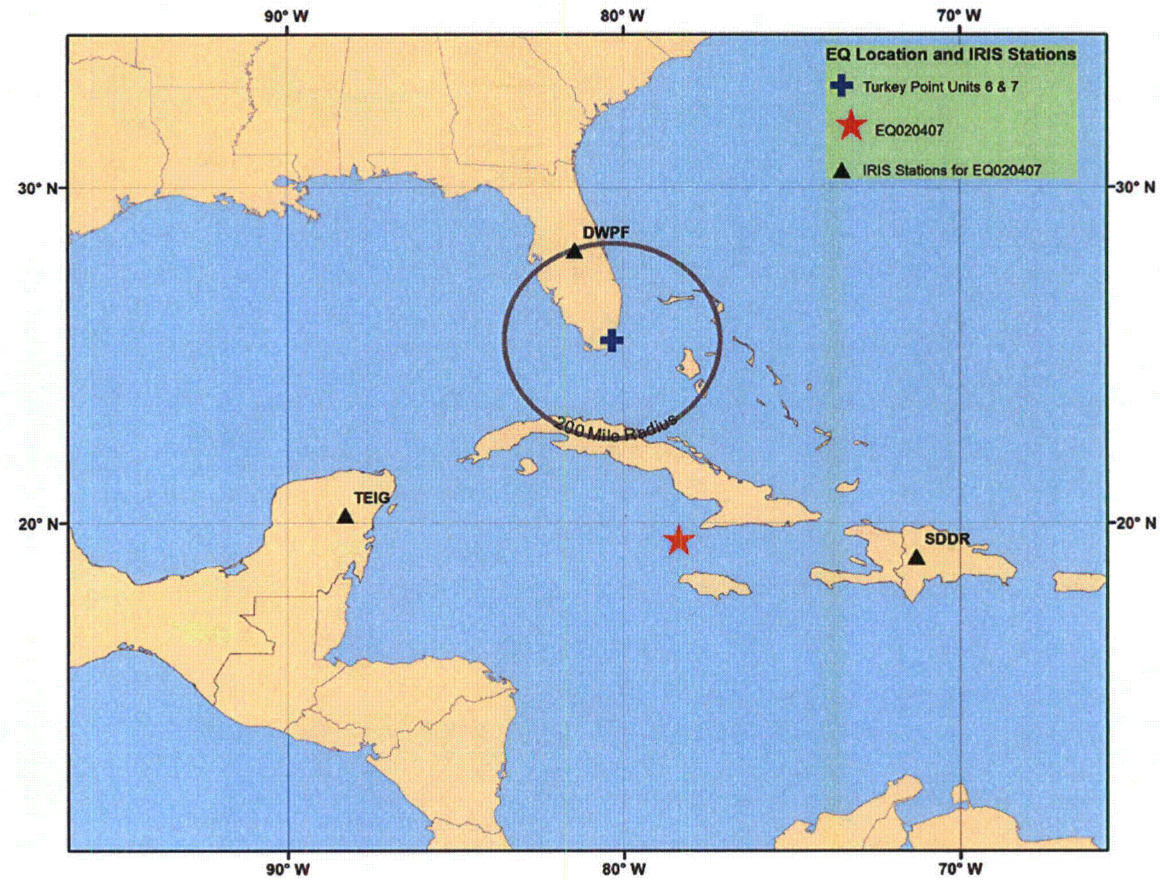


Figure 2.5.2-260b

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 1 Hz.

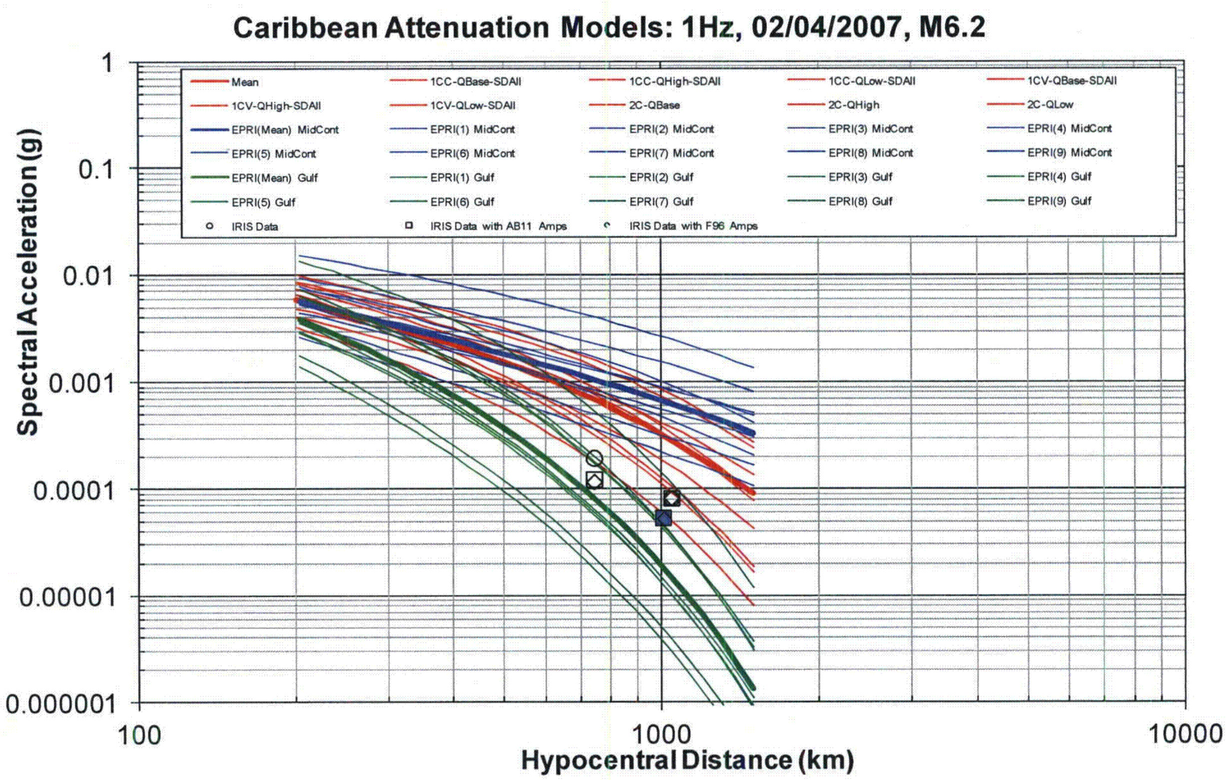


Figure 2.5.2-260c

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

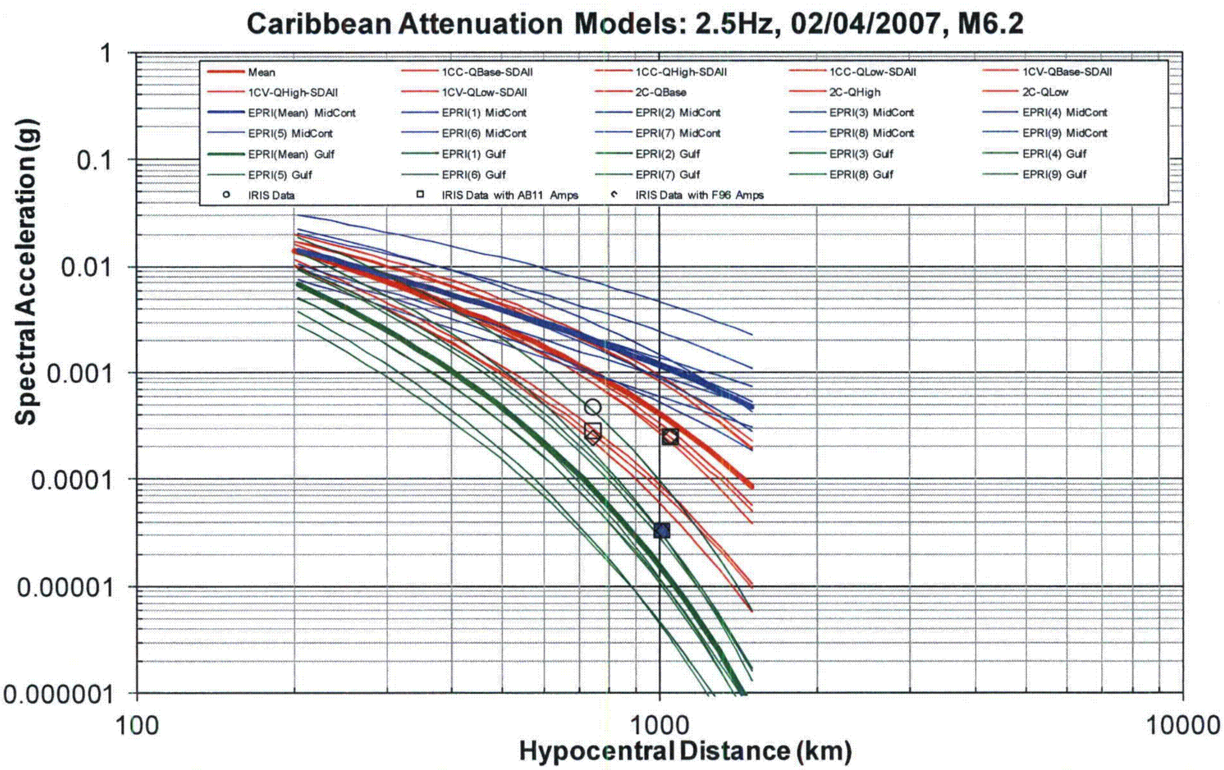


Figure 2.5.2-261a

Map showing the earthquake location for the 05/28/2009 North of Honduras earthquake (M_w7.3), the IRIS station locations used in the analysis and Turkey Point Units 6 & 7 site location.

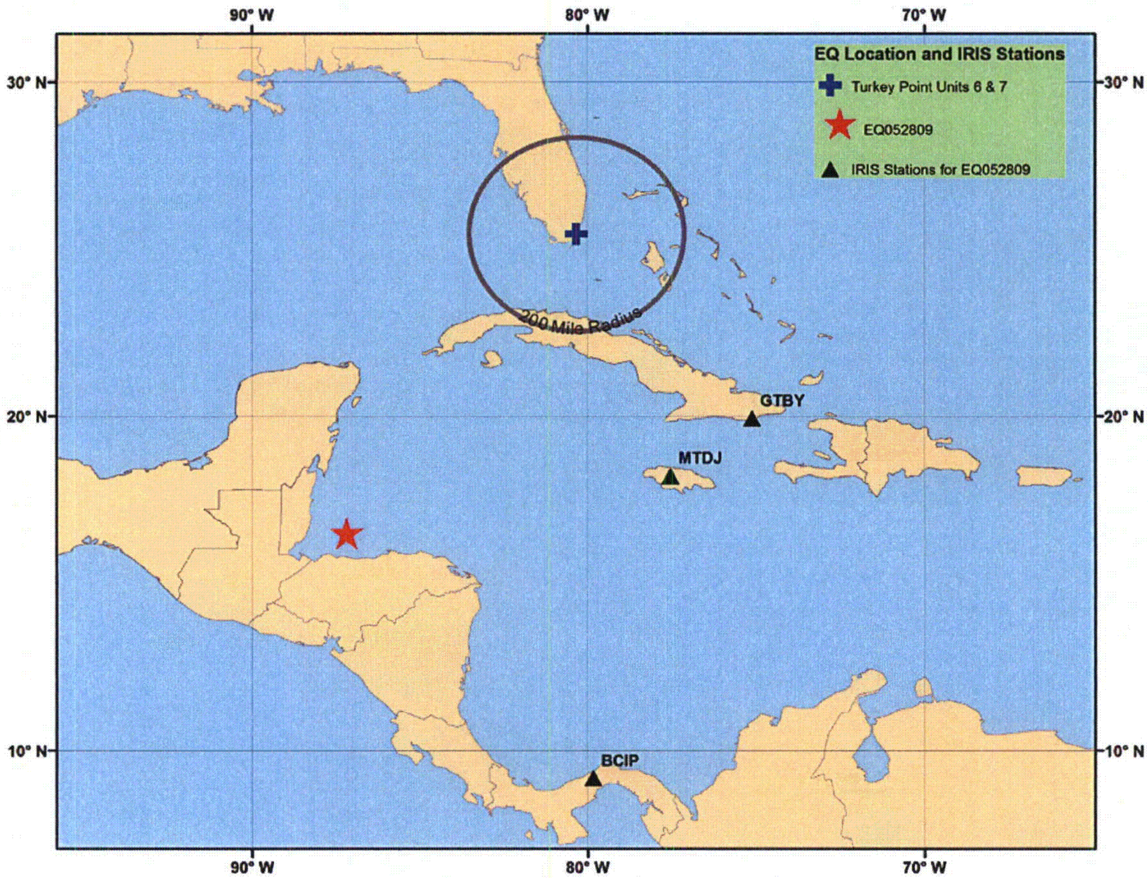


Figure 2.5.2-261b

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 1 Hz.

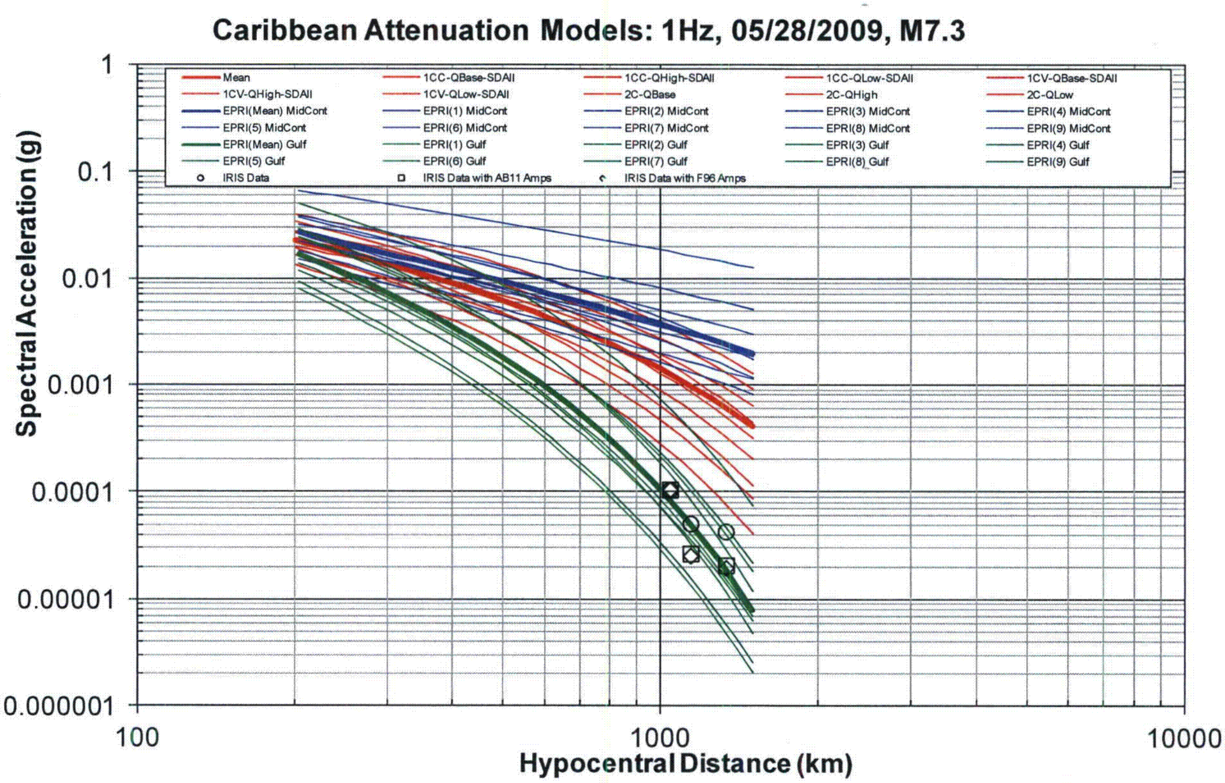


Figure 2.5.2-261c

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

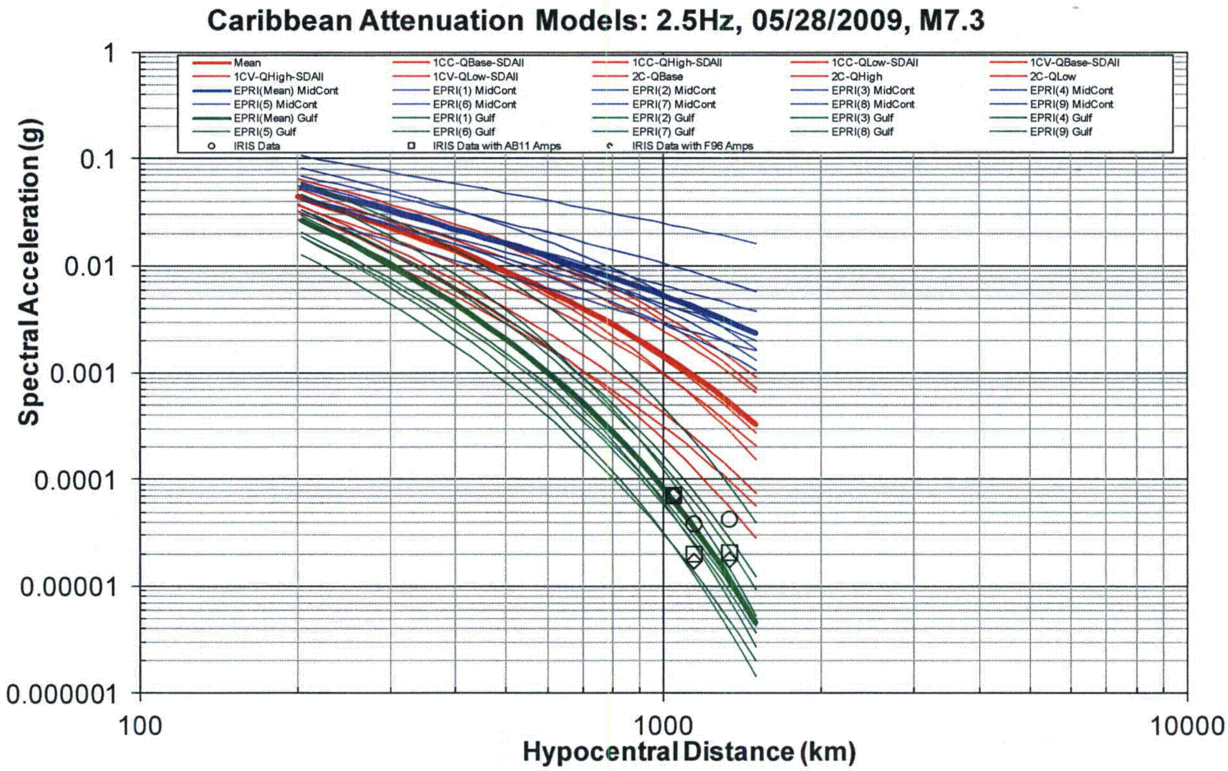


Figure 2.5.2-262a

Map showing the earthquake location for the 01/12/2010 Haiti earthquake (M_w7.0), the IRIS station locations used in the analysis and Turkey Point Units 6 & 7 site location.

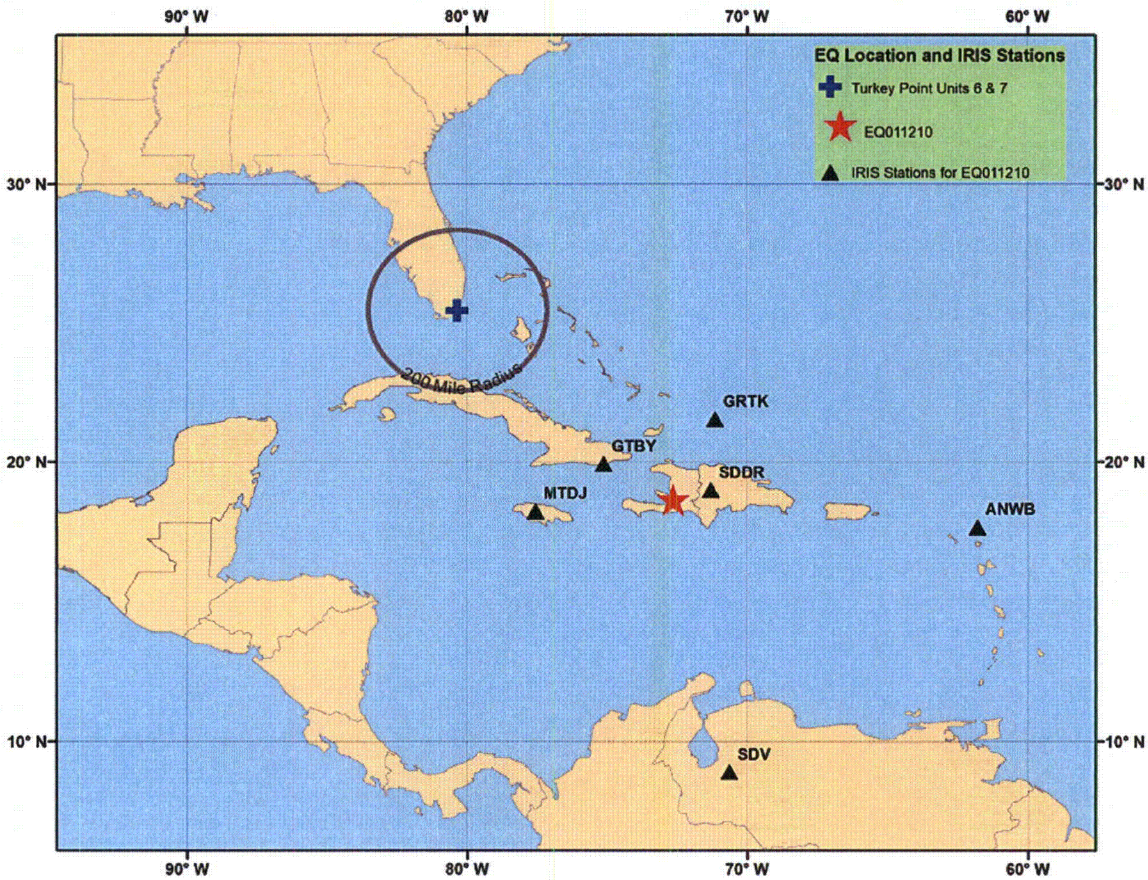


Figure 2.5.2-262b

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 1 Hz.

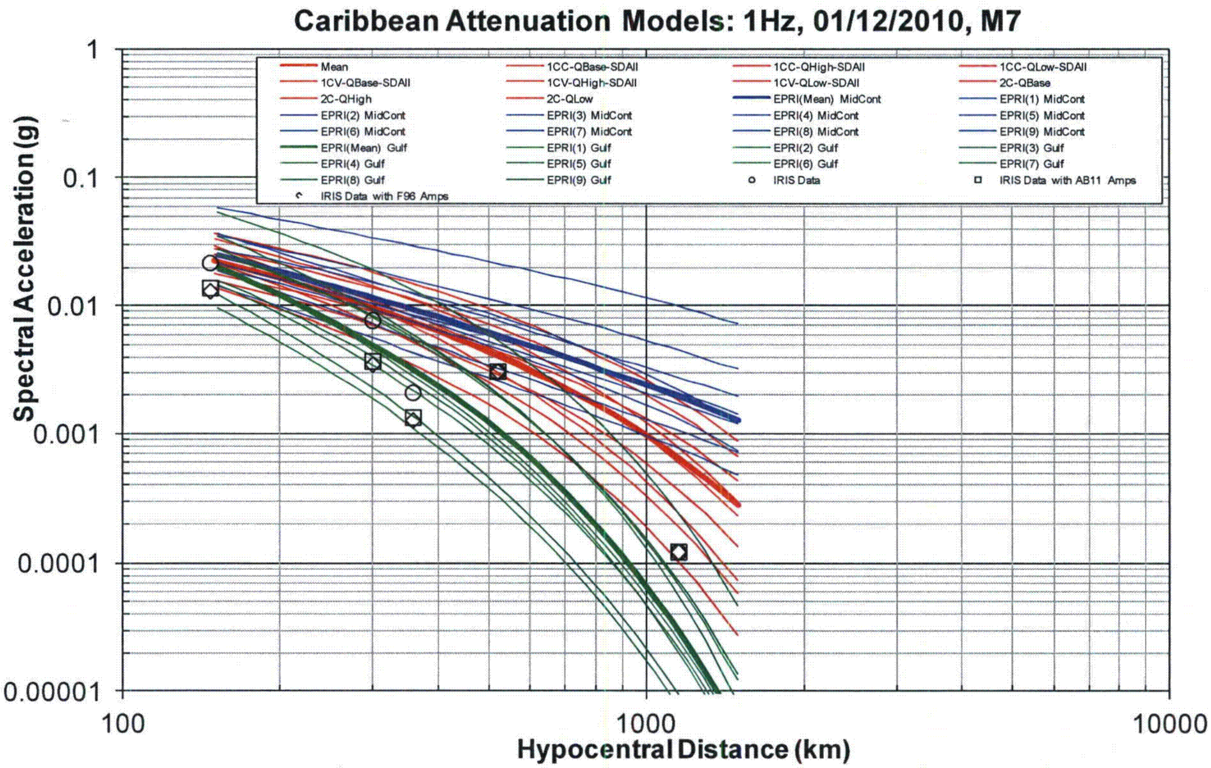


Figure 2.5.2-262c

Comparison of Caribbean (red), EPRI (2004) (Reference 242), MidContinent (blue), and Gulf Coast region (green) GMPEs with raw empirical IRIS data (open circle), IRIS data with Atkinson and Boore (2011) (Reference 359) amplification factor corrections (open squares) and IRIS data with Frankel et al. (1996) (Reference 252) amplification factor corrections (open diamonds) for a spectral frequency of 2.5 Hz.

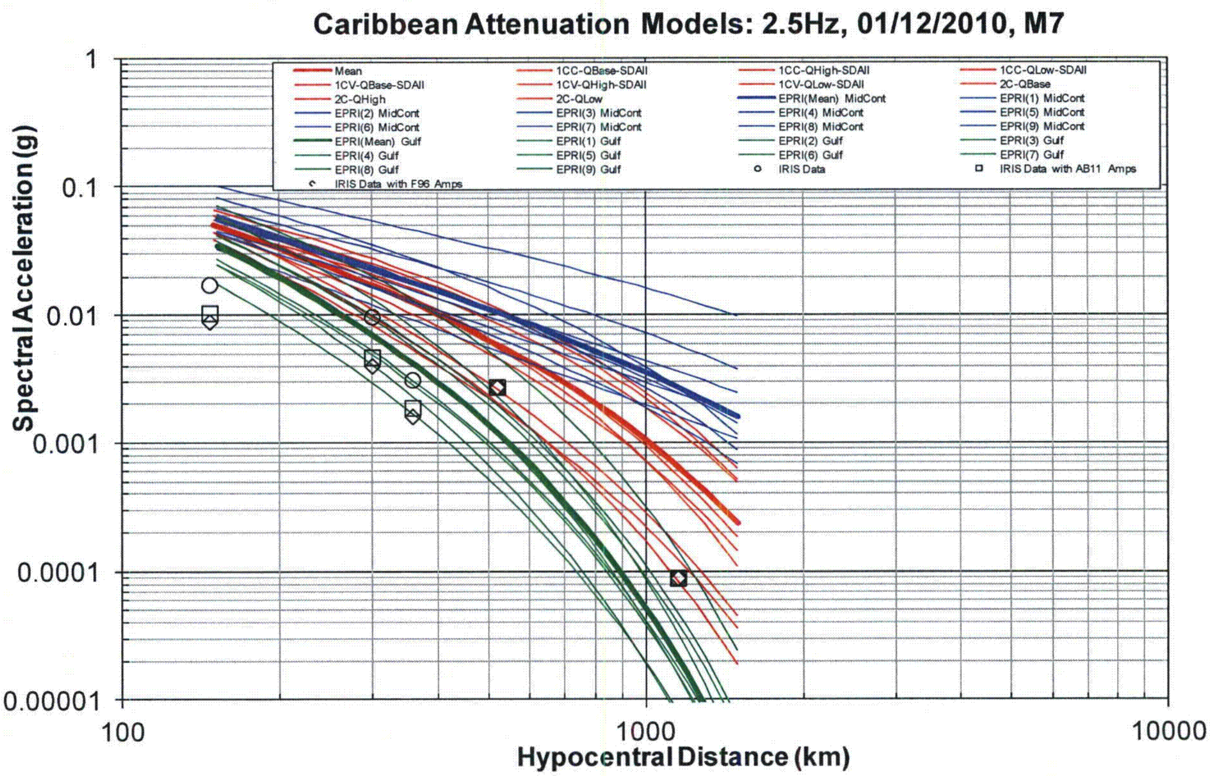


Figure 2.5.2-263

Horizontal GMRS for Caribbean sources for five GMPE models for the Turkey Point Units 6 & 7 site.

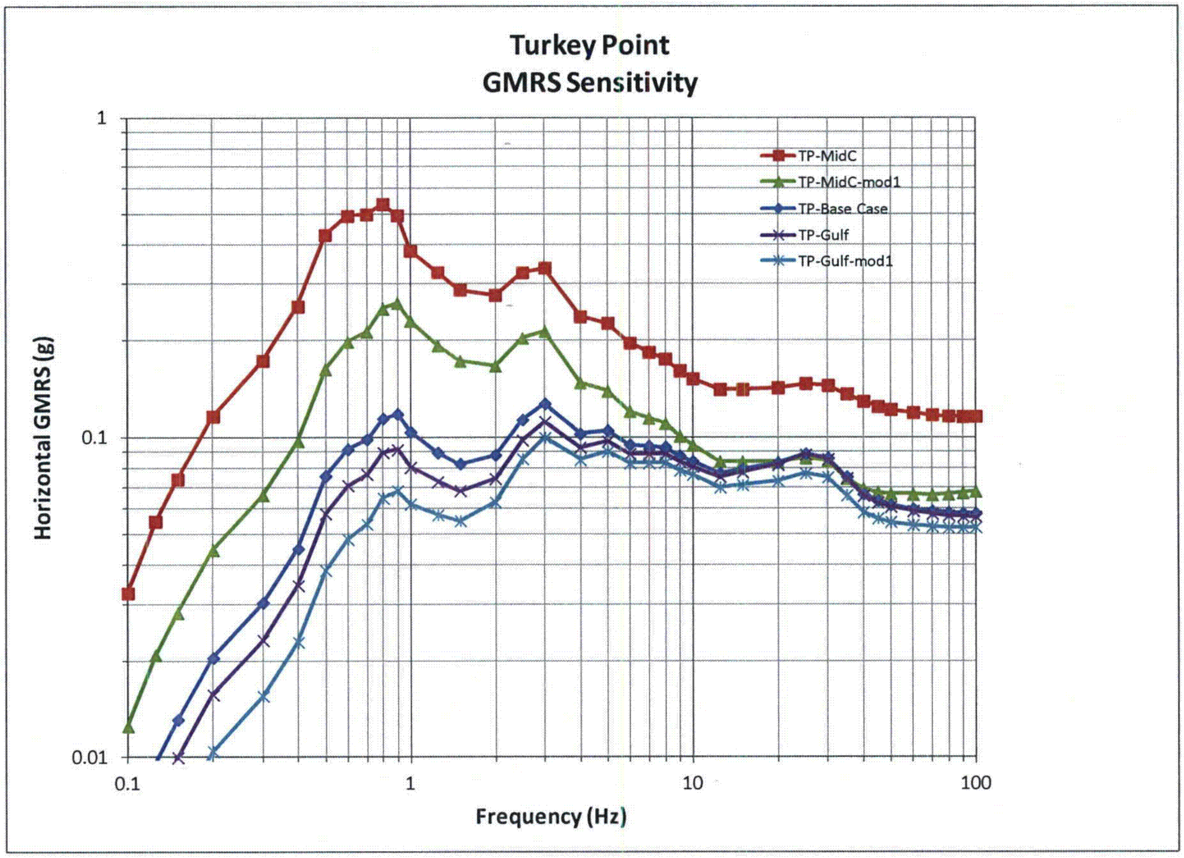


Figure 2.5.2-264

Comparison of EPRI Mid-continent (Reference 242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for PGA.

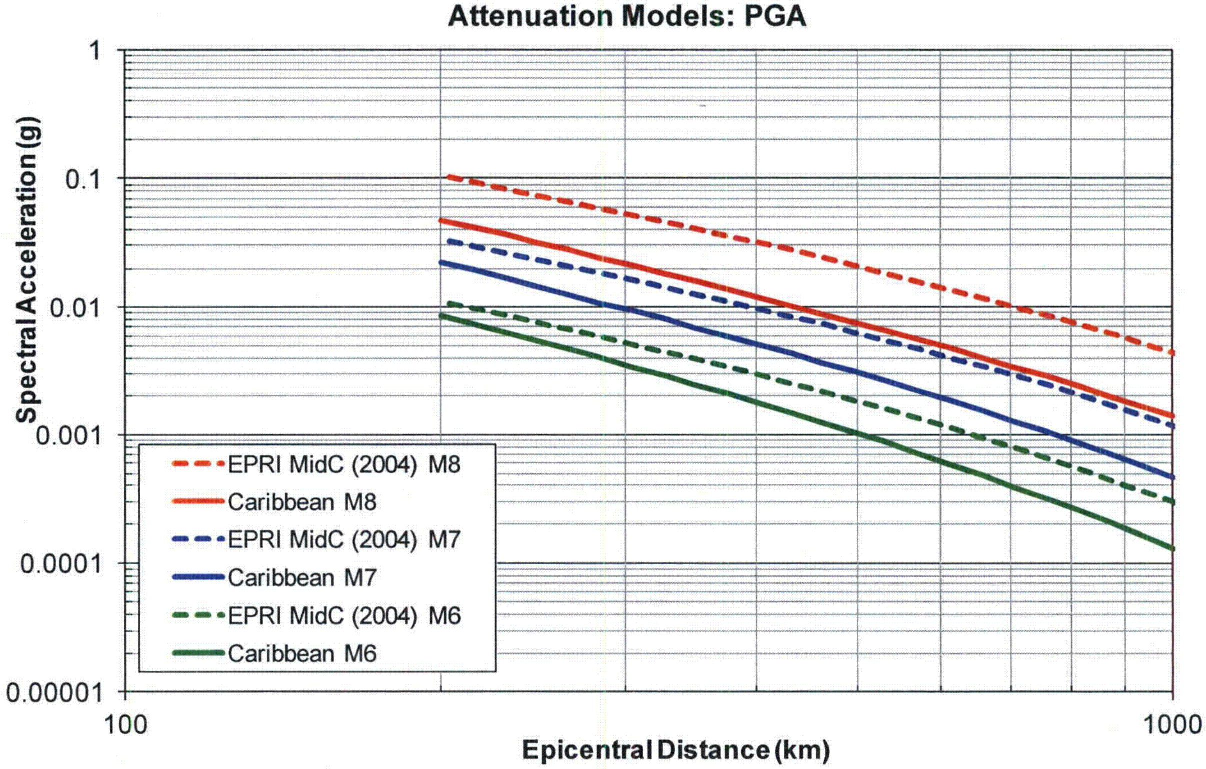


Figure 2.5.2-265

Comparison of EPRI Mid-continent (Reference 242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 25 Hz.

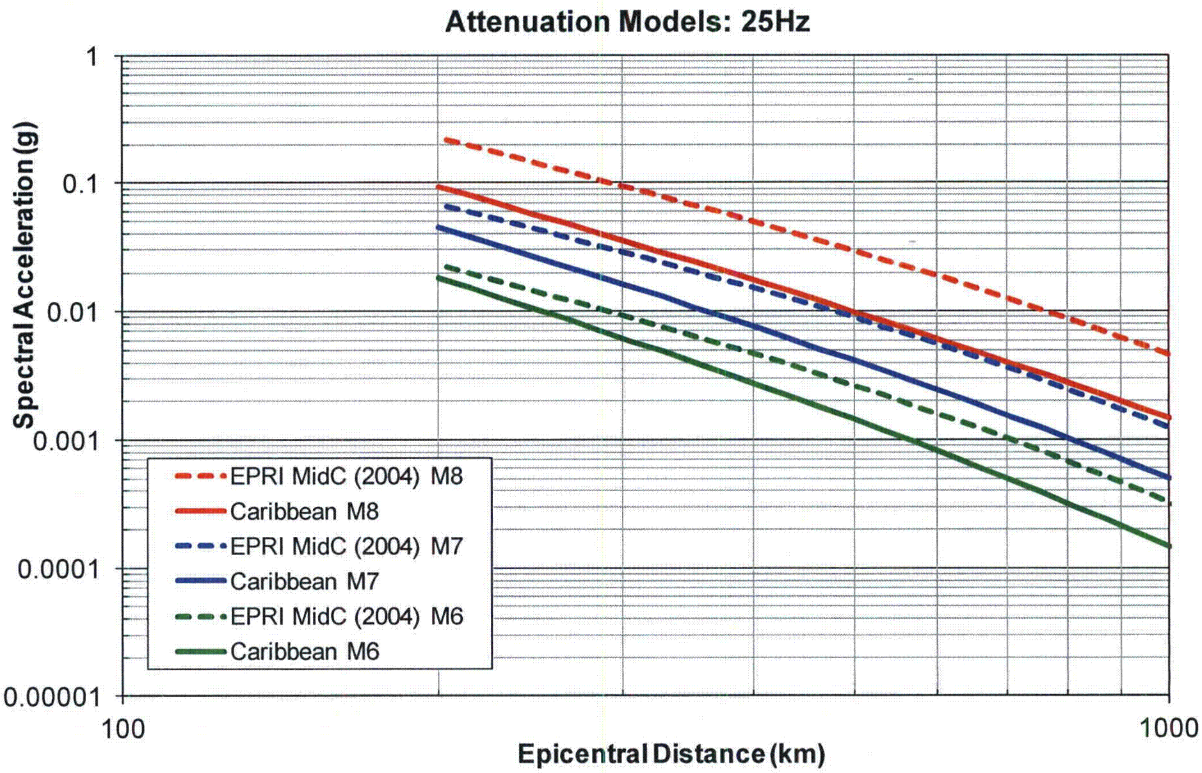


Figure 2.5.2-266

Comparison of EPRI Mid-continent (Reference 242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 10 Hz.

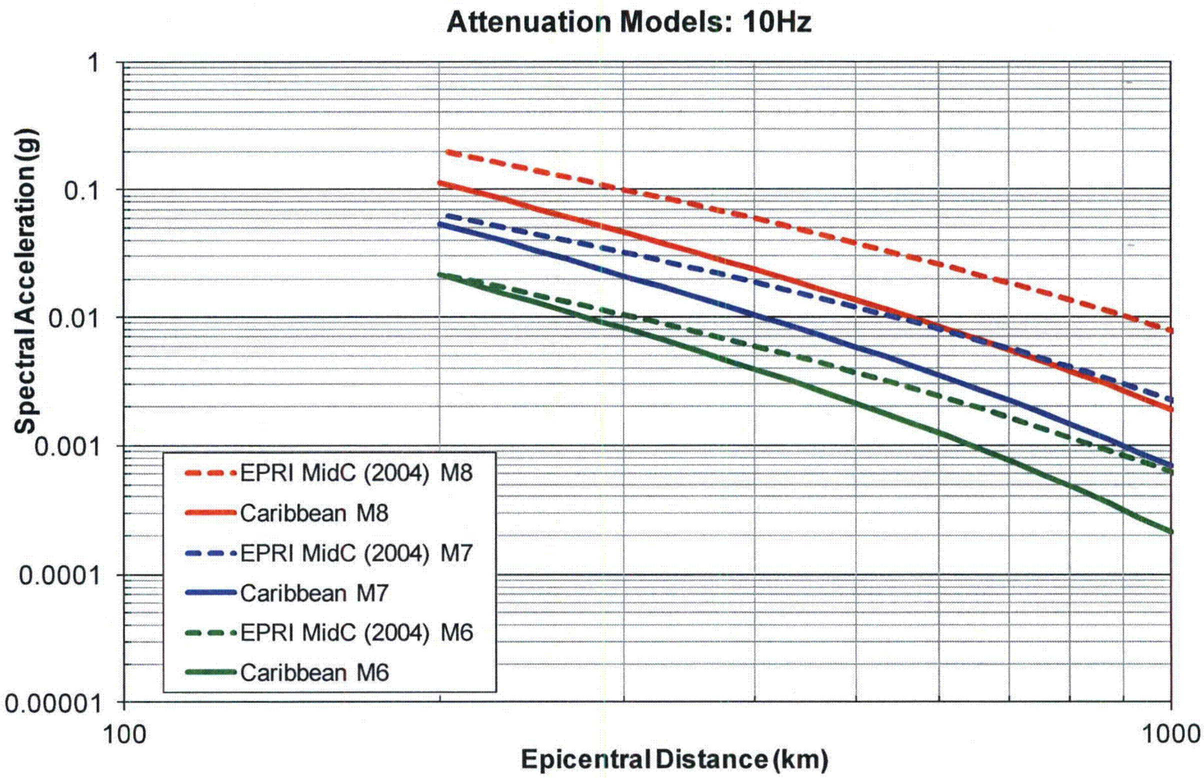


Figure 2.5.2-267

Comparison of EPRI Mid-continent (Reference 242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 5 Hz.

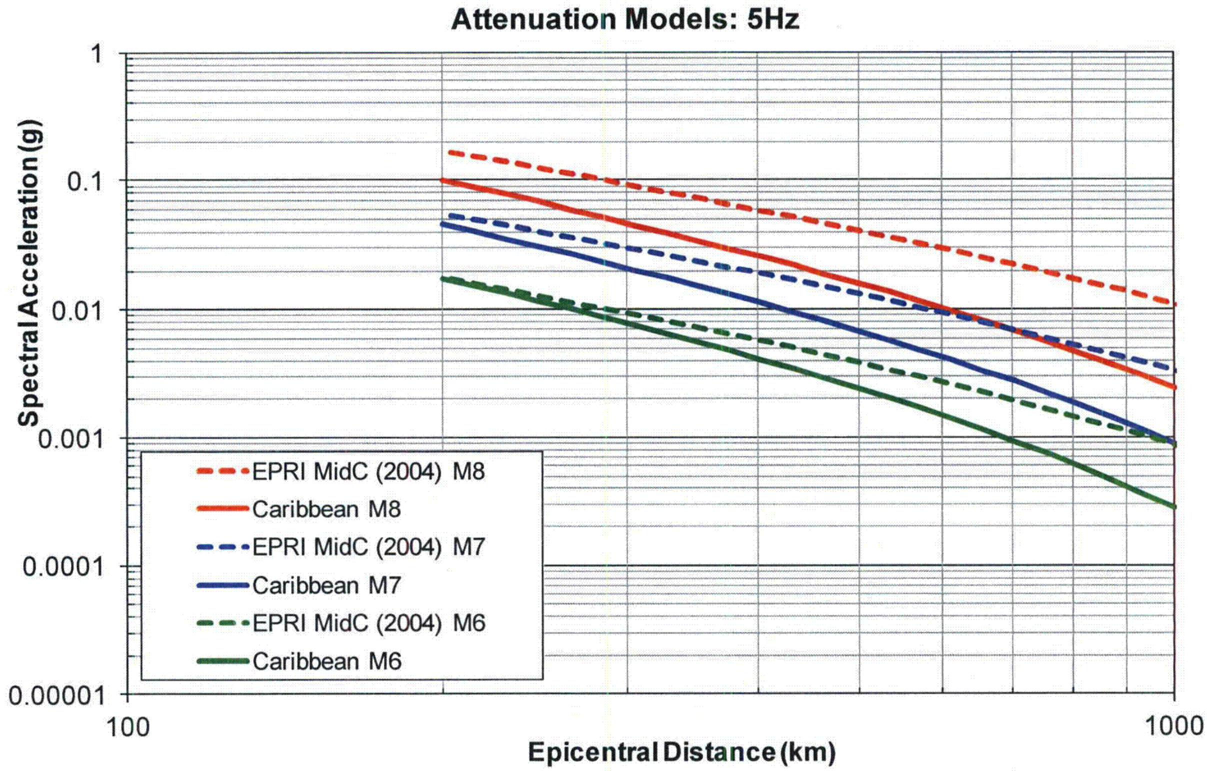


Figure 2.5.2-268

Comparison of EPRI Mid-continent (Reference 242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 2.5 Hz.

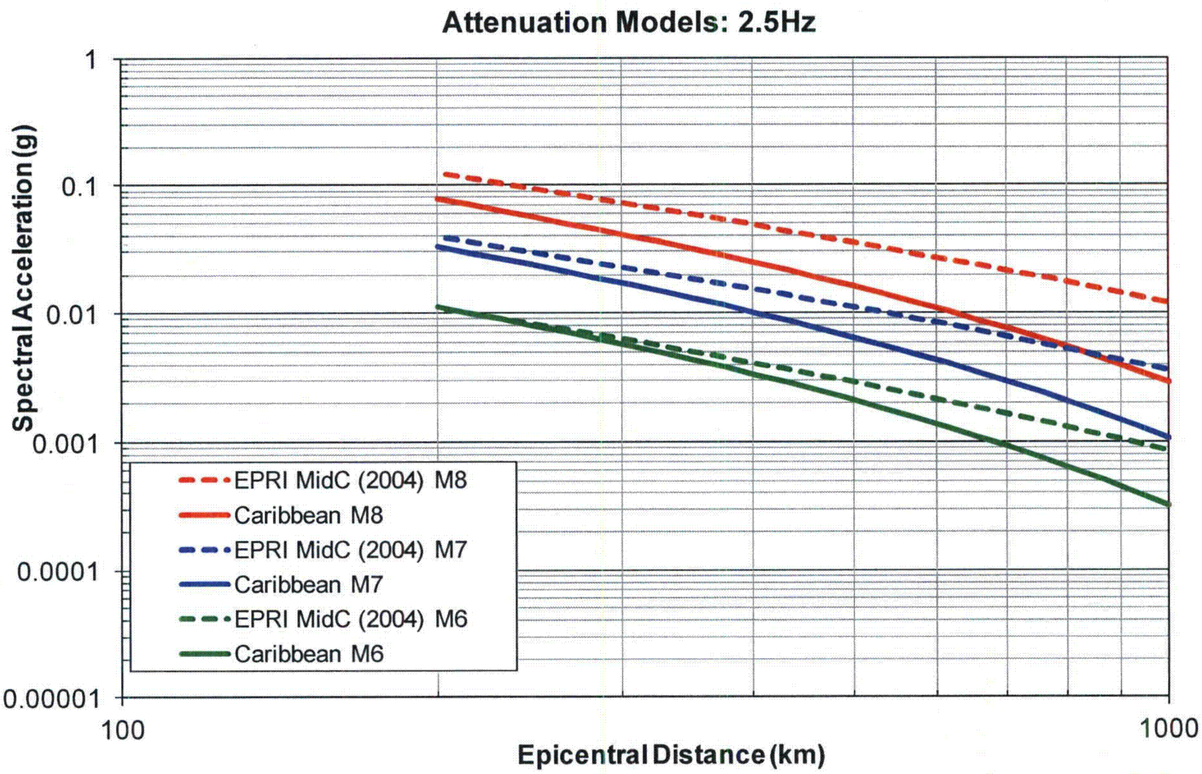


Figure 2.5.2-269

Comparison of EPRI Mid-continent (Reference 242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 1 Hz.

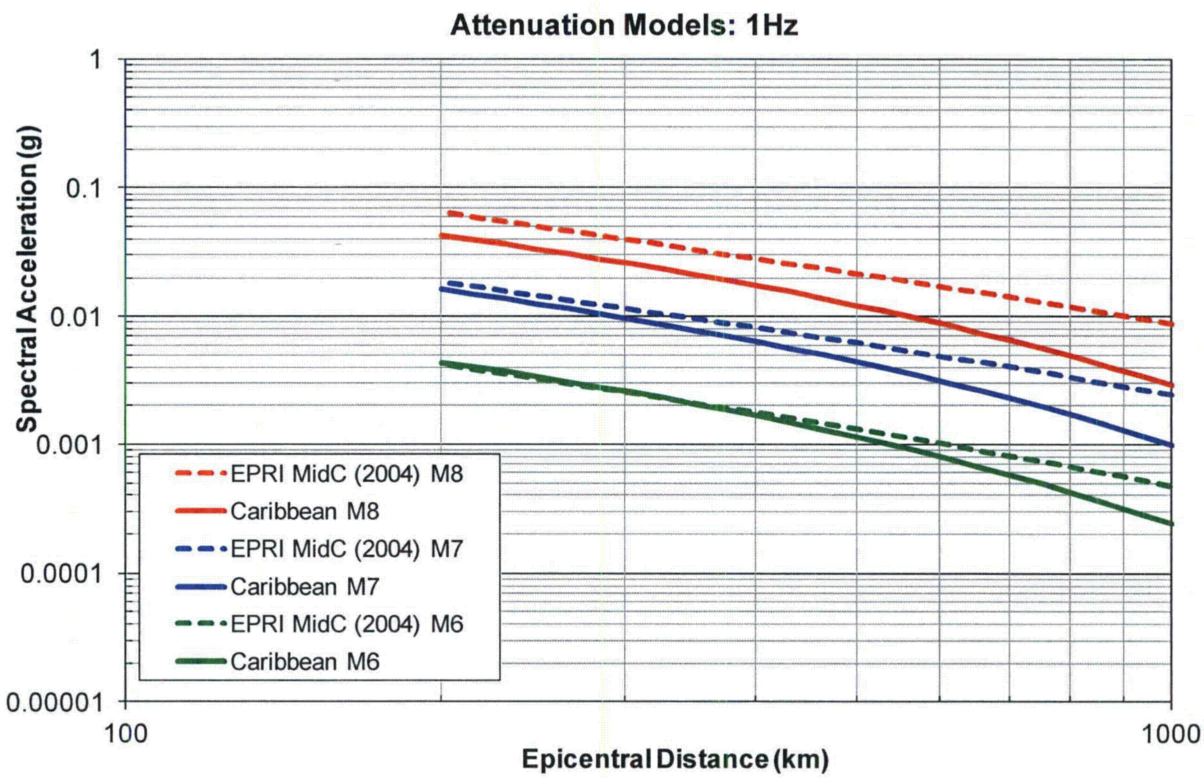
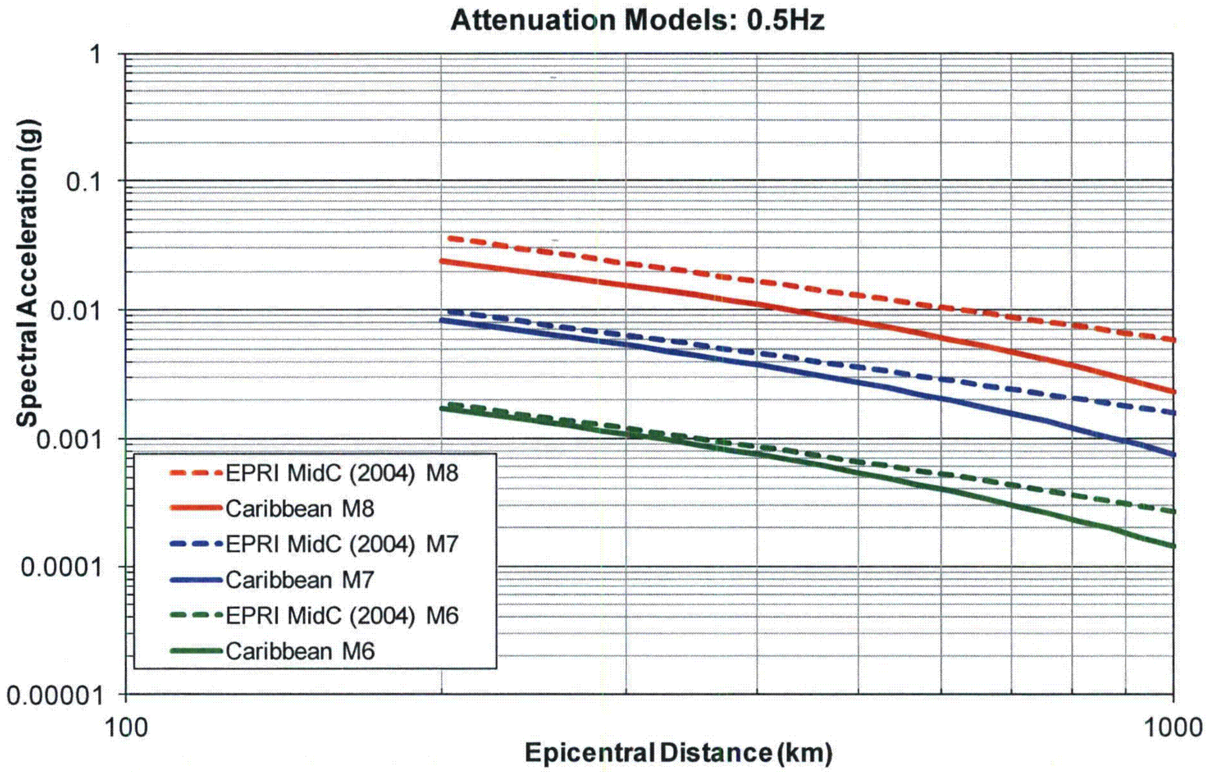


Figure 2.5.2-270

Comparison of EPRI Mid-continent (Reference 242) mean (dashed lines) and Caribbean mean (solid lines) GMPE curves for magnitudes 6, 7, and 8 for 0.5 Hz.



ASSOCIATED ENCLOSURES:

Enclosure A – SSHAC Caribbean GMPE Questionnaire