Attachment 2

Mark-ups for the Associated COLA Revisions for 2.5.2 RAIs

(Total Pages – 66)

Legend of changes on the attached RAI mark-ups:

Red text indicate the changes that were provided in the revised response to the RAI by FPL Letter L-2013-305

Green text indicates changes in COLA Revision 5 from the revised RAI response

2.5.2 Roadmap

RAI Number	***Associated COLA Revisions (Red Text and black strike through)***		***Explanation of changes from RAI Response to COLA Revision 5 (Green Text, e.g., FPL Initiated Changes, i.e., technical editing, FPL additional work,)***	***Comments***
	COLA Revision	Revision Number		
02.05.02-2	Yes.	5	In the first paragraph of the RAI response, the words ground motion prediction equations (GMPEs) was to be deleted and replaced with GMPEs. This change was not incorporated to be consistent with the FSAR style. In the response to this RAI, Figure 2.5.2-262a was revised to remove IRIS Station OTAV, this change was not incorporated in COLA Revision 5 Remaining green text changes are editorial in nature and were made to be consistent with the FSAR style or technical wording additions or corrections based on a final FPL review.	
02.05.02-3	Yes.	5	Green text changes are editorial in nature made mostly to be consistent with the FSAR style or technical wording additions or corrections based on a final FPL review.	
02.05.02-4	Yes	5	Green text changes are editorial in nature made mostly to be consistent with the FSAR style or technical wording additions or corrections based on a final FPL review.	
02.05.02-5	Yes	5	Green text changes are editorial in nature made mostly to be consistent with the FSAR style or technical wording additions or corrections based on a final FPL review.	
02.05.02-6	No	N/A		
02.05.02-7	Yes	4	None	
02.05.02-8	No	N/A		
02.05.02-9	No	N/A		
02.05.02-10	Yes	4	None	

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	COLA Revision	Revision Number		
02.05.02-11	No	N/A		
02.05.02-12	Yes	5	None	
02.05.02-13	Yes	5	Green text changes are editorial in nature made mostly to be consistent with the FSAR style or technical wording additions or corrections based on a final FPL review.	

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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~~ in accordance with the SSHAC (Reference 318) guidelines. However, what has been done in this regard is otherwise fully consistent with industry practice in general and the SSHAC (Reference 318) guidelines in particular.**

Initial development of a suite of specific GMPEs was performed by, what in SSHAC (Reference 318) nomenclature would be called, the ~~Technical Integration~~ TI 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~~ 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~~ northern Caribbean, and there are no experts identified that can be characterized as proponents as defined in SSHAC (Reference 318).

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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.~~ that is, 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~~ kilometers [311 miles], and site-specific ground conditions of soft rock), it was determined that ~~this~~ the 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~~ 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~~ **kilometers**. **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

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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

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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.

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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~~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~~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~~ kilometers/second (1.76 miles/second), 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~~ kilometers/second (1.76 miles/second). Based on a 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 Hz 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 Hz 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 Hz 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).

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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 Hz 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~~ kilometers), 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 Hz 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~~ that 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~~ kilometers), 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 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. 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 ~~S~~ southern Florida. The distribution of stations in the central United States ~~have~~ has 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 Hz and 2.5 Hz spectral frequencies.

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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~~ approximately 750 ~~km~~ kilometers [466 miles]) 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~~ kilometers), 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 and 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 Hz 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~~ that 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~~ kilometers), 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~~ attenuation 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~~ attenuation curves.

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- **January 12, 2010 – Haiti (M_w7.0, 18.61 N, -72.62 W, hypocenter depth 12.0 ~~km~~ kilometers), 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~~ 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 Hz 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~~ attenuation curves. In addition, the observation from the OTAV station is significantly lower than the entire range of 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 Hz 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~~ 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~~ 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

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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 predict~~s~~ 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~~Continent or Gulf Coast models, the consensus of the six experts was that the suite of Gulf Coast GMPE models ~~is~~ are closer to the empirical data than the Mid-~~continent~~Continent

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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~~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.~~,~~ and W. 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.~~,~~ and D. 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 D. 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.

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

Figure 2.5.2-258a

Map S~~s~~howing the E~~e~~arthquake L~~l~~ocation for the 12/14/2004 Caribbean Sea Region E~~e~~arthquake (M_w6.8), the IRIS S~~s~~tation L~~l~~ocations U~~u~~sed in the A~~a~~nalysis (S~~s~~hown as B~~b~~lack T~~t~~riangles in this and S~~s~~imilar S~~s~~ubsequent F~~f~~igures), and Turkey Point Units 6 & 7 S~~s~~ite L~~l~~ocation~~.~~

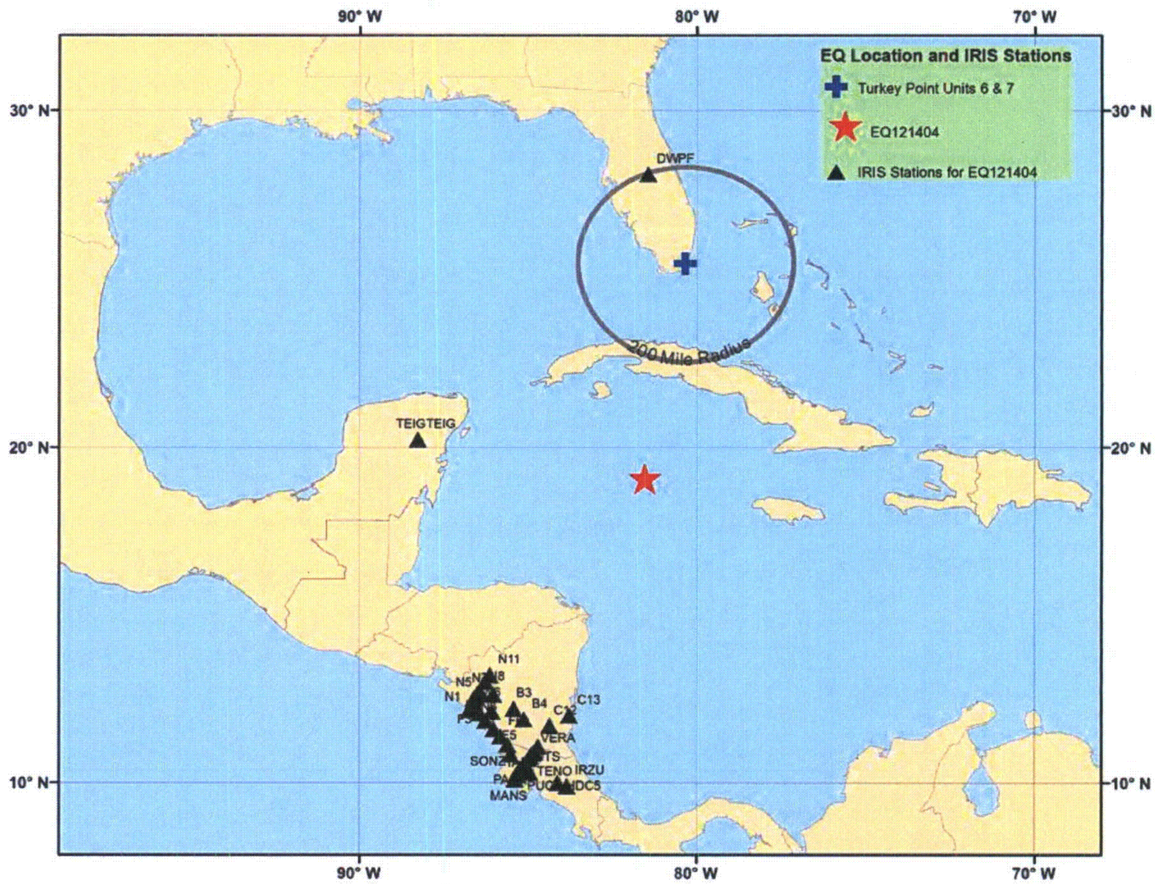

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Figure 2.5.2-258b

Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 1 Hz~~.~~

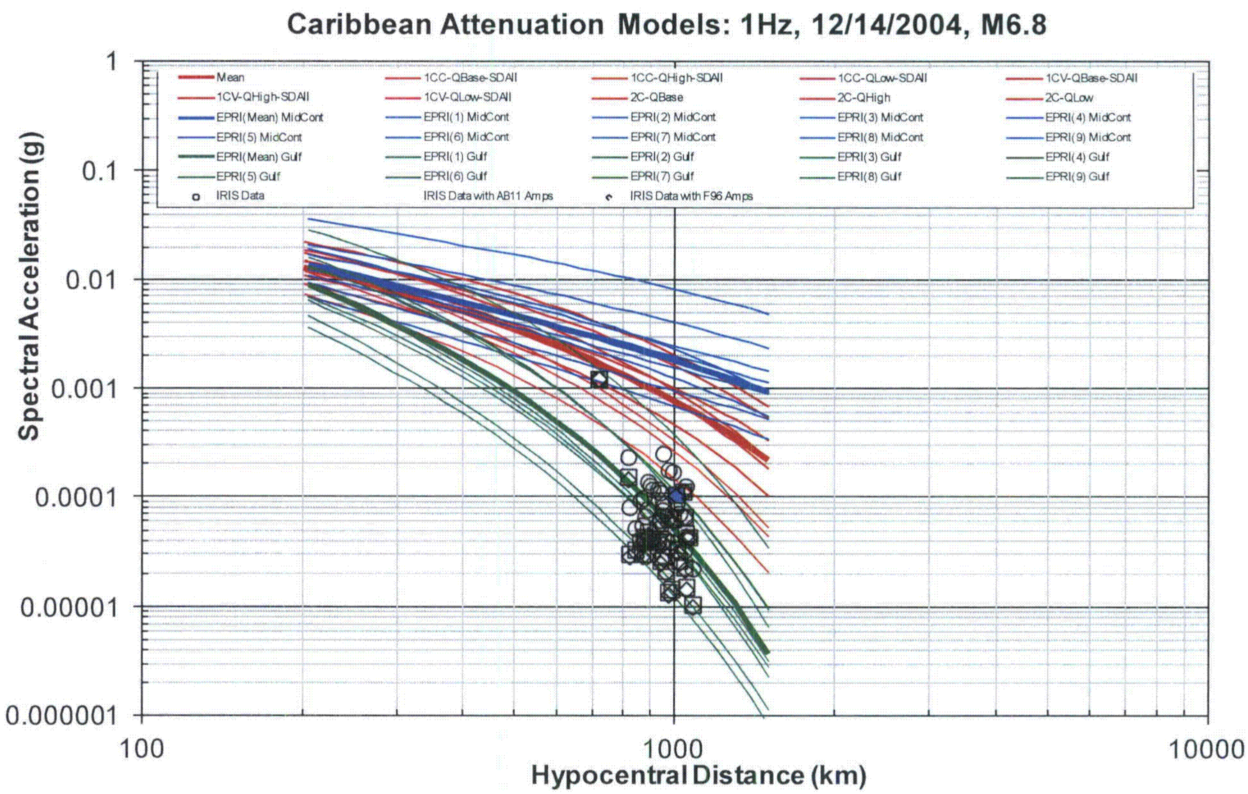

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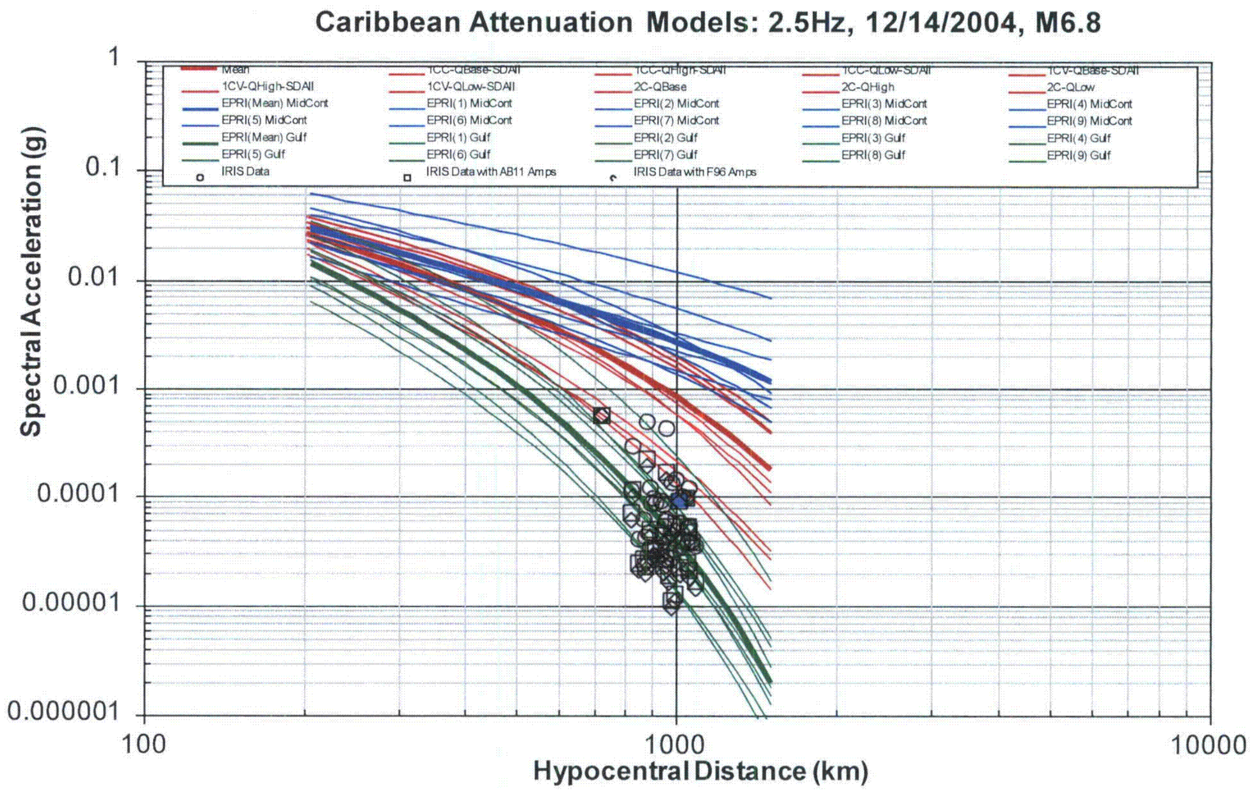
Figure 2.5.2-258c

Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 2.5 Hz~~.~~



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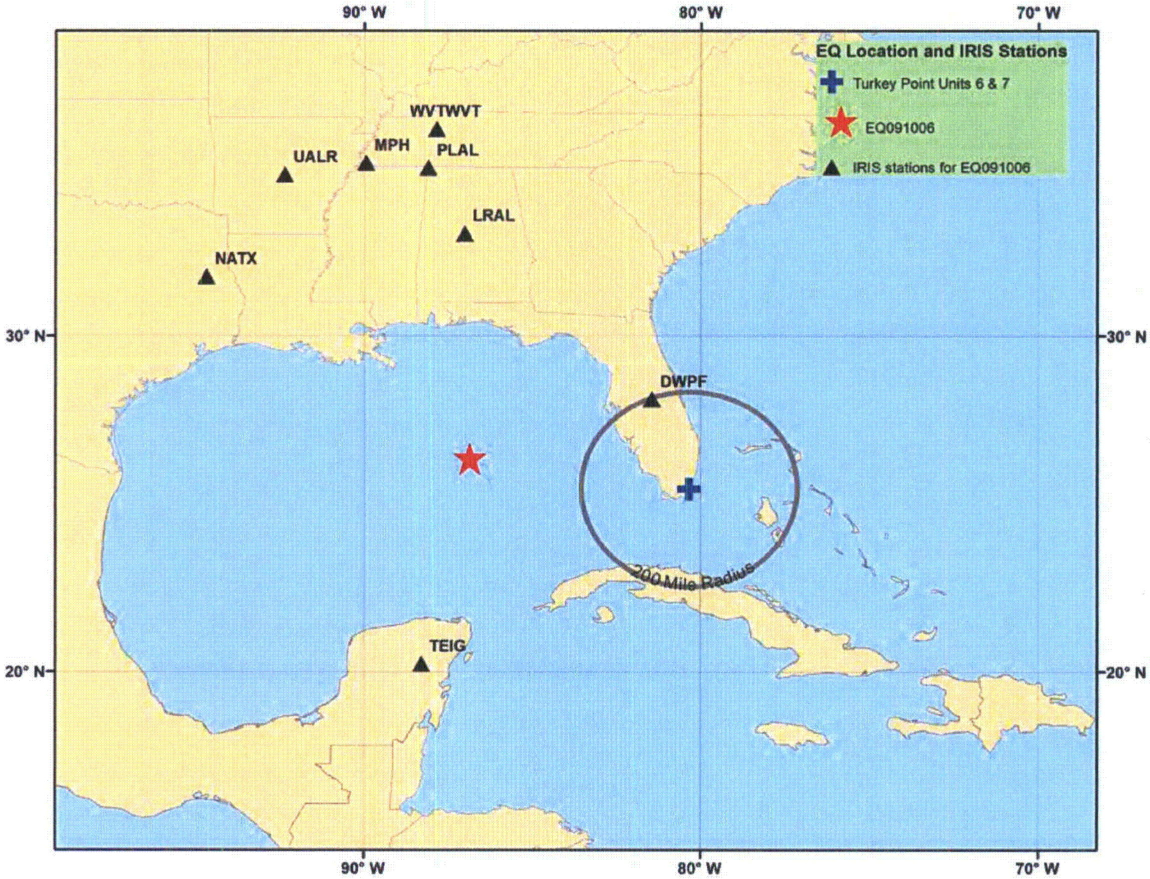
NRC RAI No. 02.05.02-2 (eRAI 5896)

Figure 2.5.2-259a

Map S~~s~~howing the E~~e~~arthquake L~~l~~ocation for the 09/10/2006 Gulf of Mexico E~~e~~arthquake (M_w5.9), the IRIS S~~s~~tation L~~l~~ocations U~~u~~sed in the A~~a~~nalysis and Turkey Point Units 6 & 7 S~~s~~ite L~~l~~ocation~~.~~



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NRC RAI No. 02.05.02-2 (eRAI 5896)

Figure 2.5.2-259b

Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 1 Hz~~.~~

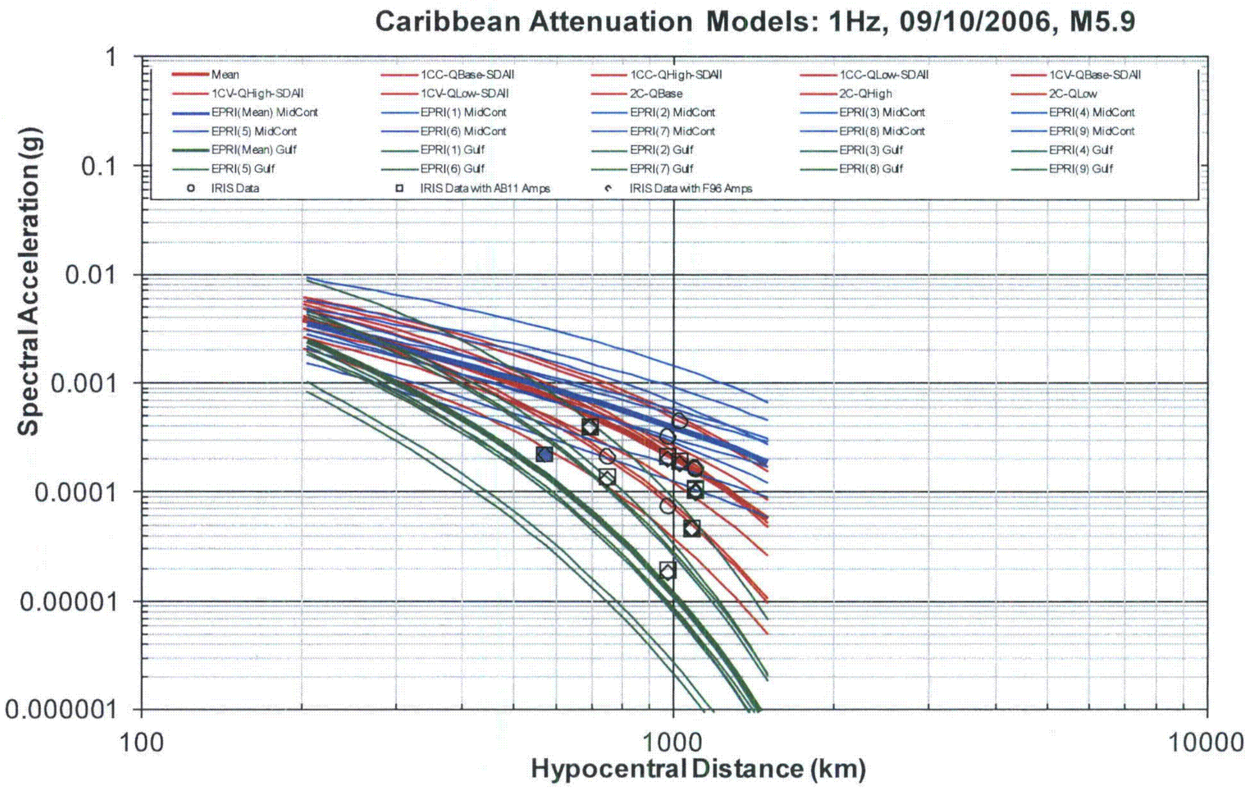

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Figure 2.5.2-259c

Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 2.5 Hz~~.~~

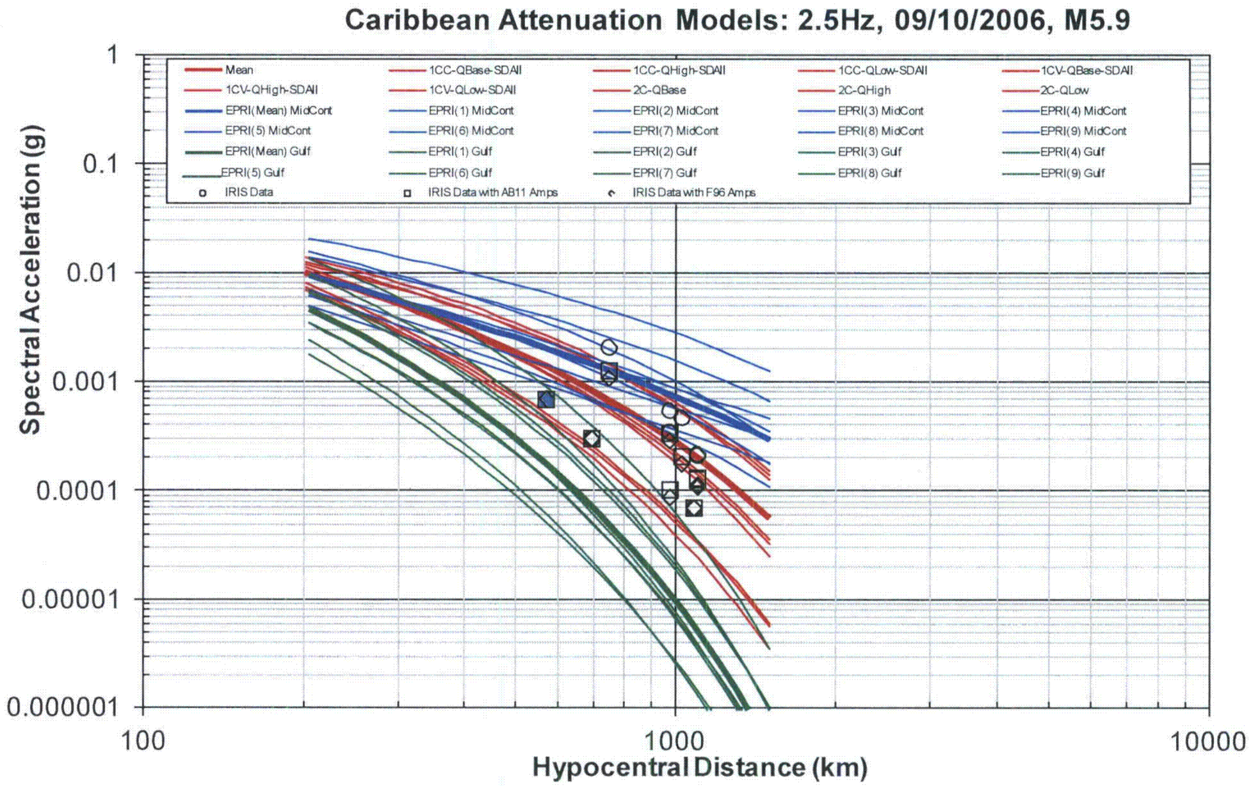

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Figure 2.5.2-260a

Map S~~s~~howing the E~~e~~arthquake L~~l~~ocation for the 02/04/2007 Cuba Region E~~e~~arthquake (M_w6.2), the IRIS S~~s~~tation L~~l~~ocations U~~u~~sed in the A~~a~~nalysis and Turkey Point Units 6 & 7 S~~s~~ite L~~l~~ocation~~.~~

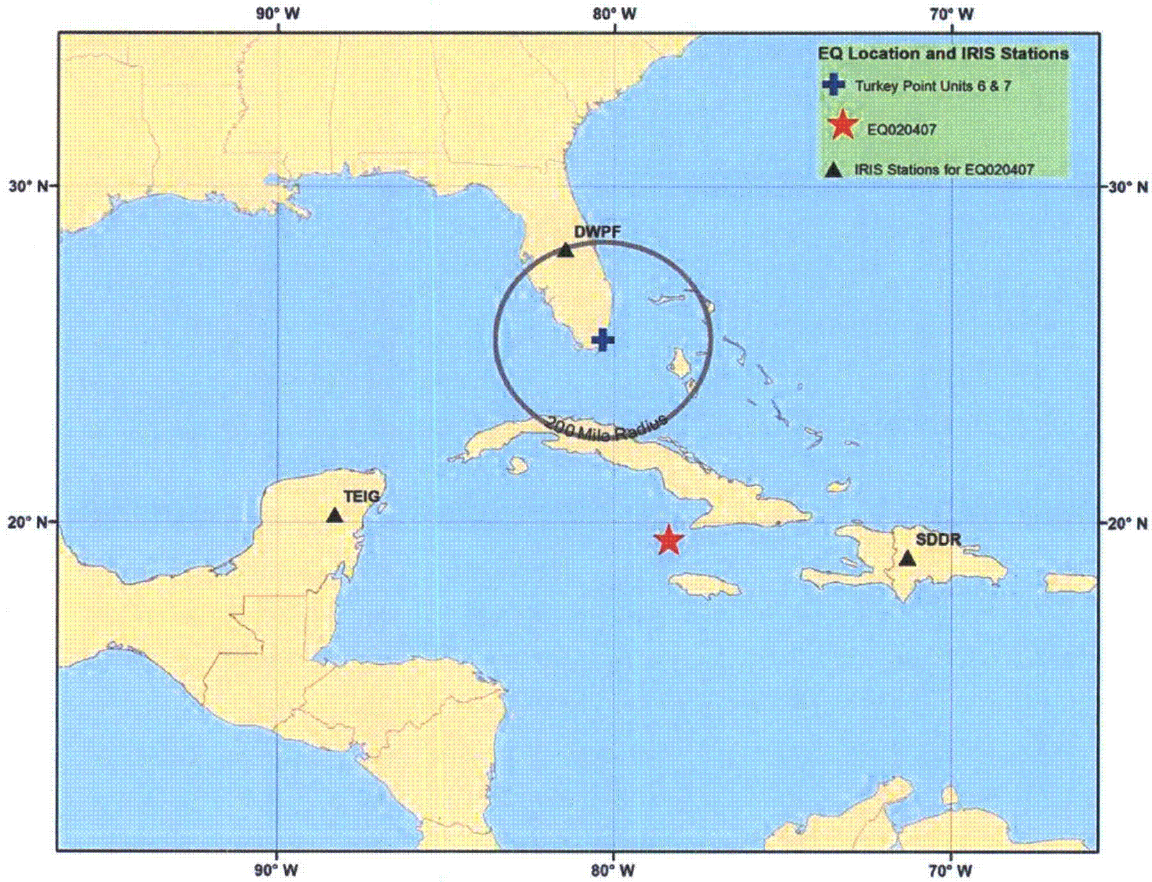

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Figure 2.5.2-260b

Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 1 Hz~~.~~

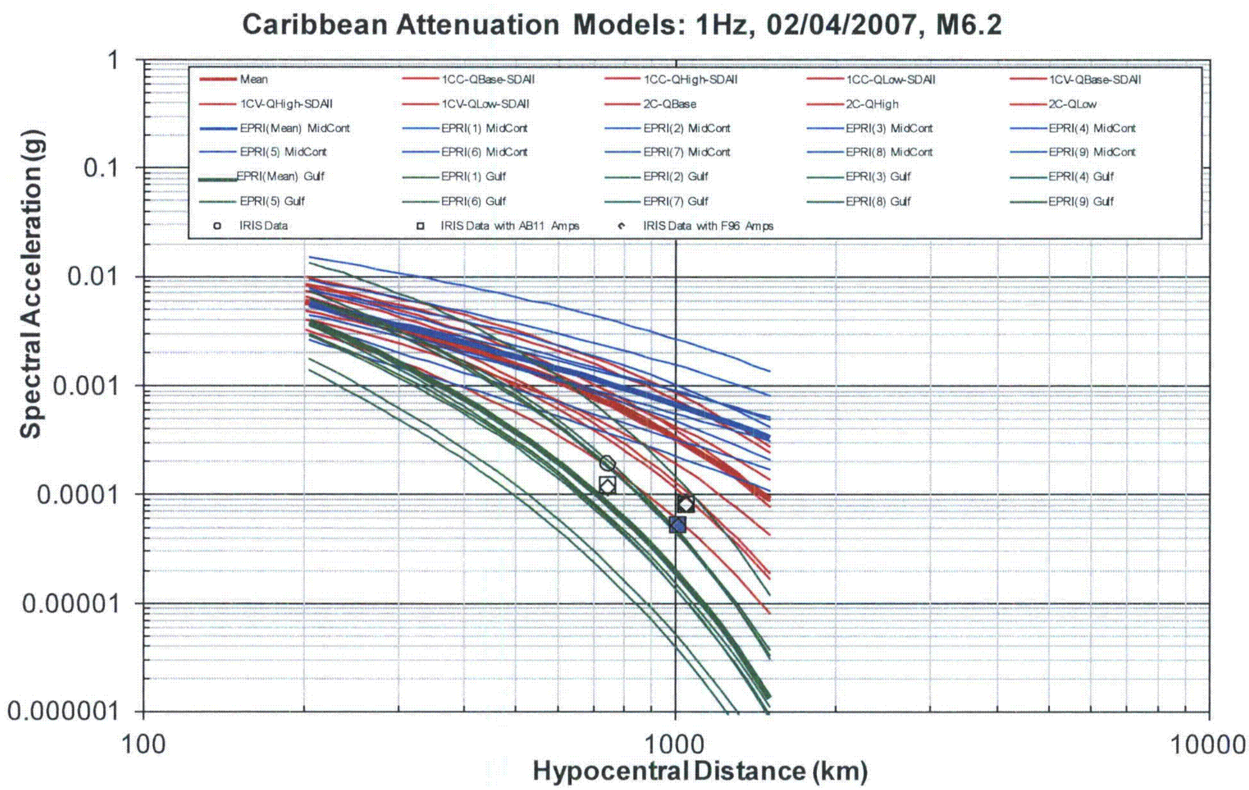

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Figure 2.5.2-260c

Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 2.5 Hz~~.~~

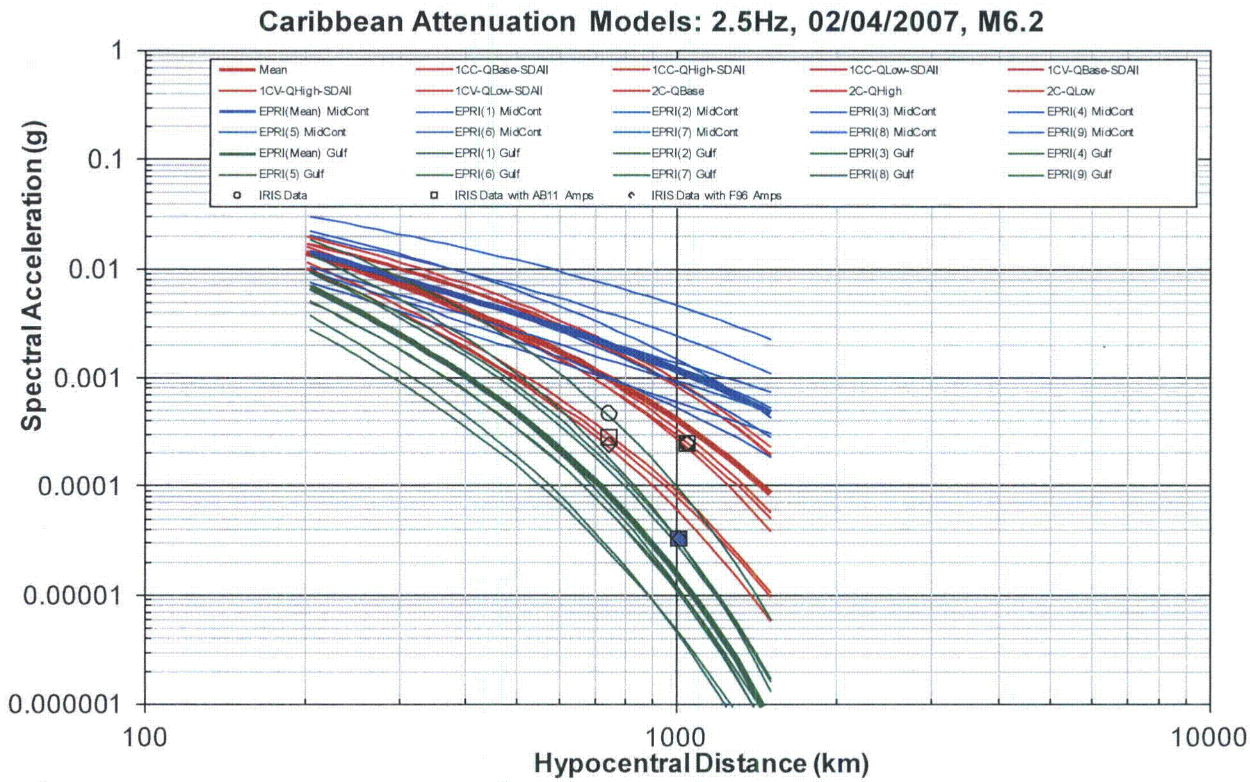

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Figure 2.5.2-261a

Map S~~s~~howing the E~~e~~arthquake L~~l~~ocation for the 05/28/2009 North of Honduras earthquake (M_w7.3), the IRIS S~~s~~tation L~~l~~ocations U~~u~~sed in the A~~a~~nalysis and Turkey Point Units 6 & 7 S~~s~~ite L~~l~~ocation~~.~~

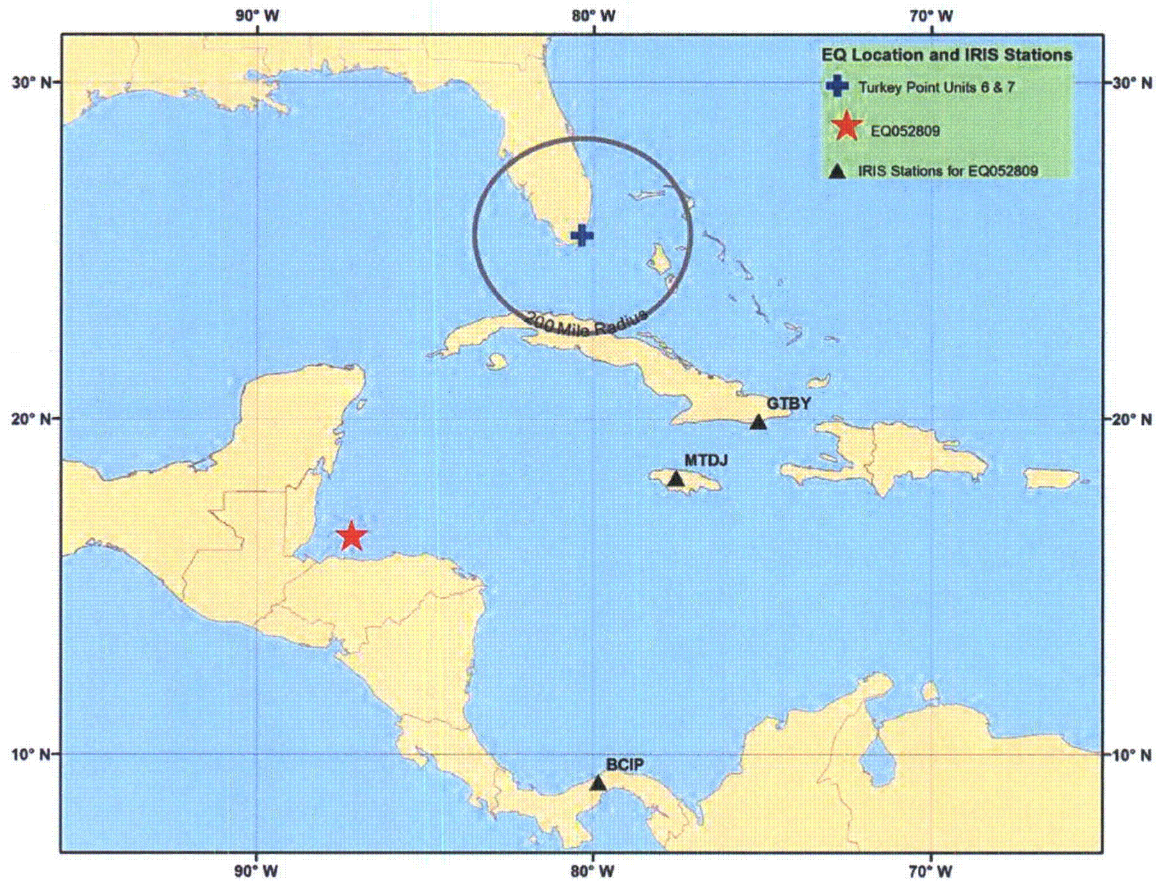

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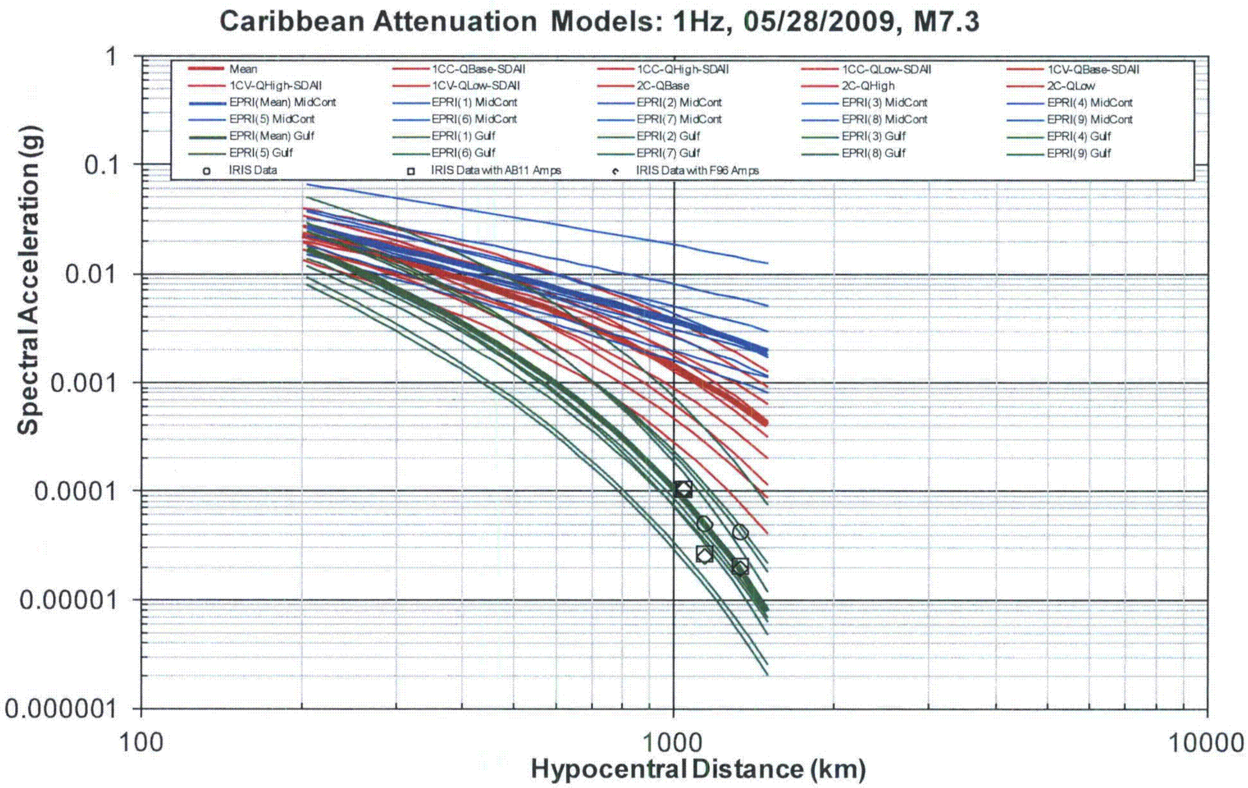
Figure 2.5.2-261b

Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 1 Hz~~.~~



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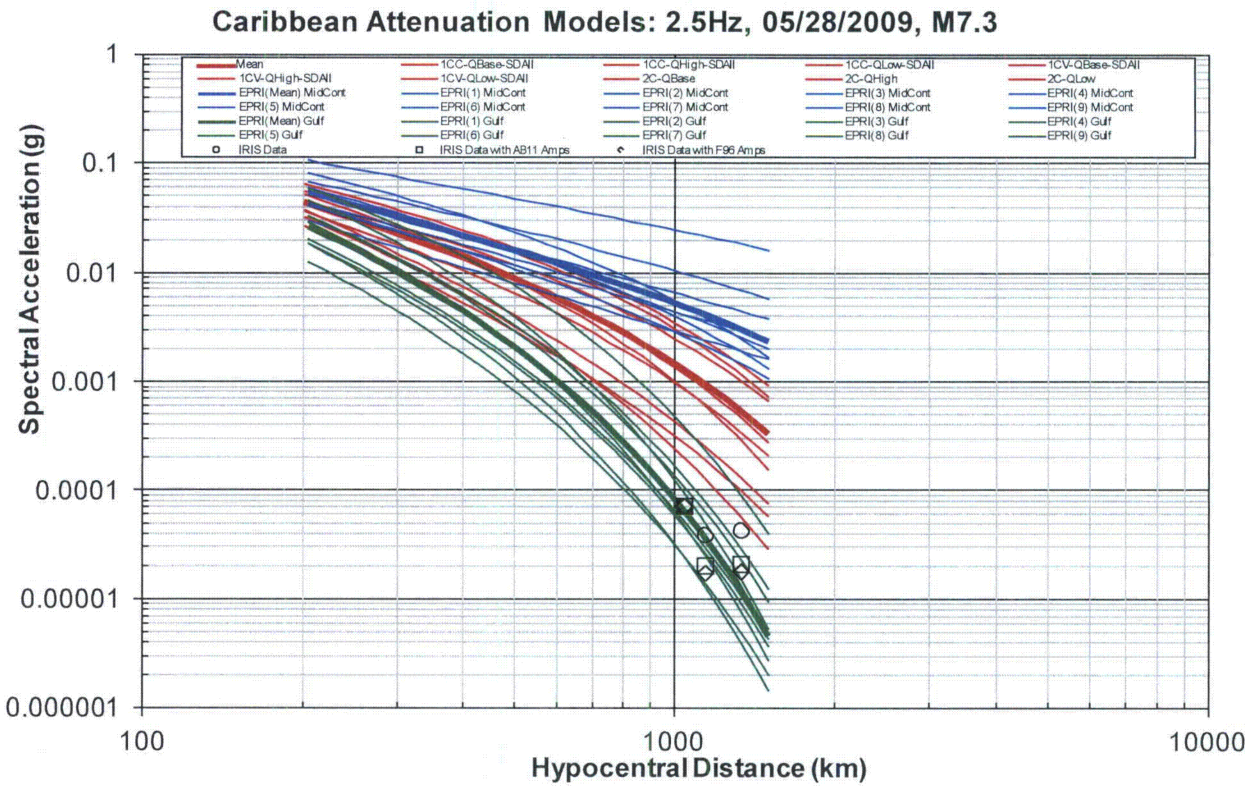
NRC RAI No. 02.05.02-2 (eRAI 5896)

Figure 2.5.2-261c

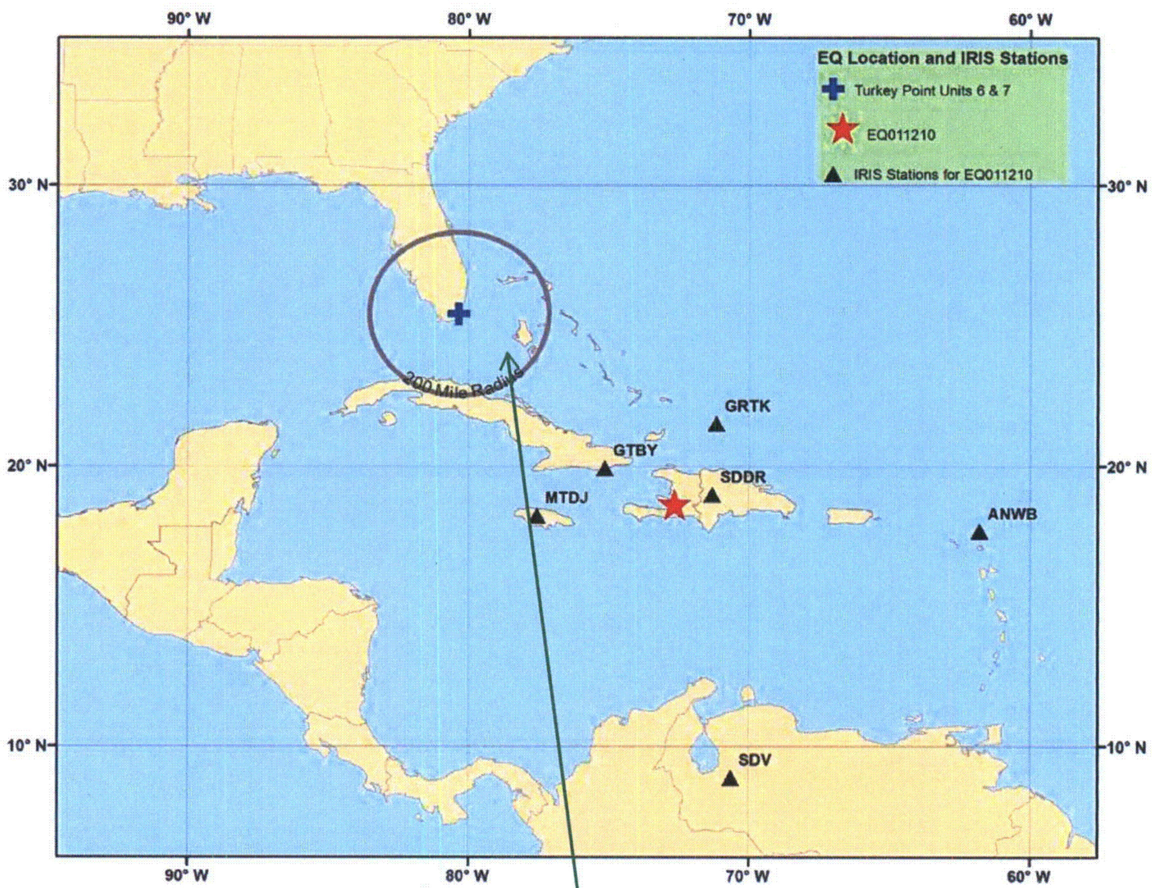
Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 2.5 Hz~~.~~



Mark-up for Revised Response to
NRC RAI No. 02.05.02-2 (eRAI 5896)

Figure 2.5.2-262a

Map S~~s~~howing the E~~e~~arthquake L~~l~~ocation for the 01/12/2010 Haiti earthquake (M_w7.0), the IRIS S~~s~~tation L~~l~~ocations U~~u~~sed in the A~~a~~nalysis and Turkey Point Units 6 & 7 S~~s~~ite L~~l~~ocation~~.~~



Iris Station OTAV was not removed in COLA Revision 5

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Figure 2.5.2-262b

Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 1 Hz~~.~~

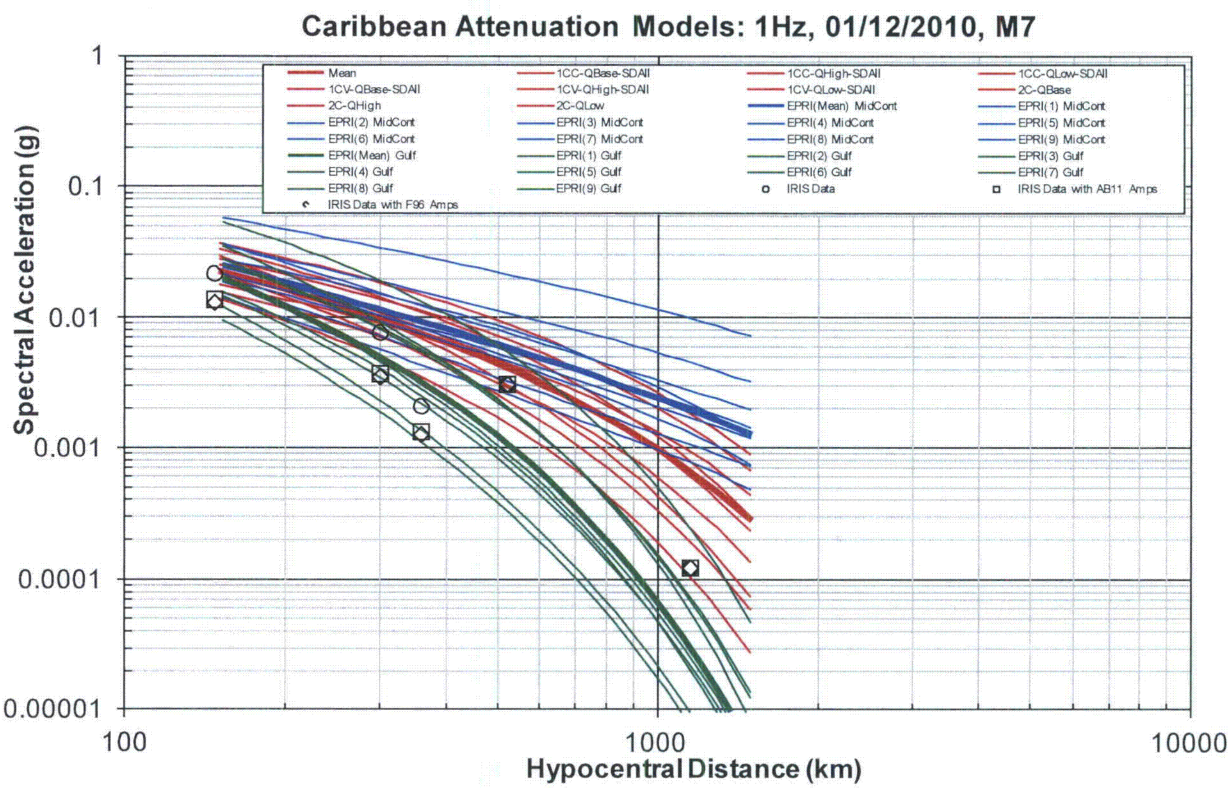

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Figure 2.5.2-262c

Comparison of Caribbean (R~~r~~ed), EPRI (2004) (Reference 242), Mid-Continent (B~~b~~lue), and Gulf Coast R~~r~~egion (G~~g~~reen) GMPEs with R~~r~~aw E~~e~~mpirical IRIS D~~d~~ata (O~~o~~pen C~~c~~ircle), IRIS D~~d~~ata with Atkinson and Boore (2011) (Reference 359) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen S~~s~~quares) and IRIS D~~d~~ata with Frankel et al. (1996) (Reference 252) A~~a~~mplification F~~f~~actor C~~c~~orrections (O~~o~~pen D~~d~~iamonds) for a S~~s~~pectral F~~f~~requency of 2.5 Hz~~.~~

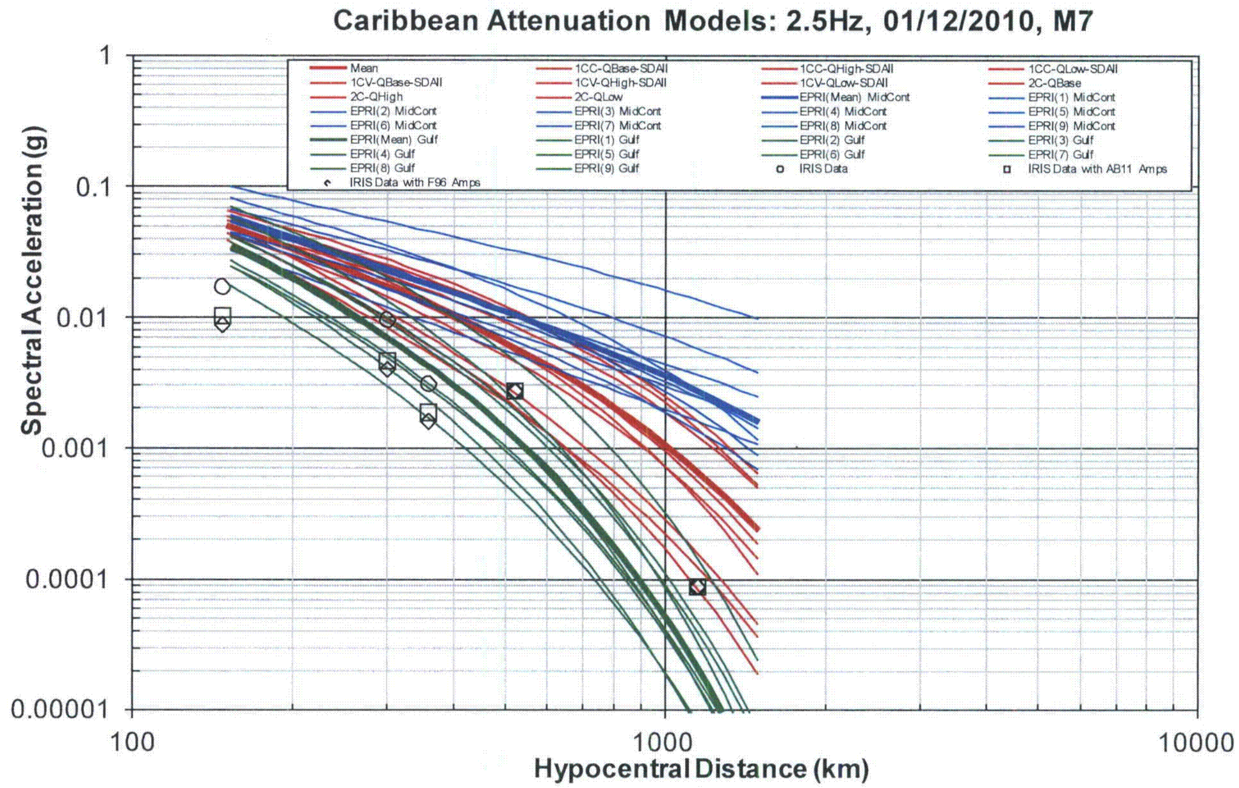

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Figure 2.5.2-263

Horizontal GMRS for Caribbean S~~s~~ources for F~~f~~ive GMPE M~~m~~odels for the Turkey Point Units 6 & 7 S~~s~~ite~~.~~

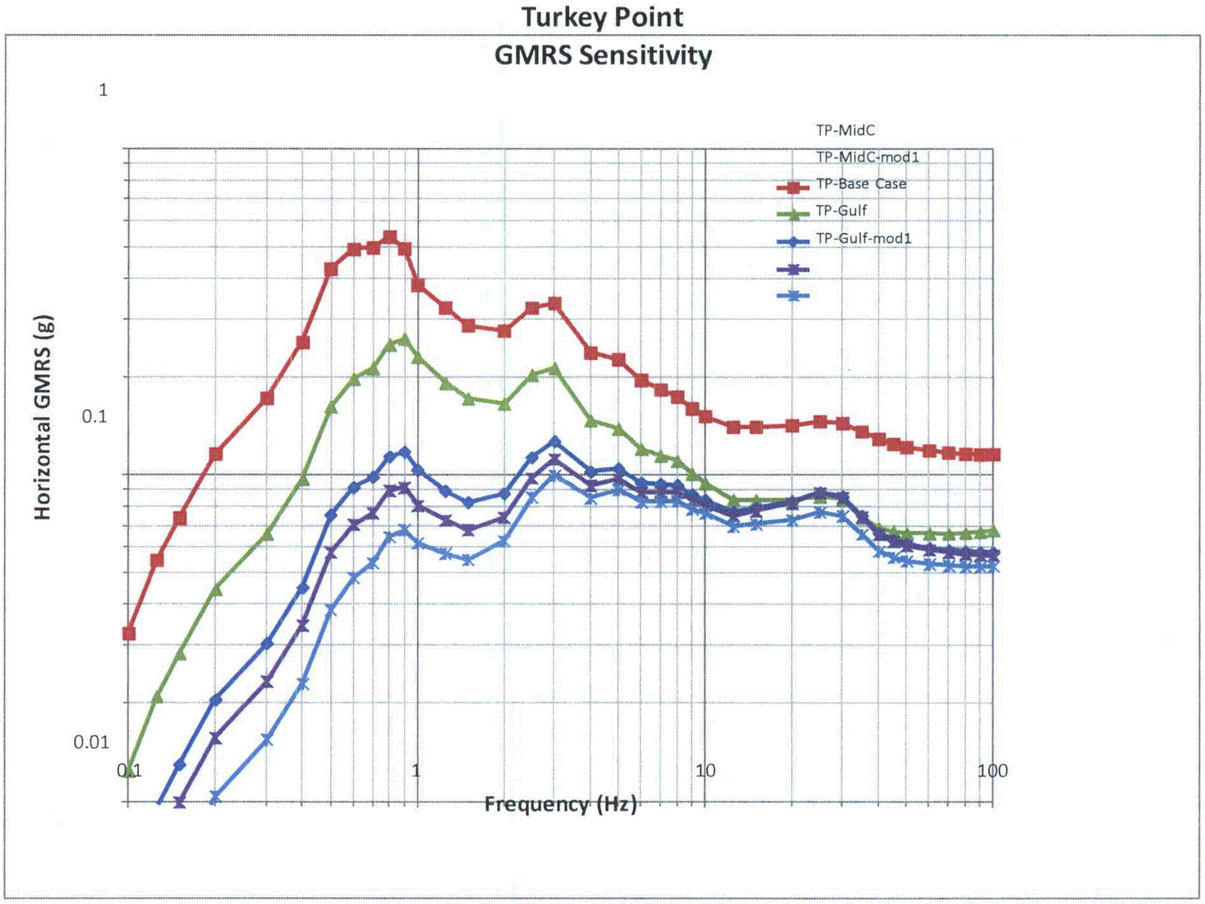

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Figure 2.5.2-264

Comparison of EPRI Mid-C~~c~~ontinent (Reference 242) M~~m~~ean (dashed lines) and Caribbean M~~m~~ean (solid lines) Attenuation ~~GMPE~~ C~~c~~urves for M~~m~~agnitudes 6, 7, and 8 for PGA~~.~~

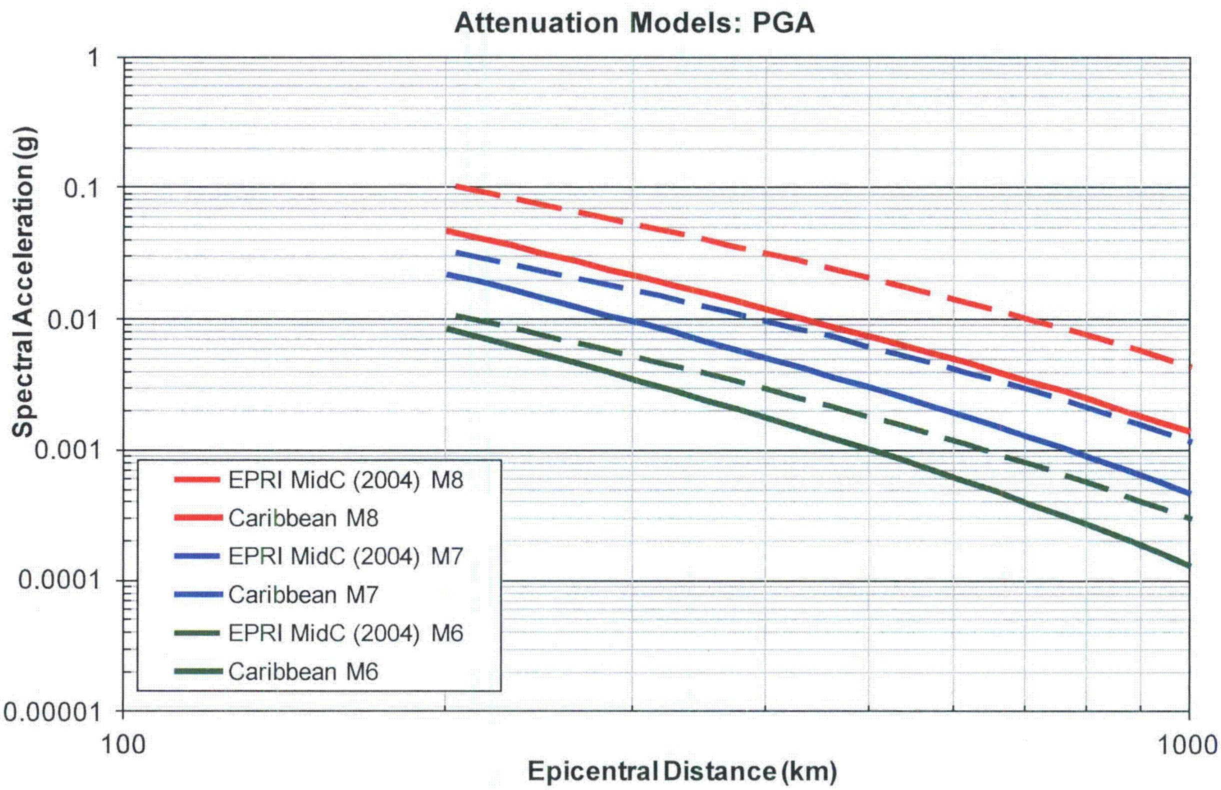

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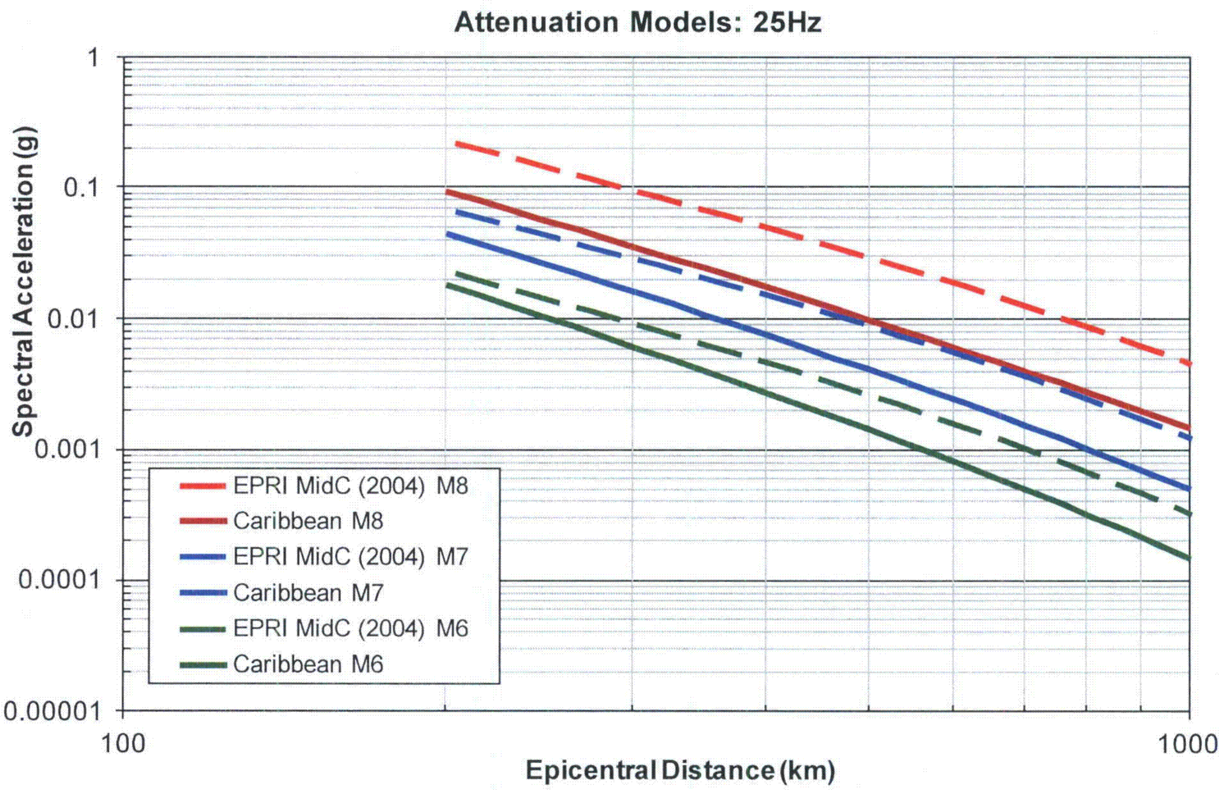
Figure 2.5.2-265

Comparison of EPRI Mid-~~C~~continent (Reference 242) M~~m~~ean (dashed lines) and Caribbean M~~m~~ean (solid lines) Attenuation ~~GMPE~~ C~~c~~urves for M~~m~~agnitudes 6, 7, and 8 for 25 Hz~~.~~



Source: Reference 242

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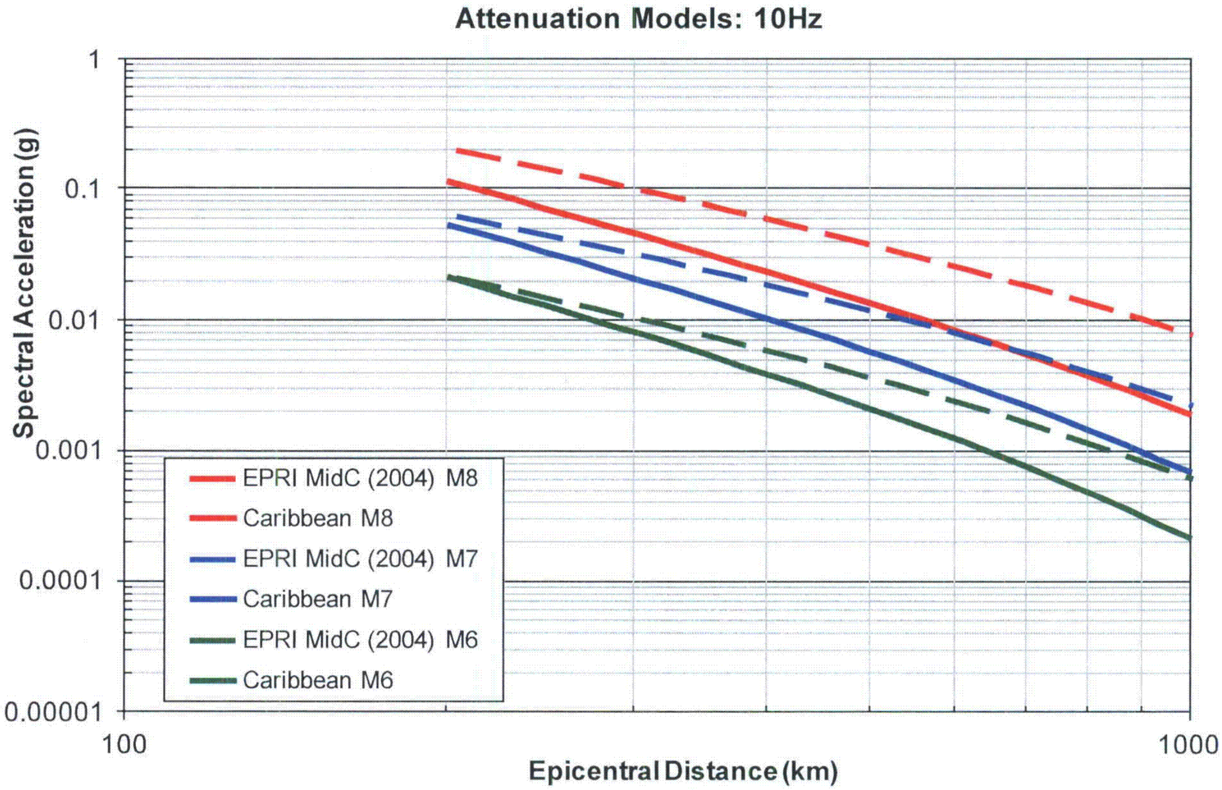
Figure 2.5.2-266

Comparison of EPRI Mid-C~~c~~ontinent (Reference 242) M~~m~~ean (dashed lines) and Caribbean M~~m~~ean (solid lines) Attenuation ~~GMPE~~ C~~c~~urves for M~~m~~agnitudes 6, 7, and 8 for 10 Hz~~.~~



Source: Reference 242

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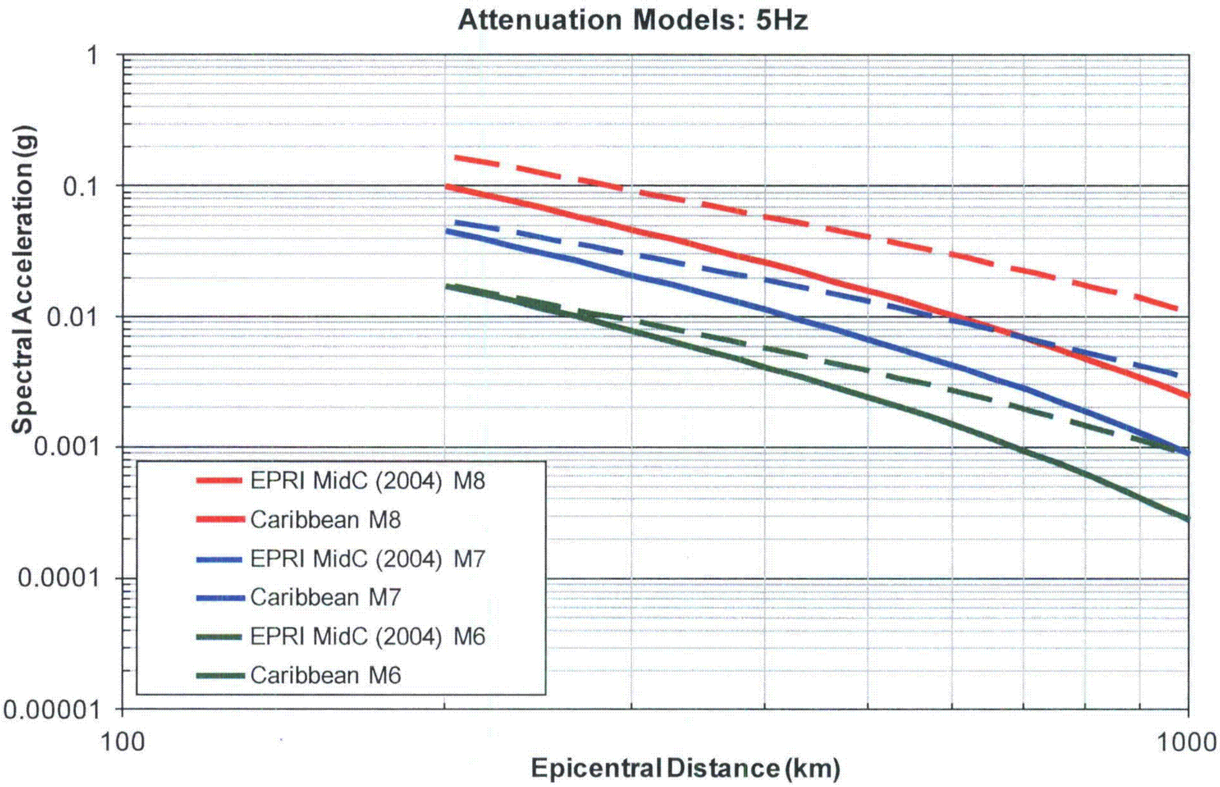
NRC RAI No. 02.05.02-2 (eRAI 5896)

Figure 2.5.2-267

Comparison of EPRI Mid-C~~c~~ontinent (Reference 242) M~~m~~ean (dashed lines) and Caribbean M~~m~~ean (solid lines) Attenuation ~~GMPE~~ C~~c~~urves for M~~m~~agnitudes 6, 7, and 8 for 5 Hz~~.~~



Source: Reference 242

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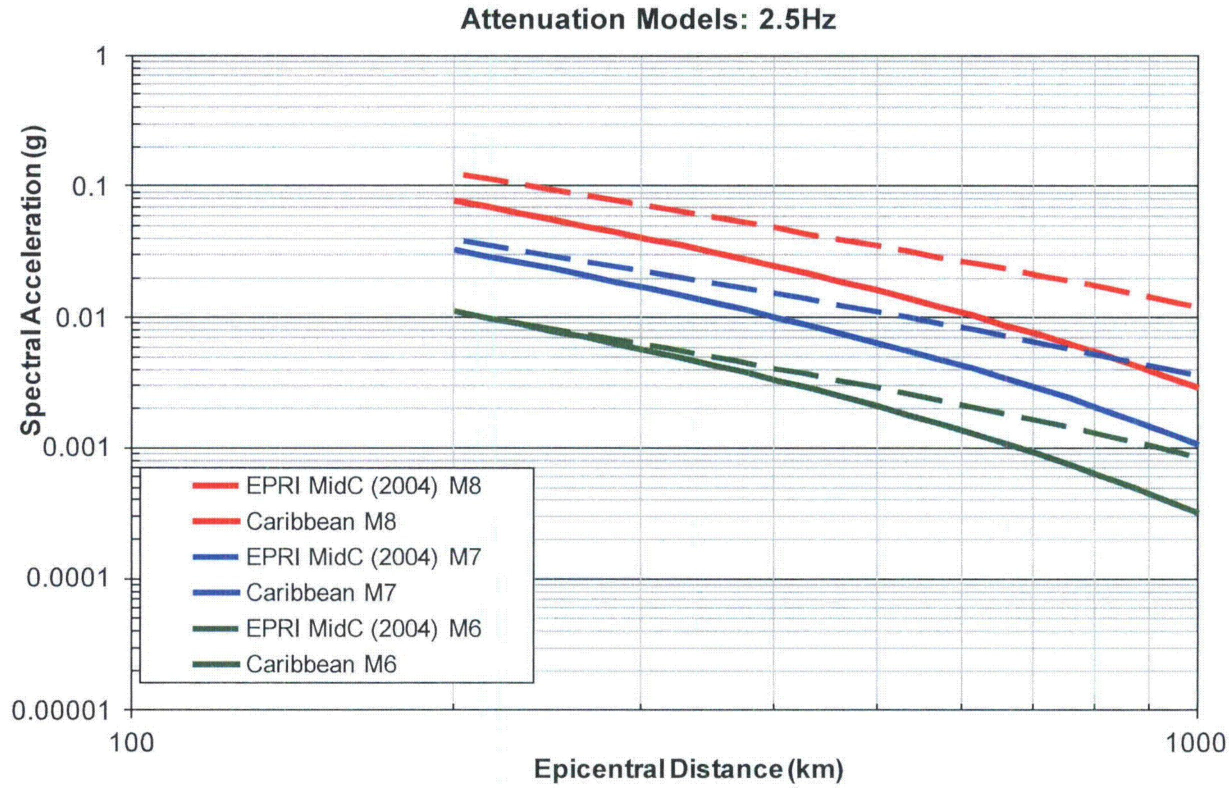
NRC RAI No. 02.05.02-2 (eRAI 5896)

Figure 2.5.2-268

Comparison of EPRI Mid-C~~c~~ontinent (Reference 242) M~~m~~ean (dashed lines) and Caribbean M~~m~~ean (solid lines) Attenuation ~~GMPE~~ C~~c~~urves for M~~m~~agnitudes 6, 7, and 8 for 2.5 Hz~~.~~



Source: Reference 242

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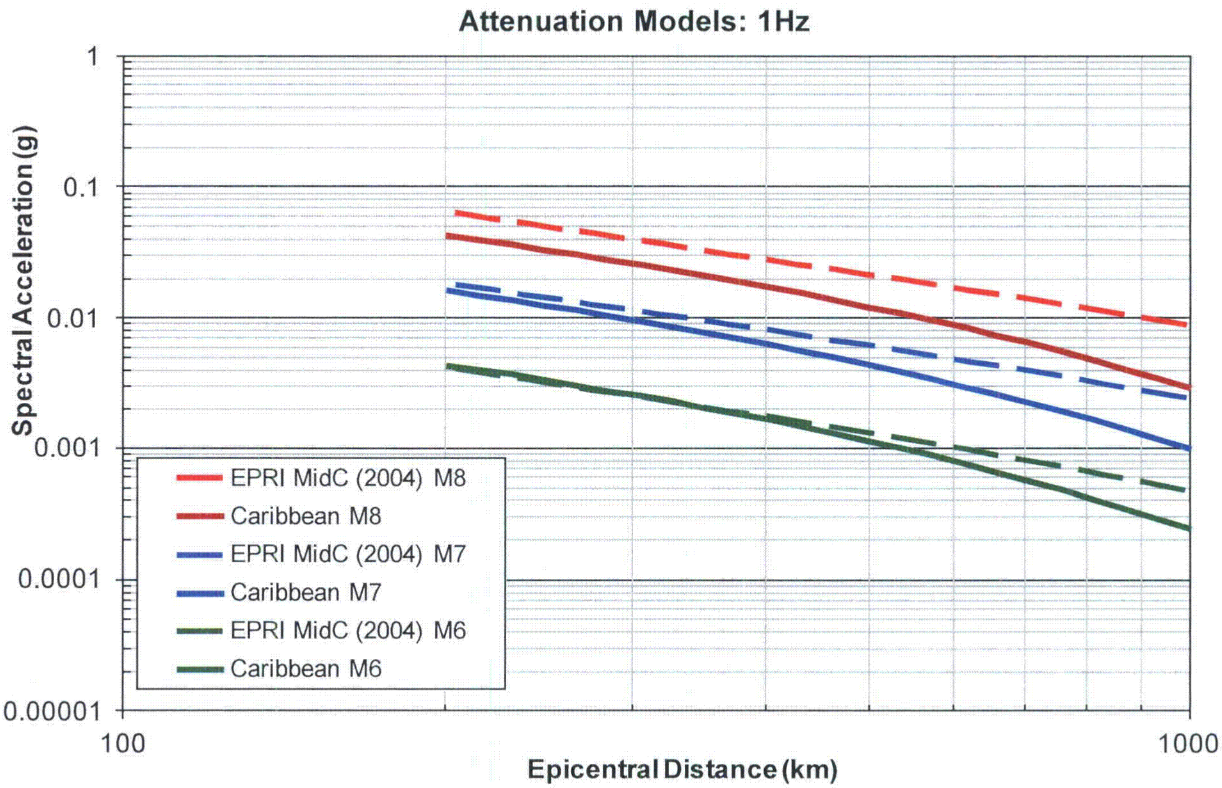
Figure 2.5.2-269

Comparison of EPRI Mid-C~~c~~ontinent (Reference 242) M~~m~~ean (dashed lines) and Caribbean M~~m~~ean (solid lines) Attenuation ~~GMPE~~ C~~c~~urves for M~~m~~agnitudes 6, 7, and 8 for 1 Hz~~.~~



Source: Reference 242

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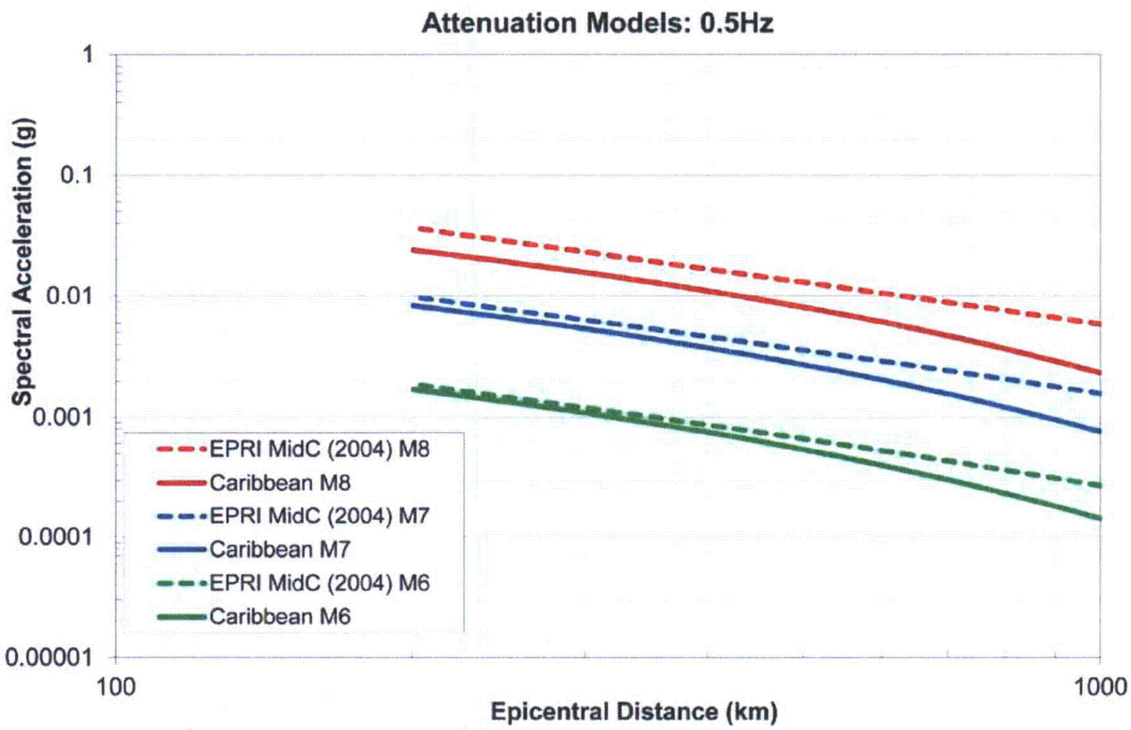
Figure 2.5.2-270

Comparison of EPRI Mid-C~~c~~ontinent (Reference 242) M~~m~~ean (dashed lines) and Caribbean M~~m~~ean (solid lines) Attenuation ~~GMPE~~ C~~c~~urves for M~~m~~agnitudes 6, 7, and 8 for 0.5 Hz~~.~~



Source: Reference 242

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ASSOCIATED COLA REVISIONS:

The following COLA changes are identified as a result of this response:

The text in FSAR Subsection 2.5.2.4.4.3.2.1, third paragraph, will be revised as follows in a future update of the FSAR:

Recent peer-reviewed literature provides support for the assessment of the lack of knowledge regarding the state of fault mapping in Cuba. For example, Cotilla-Rodriguez et al. (Reference 321) state~~s~~, "...the detailed association between destructive earthquakes and active tectonic features is extremely complex and not known in depth [...] there is not a close correlation of seismic events with individual faults in Cuba." Furthermore, **Cotilla-Rodriguez** et al. (Reference 321~~, p. 331~~) state~~s~~, "...most [historical, pre-instrumental earthquakes] have scarce data and do not permit a clear association to a seismic zone. There is no uniform knowledge about the historical seismicity of Cuba~~.~~...." ~~Additionally, recent peer-reviewed seismic hazard studies of Cuba describe a shift from a probabilistic approach that defined individual faults and source zones (Reference 254), to newer studies (Reference 255) performed by many of the same researchers that use spatially smoothed seismicity in place of source zones. The rationale for this shift is, "...to avoid drawing seismic sources in a region where the seismogenic structures are not well known" (Reference 255, p. 173). Moreover, "...since the northern part of the Cuban region lies in an intraplate region and is characterized by a moderate seismicity [sic], the association of earthquakes to faults is problematic and, consequently, the definition of [seismic sources] is based, in some cases, on subjective decisions" (Reference 255, p. 174).~~

Garcia et al. (Reference 254) present seismic hazard maps for Cuba that are based on seismogenic zone (SZ) source zones. Their SZs are narrow, elongated, areal seismic sources intended to represent potentially active faults. Seismicity rates for these "fault-like" SZs are not based on geologic- or geodetic-based fault slip rates because these data do not appear to exist. Instead, Garcia et al.'s (Reference 254) SZs are large enough to envelop sufficient numbers of earthquakes to estimate separate rates of seismicity for each source from the earthquakes observed within that source. In a subsequent publication, Garcia et al. (Reference 255) compare the results of their earlier SZ approach with those obtained by their implementation of a

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smoothed seismicity approach to hazard. Relative to the results obtained from their smoothed seismicity approach Reference 255~~, Garcia et al. (2008)~~ concludes that the seismotectonic zone approach tends to result in slightly higher PGA values in northwestern Cuba. They indicate that "an improvement of the seismicity data collection would be welcome for a better knowledge of the seismicity in northwestern Cuba" (Reference 255~~, p.193~~). Moreover, they indicate that "although the definition of SZs is positive because it focuses on understanding the regional tectonics, this exercise could be misleading when not supported by data. Consequently, a mixture of the two approaches would probably be the best solution: a seismotectonic approach for the more seismic areas and only seismicity elsewhere" (Reference 255~~, p. 174~~). According to Garcia et al. ~~(2008)~~ (Reference 255~~, p. 182~~), "the northern intraplate region [of Cuba] is related to a moderate to low seismicity." This observation of low to moderate rates of seismicity in northern Cuba is consistent with observations made from the Phase 2 earthquake catalog, which indicates a higher concentration of earthquakes and higher magnitudes in southernmost Cuba at and near the modern plate boundary relative to the rest of the island. Therefore, Garcia et al.'s (Reference 254) seismotectonic zone approach may not be applicable to the moderate to low seismicity areas of northern Cuba.

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Several new paragraphs will be inserted into a new FSAR Subsection 2.5.2.4.4.3.4.2 to describe the hazard sensitivity studies for the Cuba faults and alternative Cuba areal source zones. The text below will be added in a future FSAR revision:

2.5.2.4.4.3.4.2 Cuba Hazard Sensitivity Calculations

This subsection describes the characterization and results of intraplate Cuba seismic sources for use in a hazard sensitivity calculation performed to assess the potential impact on the Turkey Point Units 6 & 7 PSHA. As described in Subsection 2.5.1.1.1.3.2.4, it is unclear which, if any, of the faults in intraplate Cuba are capable tectonic sources. For this reason, hazard sensitivity calculations ~~are~~ were performed to assess the potential impact of intraplate Cuba seismic sources. The seismic source parameters for both areal and fault sources used in these hazard sensitivity calculations were developed through the use of ~~the senior seismic hazard analysis committee (~~SSHAC~~)~~ Level 2 methodology (Reference 318). Subsection 2.5.2.4.4.3.1 describes the SSHAC Level 2 methodology.

For the SSHAC Level 2 study of Cuba seismic sources, the TI team was comprised of Dean Ostenaa, Roland LaForge, Scott Lindvall, and Ross Hartleb. Participatory peer review was provided by Robert Creed. A total of eleven experts were contacted by the TI team with questions regarding the sensitivity calculations. These experts include geologists, seismologists, and hazard analysts from Cuba, the U.S., and elsewhere (Table 2.5.2-232). The level of detail provided to the TI team by the experts varies (Table 2.5.2-232). Some experts provided detailed responses and interacted with the TI team, whereas other experts provided only terse responses. Four experts either declined to participate or did not respond at all.

2.5.2.4.4.3.4.2.1 Cuba Seismic Sources for Hazard Sensitivity Calculation

Based on review of published literature and interaction with experts, the TI team developed a seismic source characterization for intraplate Cuba seismic sources for use in a hazard sensitivity calculation to assess the impact on hazard at the Turkey Point Units 6 & 7 site. This subsection describes the chartacteization of both areal sources and fault sources for the hazard sensitivity calculations.

Three scenarios by which areal source zones are implemented in the hazard sensitivity calculations are summarized below and in Table 2.5.2-233~~:~~.

- **<u>Single areal source zone scenario (Z1)</u>: In the single areal source zone model, a single areal source for Cuba is used, with a uniform seismicity rate throughout the zone that is based on observed seismicity from the Phase 2 earthquake catalog (Figure 2.5.2-271). This is the base case for the hazard sensitivity calculations and is the seismic source characterization for intraplate Cuba used in the PSHA (Subsection 2.5.2.4.6). The Z1 model results in a contribution to hazard that is intermediate between the Z6 and Z11% zone scenarios (Table 2.5.2-233).**

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- **<u>Elevated rate areal source zone scenario (Z11%)</u>: In the elevated rate zone scenario, a single areal source for Cuba is used, with a uniform seismicity rate throughout the zone that is based on observed seismicity from the Phase 2 earthquake catalog. The geometry of this zone is equivalent to that in the Z1 scenario. Unlike the Z1 scenario, however, the uniform rate for the Z11% scenario is based on a small subzone in northern Cuba (the "northern Cuba subzone" shown in Figure 2.5.2-271) that is located partially within the site region and that exhibits a higher rate of seismicity than surrounding regions. The seismicity rate from the northern subzone is approximately 11 percent higher than that for the entire Cuba areal source zone, and this higher rate is applied to the Z1 scenario. The Z11% scenario results in the highest contribution to hazard from the three zone scenarios (Table 2.5.2-233).**
- **<u>Six areal source zones scenario (Z6)</u>: In the six areal source zones scenario, Cuba is divided into six zones largely on the basis of observed patterns in seismicity (Figure 2.5.2-271). The seismicity *b*-value is constant across all six zones and equivalent to that used in the Z1 scenario; the seismicity *a*-values vary from zone to zone, are uniform within each zone, and are based on the observed seismicity within each zone. For the six-zone scenario (Z6), the *a*-values were determined by counting the number of events in each subzone greater than or equal to M_w 3.0. The *b*-value in base case Z1 is used for all six subzones. The Z6 scenario results in the lowest contribution to hazard from the three zone scenarios (Table 2.5.2-233).**

**All areal source scenarios are given equally weighted maximum moment magnitudes M_w of 7.0 and 7.3 with uniformly distributed seismicity parameters (complete smoothing) determined from the earthquakes within each zone. Values for Z1 and Z11% are shown in Table 2.5.2-234, using the completeness table for Cuba from Garcia et al. (Reference 255) (Table 2.5.2-235). Focal depth for all areal sources is the same as
was implemented in Subsection 2.5.2.4.6, which uses a three-point distribution to represent the 0 - 15 ~~km~~ kilometer (0-9 miles) seismogenic thickness: 2.5, 7.5, and 12.5 ~~km~~ kilometers (1.6, 4.7, and 7.8 miles), equally weighted.**

The input parameters for the Cuba sensitivity fault sources are described below and are summarized in Table 2.5.2-236 and Figure 2.5.2-272:

- **<u>Fault sources and geometries</u>: Intraplate Cuba fault sources include Cotilla-Rodriguez et al.'s (Reference 321) seismoactive faults in Cuba, plus the Pinar fault (Figure 2.5.2-272). For the purpose of the hazard sensitivity calculation, it is assumed that all of these faults are capable tectonic sources. The Nortecubana fault is divided into three sensitivity fault sources, the Nortecubana West, Nortecubana Central, and Nortecubana East fault sources. The Baconao fault is divided into two sensitivity fault sources, the Baconao Northwest and the Baconao Southeast fault sources. Seismogenic depth for all fault sources in the hazard sensitivity calculation extends from 0 - 15 ~~km~~ kilometers (0-9 miles). All fault sources are modeled with vertical dip angle, except the three Nortecubana fault sources, all of which are modeled as dipping 30 degrees to the south.**

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- Probability of activity: For the purpose of the hazard sensitivity calculation, it is assumed that each of the Cuba faults listed in Table 2.5.2-236 is a capable tectonic source with a probability of activity of 1.0. This is a conservative decision given the available geologic data.
- Maximum magnitude assessment: Modeled magnitude distribution [and weight] for all of the Cuba sensitivity fault sources is M_w 7.0 [0.5], 7.3 [0.5]. These values and weights are the same as those used in the Cuba areal source zone (Subsection 2.5.2.4.4.3.2.1). The maximum magnitude (Mmax) values for the sensitivity fault sources are higher than those presented in published literature. For example, Garcia et al.'s (Reference 254) Table 4 shows the range of Mmax values for fault sources in intraplate Cuba (their sources 1 through 24) from their study and previous studies, which range from M_w 5.0 to 7.0, with many at the middle to low end of this range.
- Slip rate assessment: There are no data to directly determine late Quaternary slip rates for potential Cuba sensitivity fault sources. For most sensitivity fault sources, slip rates in ~~mm~~ millimeters/year [and weights] are assigned as 0.001 [0.33], 0.01 [0.34], 0.1 [0.33]. For the three sensitivity fault sources most proximal to the modern plate boundary, higher slip rates are assigned as 0.01 [0.1], 0.1 [0.5], 1.0 [0.4]. These slip rate distributions span orders of magnitude, reflecting the lack of data and considerable uncertainty. It is assumed that all slip is seismogenic (i.e., fully coupled).
- Recurrence model: For the purpose of the hazard sensitivity calculation, a characteristic earthquake recurrence model is assumed for the Cuba sensitivity fault sources, but with no contribution from the exponential portion of the recurrence curve at lower magnitudes.

For the hazard sensitivity calculations, there are three scenarios for fault sources, as shown in Table 2.5.2-233 and summarized below:

- No fault sources scenario: This scenario excludes fault sources from the hazard sensitivity calculations. This is consistent with the seismic source characterization used for the PSHA presented in Subsection 2.5.2.4.6.
- Full fault model scenario (FF): The full fault model scenario includes 15 fault sources, as summarized in Table 2.5.2-236.
- Scaled fault model scenario (SF): The SF scenario is derived from the FF scenario such that the total seismic moment rate from the fault sources is equivalent to the seismic moment rate from the observed seismicity (Z1 scenario). The SF scenario results in a contribution to hazard that is lower than that from the FF fault source scenario (Table 2.5.2-233).

A total of eleven possible combinations of areal and fault scenarios are shown in Table 2.5.2-233. The results of hazard sensitivity calculations using these scenarios is presented in Subsection 2.5.2.4.4.3.4.2.2. The hazard sensitivity calculations for both the areal and fault source scenarios use ground motion attenuation relationships developed for Caribbean crustal seismic sources described in Subsection 2.5.2.4.5.2.

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2.5.2.4.4.3.4.2.2 Results of Cuba Hazard Sensitivity Calculations

This section describes the results of hazard sensitivity calculations for individual areal and fault source scenarios, as well as scenarios that combine areal and fault sources. A total of eleven possible combinations of areal and fault scenarios are shown in Table 2.5.2-233. One of these (Z1) is the base case used in the PSHA (Subsection 2.5.2.4.6). In addition to Z1, five of these scenarios are evaluated quantitatively (Z6, Z11%, SF, Z1+SF, and FF) and are described below in this subsection. Figures 2.5.2-273 and 2.5.2-274 present 1 Hz and 10 Hz hazard curves for these five scenarios. These figures also present the corresponding total hazard curves that include each of these Cuba scenarios.

- **The Z6 scenario results in a decrease in hazard relative to the Z1 base case.**
- **The Z11% scenario results in an increase in hazard relative to the Z1 base case.**
- **The SF scenario results in a lower hazard relative to the Z1 base case.**
- **The Z1+SF scenario results in a higher hazard relative to the Z1 base case.**
- **The FF scenario results in a higher hazard relative to the Z1 base case.**

Of these five scenarios, four are judged by the TI team to be most likely to encompass the center, body, and range of the views of the informed technical community (Z6, Z11%, SF, and Z1+SF). In contrast, the FF scenario is judged as overly conservative and therefore technically indefensible. The rationale for this assessment is based on the discrepancy between the observed historical rate of large earthquakes in Cuba and that predicted by the moment rate for the FF scenario. The moment rate for the FF scenario is derived from the weighted mean of slip rate distributions for the 15 Cuba fault sources. The bottom row of Table 2.5.2-237 illustrates that the moment rate for the weighted mean slip rate (FF model) yields a return period of 124 years for M_w 7.0 events. The completeness period for earthquakes in Cuba in the M_w 6.0 to 7.0 range is given as about 500 years according to Garcia et al. (Reference 255) (Table 2.5.2-234). In the approximately 500-year record of observed seismicity in Cuba, there are no magnitude 7 events, and the largest earthquake in that time in the Phase 2 earthquake catalog from intraplate Cuba is approximately M_w 6.3 (Subsection 2.5.2.4.4.3.3.1). Another way to examine the overly conservative rate derived from the FF scenario is to compare the ratio of moment rate derived from seismicity to moment rate derived from the assumed fault slip rates in the middle column of Table 2.5.2-237. That comparison shows that the FF scenario moment rate is 367 percent greater (3.67 factor in Table 2.5.2-237) than the moment rate derived from historical seismicity. While the individual FF scenario is presented in Figures 2.5.2-273 and 2.5.~~3~~2-274, it is not considered further. Likewise, combinations involving the FF scenario are also eliminated and not presented, as they would be overly conservative and technically indefensible.

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The remaining five combination scenarios (Z6+FF, Z1+FF, Z11%+FF, Z6+SF, and Z11%+SF) are discarded from further consideration based on the rationale provided below:

- **Three combination scenarios, Z6+FF, Z1+FF, and Z11%+FF, are discarded due to the inclusion of the FF scenario as described above.**
- **The Z6+SF combination scenario is judged to lie within the likely center, body, and range of the views of the informed technical community, but would result in an intermediate hazard not useful for this sensitivity analyses because SF is also combined with the Z1 scenario. The Z1+SF scenario results in higher hazard (Figures 2.5.2-273 and 2.5.2-274).**
- **The Z11%+SF combination scenario includes an areal zone scenario that is based on an arbitrary activity rate increase applied to the entire zone.**

~~In order t~~To assess the impact of various Cuba sensitivity scenarios on the Turkey Point Units 6 & 7 site hazard, based on the evaluation of the hazard results presented in Figures 2.5.2-273 and 2.5.2-274, four sensitivity scenarios (Z6, Z11%, SF, and Z1+SF) were selected to represent the Cuba hazard in lieu of the Z1 base case scenario used for the original base case hazard total. Total hazard curves that include these four scenarios are presented in Figure 2.5.2-275, along with the original total hazard.

Detailed comparisons of the differences in total hazard for the four scenarios with respect to the base case total hazard are compiled in Tables 2.5.2-238 and 2.5.2-239. Two acceleration spectral response frequencies (1 Hz and 10 Hz) and two MAFE levels (10^{-4} and 10^{-5}) are considered. Table 2.5.2-238 shows the percent differences in MAFE for each scenario at the respective base case amplitudes. Negative values indicate lower hazard levels than the base case levels, positive values are higher. The base case values are shown in the first pair of columns, and the subsequent four scenarios increase in hazard level from left to right. Differences for the Z6 scenario range from -8.8 percent to -1.1 percent of the base case total. Differences for the SF scenario range from -12 percent to 1.0 percent. The Z11% scenario is based on an increased seismicity rate for the entire areal zone compared to the base case and results in differences which range from -0.1 percent to 2.5 percent. For the Z1+SF scenario, differences are the greatest, ranging from 1.4 percent to 13.1 percent. Note that the apparent decrease (-0.1 percent) in 10 Hz MAFE at the 10^{-5} MAFE amplitudes for scenario Z11% is due to the limited number of significant digits presented in the base case for total mean hazard, the process of interpolation, and rounding. That this is only an apparent decrease is supported by the fact that the 10^{-5} MAFE amplitudes for scenario Z11% match the base case amplitudes exactly to three significant figures (Table 2.5.2-239).

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Table 2.5.2-239 shows the changes in rock motion amplitude for the four scenarios. The largest of these changes ~~are~~ is negative relative to the base case amplitudes. These are shown as absolute and percent differences in amplitudes. The largest percent increase is 4.4 percent and results from the Z1+SF scenario and the greatest decrease is -6.9 percent from the SF scenario. Of greater importance than the percentages is the maximum increase in rock motion amplitude from the different scenarios. None of the increases in rock motions from all scenarios exceeds 0.004 g.

The scenarios presented in Figure 2.5.2-275 are derived from a reasonable range of technically defensible seismic source characterizations for intraplate Cuba. As shown in Table 2.5.2-239, this range of seismic source characterizations results in only small changes in hazard at the Turkey Point Units 6 & 7 site. Based on the results of these hazard sensitivity calculations, it is concluded that the use of a single areal source zone and the parameters used to characterize it as presented in Subsection 2.5.2.4.6 gives a reasonably conservative estimate of the contribution to site hazard from intraplate Cuba seismic sources.

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The following table will be revised in a future revision of the FSAR:

**Table 2.5.2-217
Summary of Cuba and Northern Caribbean Seismic Source Parameters**

Area Source	Closest Distance to Units 6 & 7 (mi)	Annual Number of Earthquakes of M_w 5.0 and Greater	*b*-value	Mmax (M_w)
1. Cuba areal source zone	140	**0.0592**	**0.839**	7.0 [0.5] 7.25 [0.5][(a)]

(a) **For the PSHA calculation, this value was rounded up to M_W 7.3.**

Fault Source	Closest Distance to Units 6 & 7 (mi)	Fault Type/ Dip	Slip Rate (mm/yr)	Seismic Coupling	Mmax (M_w)
2. Oriente – Western	420	Strike-slip/ 90°	8 [0.1] 11 [0.7] 13 [0.2]	0.6 [0.2] 0.8 [0.2] 1.0 [0.6]	7.5 [0.3] 7.7 [0.4] 8.0 [0.3]
3. Oriente – Eastern	445	Strike-slip/ 90°	8 [0.1] 11 [0.7] 13 [0.2]	1.0 [1.0]	7.5 [0.2] 7.7 [0.6] 7.9 [0.2]
4. Septentrional	545	Strike-slip/ 90°	6 [0.2] 9 [0.6] 12 [0.2]	1.0 [1.0]	8.0 [0.5] 8.25 [0.5]
5. Northern Hispaniola – Western	550	Thrust/ 20-25° south	4 [0.2] 6 [0.7] 8 [0.1]	1.0 [1.0]	7.8 [0.2] 8.0 [0.6] 8.3 [0.2]
6. Northern Hispaniola – Eastern	760	Thrust/ 20-25° south	4 [0.2] 6 [0.7] 8 [0.1]	1.0 [1.0]	8.6 [0.2] 8.3 [0.6] 8.6 [0.2]
7. Swan Islands – Western	620	Strike-slip/ 90°	18 [0.2] 19 [0.6] 20 [0.2]	1.0 [1.0]	7.8 [0.2] 8.0 [0.7] 8.3 [0.1]
8. Swan Islands – Eastern	540	Strike-slip/ 90°	18 [0.2] 19 [0.6] 20 [0.2]	0.6 [0.2] 0.8 [0.2] 1.0 [0.6]	7.2 [0.4] 7.5 [0.5] 7.7 [0.1]
9. Walton – Duanvale	490	Strike-slip/ 90°	6 [0.2] 8 [0.6] 10 [0.2]	0.8 [0.3] 1.0 [0.7]	7.3 [0.3] 7.6 [0.6] 7.8 [0.1]
10. Enriquillo-Plantain Garden ~~fault~~	560	Strike-slip/ 90°	6 [0.2] 8 [0.6] 10 [0.2]	1.0 [1.0]	7.5 [0.2] 7.7 [0.6] 7.9 [0.2]

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The following will be added as a new FSAR table in a future revision of the FSAR:

Table 2.5.2-232
Experts Contacted for the SSHAC Level 2 Study in Support of Cuba Hazard Sensitivity Calculations

Expert	Affiliation	Expertise	Response
Coppersmith, Kevin	Coppersmith Consulting	Seismic hazard modeling, seismic source characterization	Email response.
Cotilla Rodriguez, Mario Octavio	Departamento de Física de la Tierra y Astrofísica, Facultad de Ciencias Físicas, Universidad Complutense de Madrid (Madrid, Spain)	Cuba faults and neotectonics	Detailed email response.
Garcia, Julio	Centro Nacional de Investigaciones Sismológicas (CENAIS) (Havana, Cuba)	Seismic hazard modeling in Cuba	No response.
Hanson, Kathryn	AMEC	Seismic hazard modeling, seismic source characterization	Declined to participate.
Ituralde-Vinent, Manuel	Museo Nacional de Historia Natural (Havana, Cuba) and Departamento de Geociencias, Instituto Superior Politécnico J. A. Echeverría (Havana, Cuba)	Geology of Cuba	No response.
Moreno Toiran, Bladimir	Inst. Of Solid Earth Physics, University of Bergen (Norway) and Centro Nacional de Investigaciones Sismologicas (CENAIS) (Santiago de Cuba, Cuba)	Seismology and geophysics of Cuba	Email response.
Slejko, Dario	Istituto Nazionale di Oceanografia e di Geofisica Sperimetale (OGS) (Trieste, Italy)	Seismic hazard modeling in Cuba	Detailed email response.
Toscano, Marguerite	Department of Paleobiology, Smithsonian Institute	Marine terrace mapping and dating in northern Cuba	Email response and telephone conversation regarding marine terraces in northern Cuba.
Wong, Ivan	URS Corporation	Seismic hazard modeling, seismic source characterization	Detailed email responses.

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Youngs, Robert	AMEC	Seismic hazard modeling	Declined to participate.
Zapata Balanque, Jose Alejandro	Universidad de Oriente (Santiago de Cuba, Cuba)	Cuba faults and neotectonics	Email response regarding plans for future paleoseismic studies in Cuba.

The following will be added as a new FSAR table in a future revision of the FSAR:

Table 2.5.2-233
Cuba Seismic Source Alternatives for Hazard Sensitivity Calculations

		Source Zone Scenarios Increasing hazard □			
		No areal sources	Z6 Six areal sources	Z1 Single areal source	Z11% Elevated rate areal source (+11% increase in rate)
Fault Source Scenarios Increasing hazard	No fault sources	N/A	Z6	Z1	Z11%
	SF Scaled fault sources	SF	Z6+SF*(a)	Z1+SF*(a)	Z11%+SF**(b)
	FF Full fault sources	FF***(c)	Z6+FF***(c)	Z1+FF***(c)	Z11%+FF***(c)

~~Shaded source scenarios not quantitatively evaluated.~~

*(a) Z1+SF was evaluated as a reasonable combination scenario in the hazard sensitivity calculations. As discussed in the text, area source scenario Z6 was found to result in lower hazard than area source scenario Z1. Thus, it is unnecessary to further investigate the combination scenario Z6+SF.

**(b) As discussed in the text, source area scenario Z11% is considered a conservative assessment of the seismic hazard derived from the cataloged seismicity, therefore the combination scenario Z11%+SF is considered overly conservative for consideration in the hazard sensitivity calculations.

***(c) As discussed in the text, fault source scenario FF was determined to be technically indefensible compared to the cataloged seismicity. Therefore, any combination scenarios with FF were similarly eliminated as technically indefensible

Shaded source scenarios not quantitatively evaluated.

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The following will be added as a new FSAR table in a future revision of the FSAR:

Table 2.5.2-234
Cuba Areal Source Zone and Northern Cuba Subzone Recurrence Parameters

Zone	Zone area (km^2)	# Events[a]	a-value[b]	b-value	Rate of M_w 5 to 7.3 events per year/km^2
Cuba areal source zone	250,286	152	-2.430	0.839	2.341E-7
Northern Cuba subzone	80,770	46	-2.383[d]	0.839[c]	2.609E-7

(a) Events ≥ M_w 3.0, filtered for completeness periods.

(b) Normalized to events per year/km^2

~~(c)~~ (d) Fixed to Cuba areal source zone b-value

~~(d)~~ (c) Value represents the 11 percent increase discussed in text

The following will be added as a new FSAR table in a future revision of the FSAR:

Table 2.5.2-235
Completeness Periods and Earthquake Counts in Each Bin from the Phase 2 Earthquake Catalog

Magnitude Range (M_w)	Start Date	End Date	Number of Earthquakes from Phase 2 Earthquake Catalog
3.0 – 4.0	1/1960	3/2008	119
4.0 – 5.0	1/1940	3/2008	17
5.0 – 6.0	1/1850	3/2008	14
6.0 – 7.0	1/1500	3/2008	2

Source: Reference 255

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The following will be added as a new FSAR table in a future revision of the FSAR:

Table 2.5.2-236
Summary of Seismic Source Parameters for Intraplate Cuba Fault Sources for Hazard Sensitivity Calculation

Sensitivity Fault Source	Dip	Rupture Depth Range (km)	Length (km)	Magnitude (M_w) [and weight]	Slip Rate (mm/yr) [and weight]
Baconao SE	90°	0-15	101	7.0 [0.5] 7.3 [0.5]	0.01 [0.1] 0.1 [0.5] 1.0 [0.4]
Baconao NW	90°	0-15	191	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Camaguey	90°	0-15	131	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Cochinos	90°	0-15	68	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Cubitas	90°	0-15	283	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Guane	90°	0-15	292	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Habana-Cienfuegos	90°	0-15	269	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Hicacos	90°	0-15	114	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
La Trocha	90°	0-15	257	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Las Villas	90°	0-15	197	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Nipe	90°	0-15	292	7.0 [0.5] 7.3 [0.5]	0.01 [0.1] 0.1 [0.5] 1.0 [0.4]
Nortecubana West	30° S	0-15	595	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Nortecubana Central	30° S	0-15	441	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]
Nortecubana East	30° S	0-15	340	7.0 [0.5] 7.3 [0.5]	0.01 [0.1] 0.1 [0.5] 1.0 [0.4]
Pinar	90°	0-15	215	7.0 [0.5] 7.3 [0.5]	0.001 [0.33] 0.01 [0.34] 0.1 [0.33]

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The following will be added as a new FSAR table in a future revision of the FSAR:

Table 2.5.2-237
Moment Rates, Ratio of Seismicity-Based Moment Rate to Fault-Based Moment Rates, and Return Periods for M_w 6.5 and 7.0 from Cuba Sensitivity Options

Moment Rate Options	Moment Rate (dyne-cm/yr)	Ratio, Seismicity/Fault-based	Return Period for M_w 6.5 (years)	Return Period for M_w 7 (years)
Historical Seismicity*(a)	7.7844E+23	Not applicable	81	456
Low Slip Rate Option**(b)	6.6686E+22	0.0857	946	5321
Middle Slip Rate Option**(b)	6.6686E+23	0.8567	95	532
High Slip Rate Option**(b)	6.6686E+24	8.5666	9.5	53
Weighted Mean Slip Rate***(c)	2.8535E+24	3.6657	22	124

*(a) Moment rate obtained from seismicity catalog and used for Cuba areal source (Z1) and for scaled fault scenario (SF).

**(b) Moment rates obtained from low, middle, and high slip rate values presented in Table 2.5.2-236.

***(c) Moment rate obtained from weighted mean of slip rate values presented in Table 2.5.2-236 and used for full fault scenario (FF).

The following will be added as a new FSAR table in a future revision of the FSAR:

Table 2.5.2-238
Summary of Hazard Sensitivity Study Results: Comparison of MAFE

	Base case Z1		Scenario Z6		Scenario SF		Scenario Z11%		Scenario Z1+SF	
	10^{-4} mean annual frequency of exceedance (MAFE)									
Freq	MAFE	Amp*(a)	MAFE	% Diff	MAFE	% Diff	MAFE	% Diff	MAFE	% Diff
1 Hz	1.00E-04	0.0343	9.499E-05	-5.0%	9.676E-05	-3.2%	1.018E-04	1.8%	1.114E-04	11.4%
10 Hz	1.00E-04	0.0822	9.122E-05	-8.8%	8.798E-05	-12.0%	1.025E-04	2.5%	1.094E-04	9.4%
	10^{-5} mean annual frequency of exceedance (MAFE)									
Freq	MAFE	Amp*(a)	MAFE	% Diff	MAFE	% Diff	MAFE	% Diff	MAFE	% Diff
1 Hz	1.00E-05	0.0663	9.539E-06	-4.6%	1.010E-05	1.0%	1.013E-05	1.3%	1.131E-05	13.1%
10 Hz	1.00E-05	0.278	9.891E-06	-1.1%	9.969E-06	-0.3%	9.992E-06	-0.1%	1.014E-05	1.4%

*(a) Rock motion (g)

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The following will be added as a new FSAR table in a future revision of the FSAR:

Table 2.5.2-239

Summary of Hazard Sensitivity Results: Comparison of Rock Motion Amplitudes

	Base case Z1	Scenario Z6			Scenario SF			Scenario Z11%			Scenario Z1+SF		
	Rock motions (g) at 10^{-4} mean annual frequency of exceedance (MAFE)												
Freq	Amp	Amp	Amp Diff	% Diff	Amp	Amp Diff	% Diff	Amp	Amp Diff	% Diff	Amp	Amp Diff	% Diff
1 Hz	0.0343	0.0338	-0.0005	-1.5%	0.0340	-0.0003	-0.9%	0.0345	0.0002	0.6%	0.0354	0.0011	3.2%
10 Hz	0.0822	0.0784	-0.0038	-4.6%	0.0765	-0.0057	-6.9%	0.0832	0.0010	1.2%	0.0858	0.0036	4.4%
	Rock motions (g) at 10^{-5} mean annual frequency of exceedance (MAFE)												
Freq	Amp	Amp	Amp Diff	% Diff	Amp	Amp Diff	% Diff	Amp	Amp Diff	% Diff	Amp	Amp Diff	% Diff
1 Hz	0.0663	0.0654	-0.0009	-1.4%	0.0665	0.0002	0.3%	0.0665	0.0002	0.3%	0.0686	0.0023	3.5%
10 Hz	0.278	0.276	-0.0020	-0.7%	0.278	0.0000	0.0%	0.278	0.0000	0.0%	0.280	0.0020	0.7%

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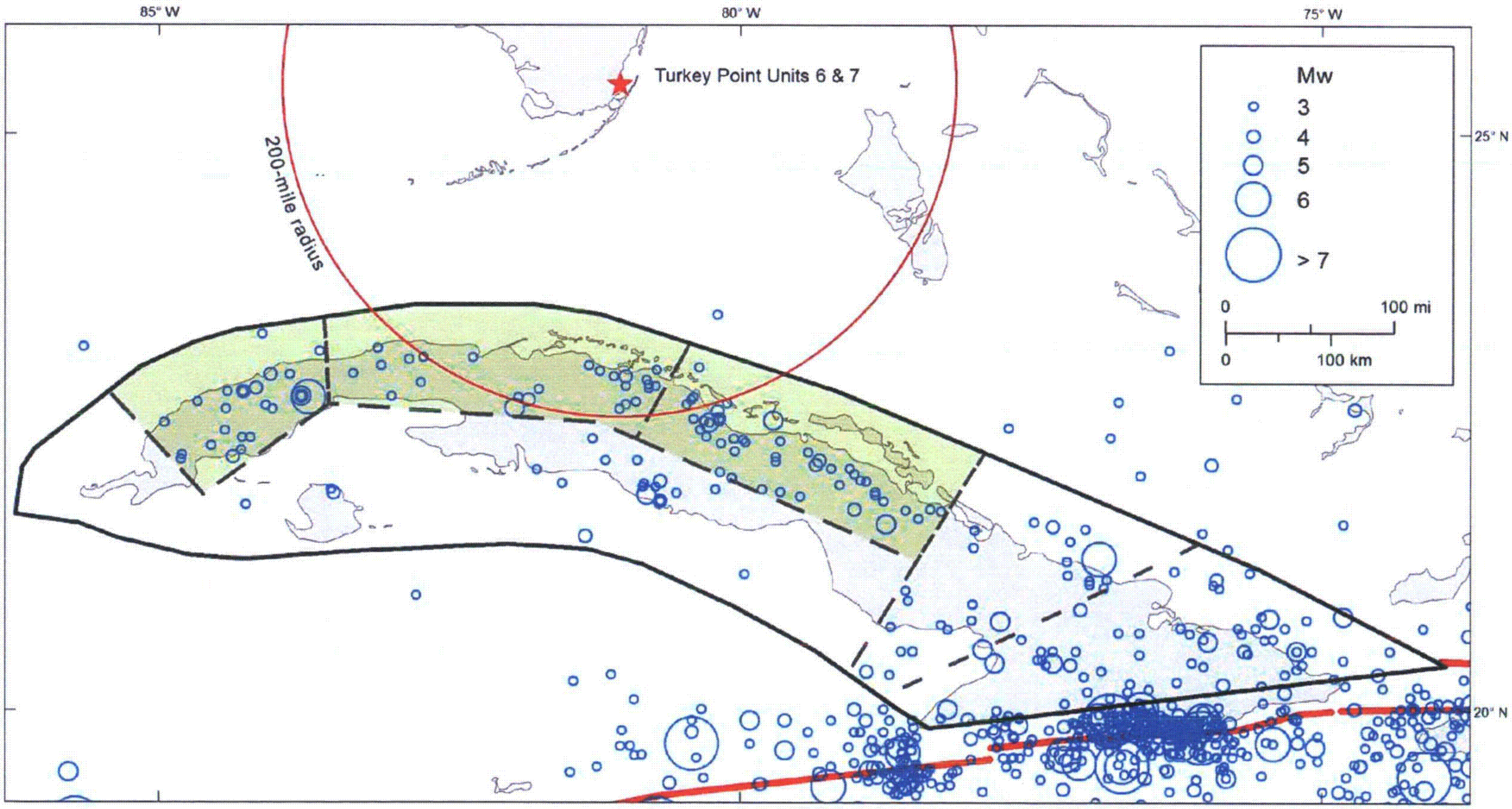
The following will be added as a new FSAR figure in a future revision of the FSAR

Figure 2.5.2-271 Map S~~s~~howing Cuba S~~s~~ingle A~~a~~real S~~s~~ource Z~~z~~one (solid black line), S~~s~~ix S~~s~~ensitivity A~~a~~real S~~s~~ource Z~~z~~ones (dashed black lines), and N~~n~~orthern Cuba S~~s~~ubzone U~~u~~sed in H~~h~~azard S~~s~~ensitivity C~~c~~alculation (green shading). Seismicity (blue circles) is from the Phase 2 E~~e~~arthquake C~~c~~atalog. Thick R~~r~~ed L~~l~~ines S~~s~~how P~~p~~late B~~b~~oundary F~~f~~ault S~~s~~ources I~~i~~ncluded in PSHA.



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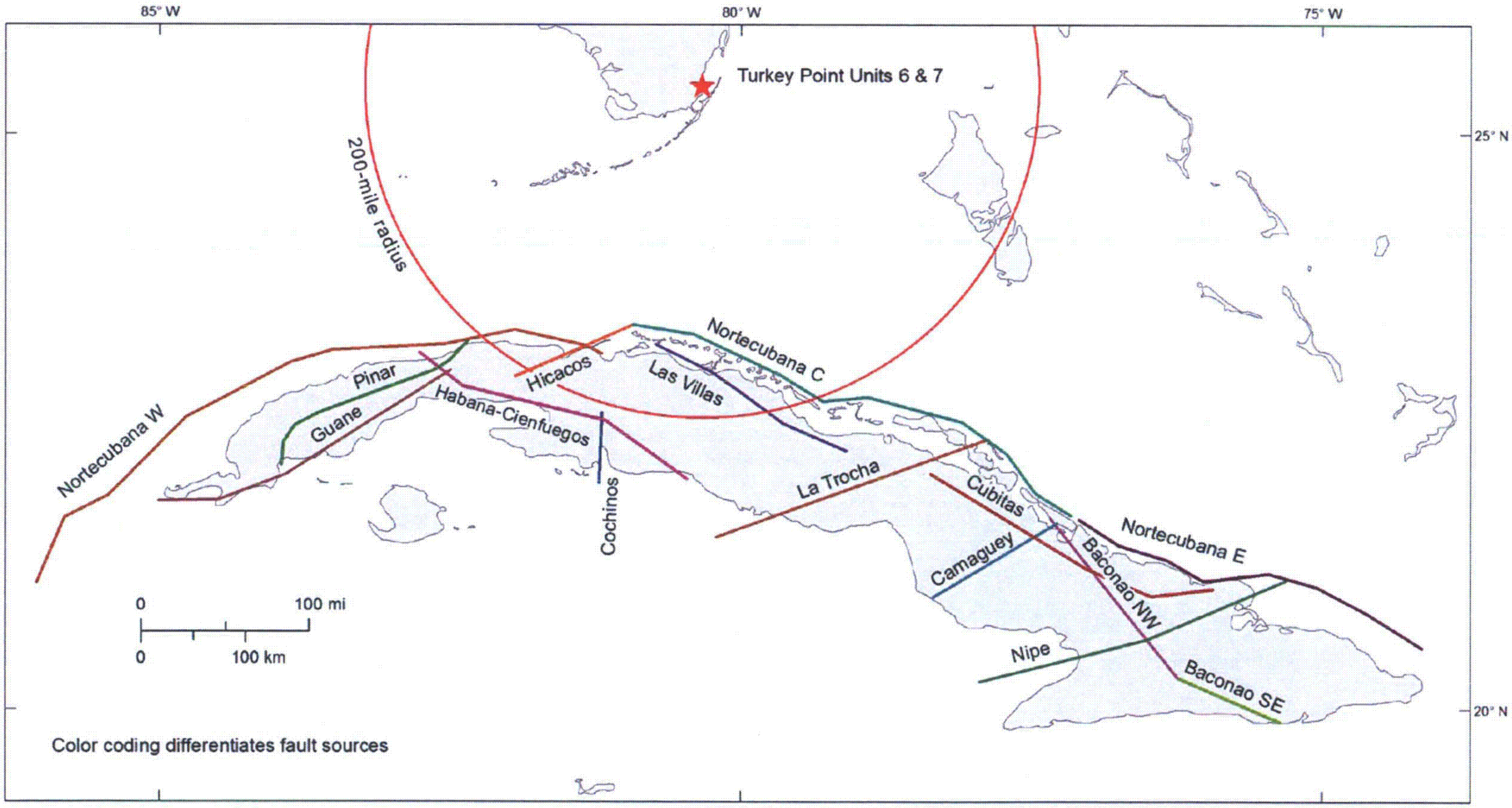
The following will be added as a new FSAR figure in a future revision of the FSAR

Figure 2.5.2-272 Map of Intraplate Cuba Fault Sources for Hazard Sensitivity Calculation



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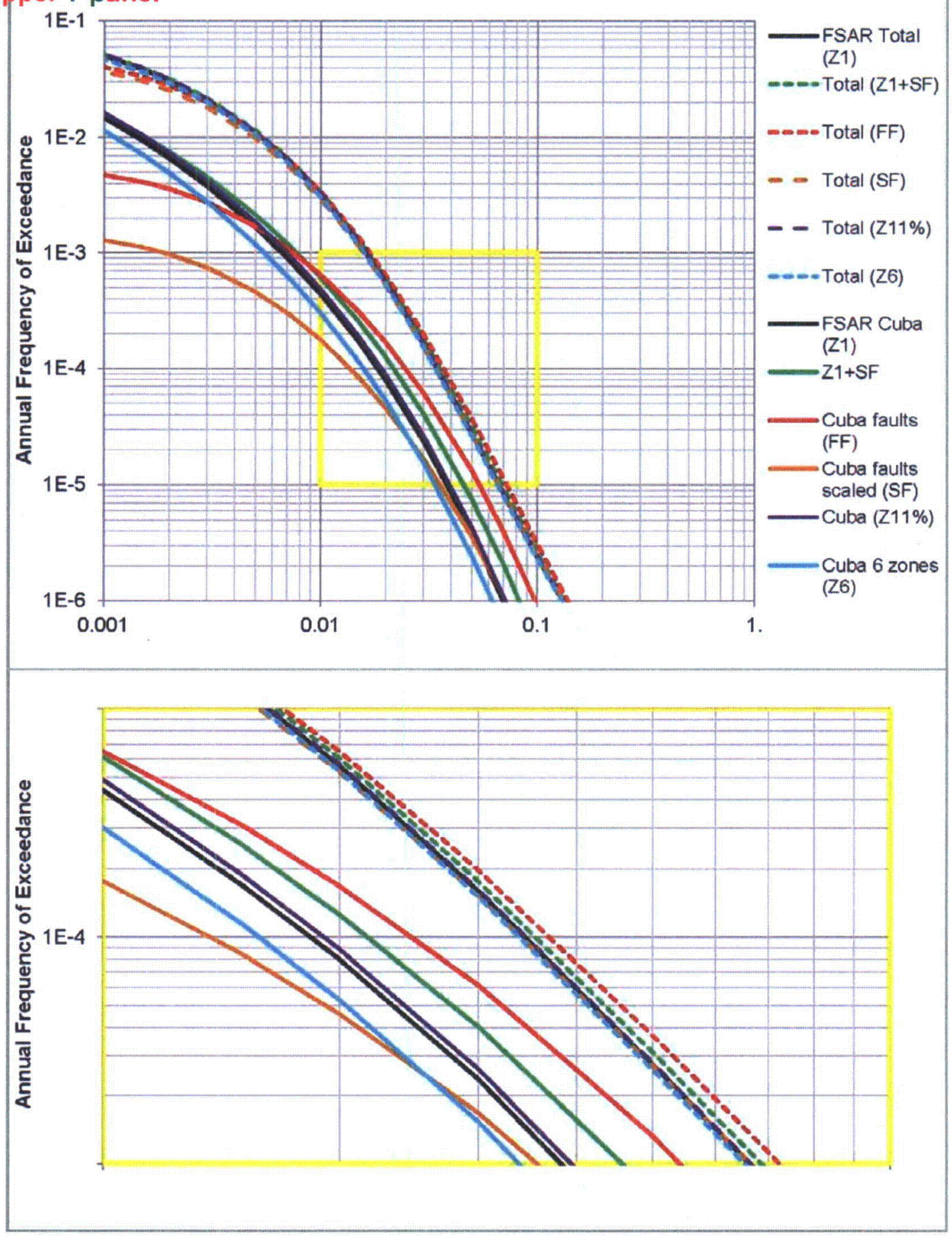
The following will be added as a new FSAR figure in a future revision of the FSAR:

Figure 2.5.2-273 1 Hz M~~m~~ean H~~h~~azard C~~c~~urves S~~s~~howing S~~s~~ensitivity to Cuba S~~s~~ource S~~s~~cenarios. Lower P~~p~~anel is E~~e~~xpanded V~~v~~iew of Y~~y~~ellow B~~b~~ox in U~~u~~pper P~~p~~anel



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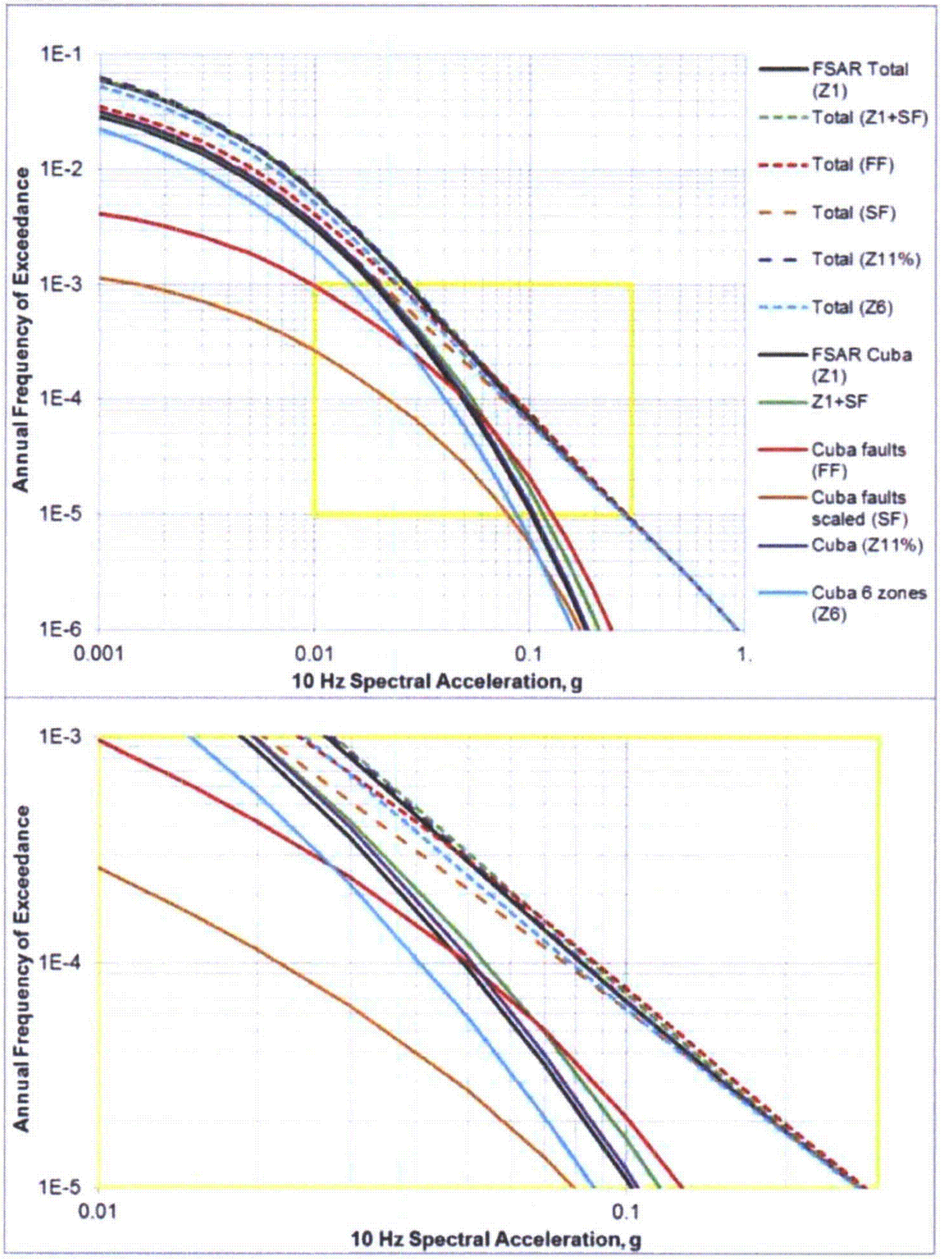
The following will be added as a new FSAR figure in a future revision of the FSAR:

Figure 2.5.2-274 10Hz M~~m~~ean H~~h~~azard C~~c~~urves S~~s~~howing S~~s~~ensitivity to Cuba S~~s~~ource S~~s~~cenarios. Lower P~~p~~anel is E~~e~~xpanded V~~v~~iew of Y~~y~~ellow B~~b~~ox in U~~u~~pper P~~p~~anel.



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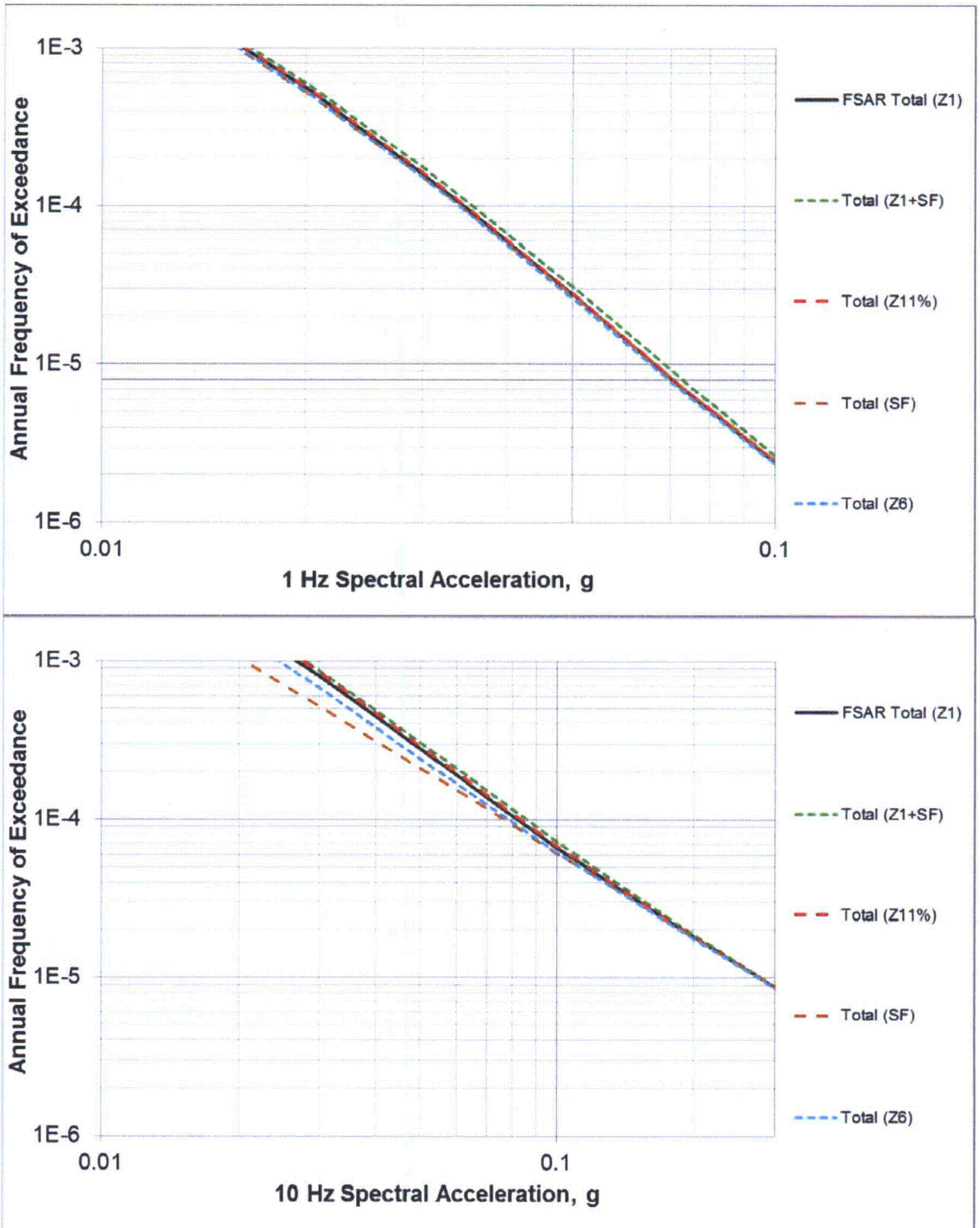
The following will be added as a new FSAR figure in a future revision of the FSAR:

Figure 2.5.2-275 Total M~~m~~ean H~~h~~azard C~~c~~urves for 1 Hz (U~~u~~pper) and 10Hz (L~~l~~ower) S~~s~~howing S~~s~~ensitivity to F~~f~~our Cuba S~~s~~ource S~~s~~cenarios



Source: Reference 242

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ASSOCIATED COLA REVISIONS:

The entire FSAR subsection 2.5.2.1.3.1 should be replaced with the following new text.

2.5.2.1.3.1 Uniform Magnitude M_w

~~In the Phase 2 earthquake catalog, Mw was used as the unifying magnitude because it is the most commonly used magnitude in recent seismic hazard studies.~~

~~**Converting Various Magnitude Scales to Mw**~~

~~Various magnitude scales may be available for a given event. Each available magnitude was considered in the evaluation of Mw for that event. If an Mw was available, it was adopted directly. Other magnitudes were converted to estimates of Mw using the Equation 2.5.2-8 (Reference 240).~~

~~Global average relationships between MS and log M0 (logarithm of the seismic moment) were used in which the independent variable is log M0 based on the assumption that the slope of the regression is 1 for small and 2/3 for large values of M0 (Reference 240). The following global log M0-MS relation was used to convert surface-wave magnitude (MS) to seismic moment (M0) for all events:~~

~~logM0 = 19.24 + MS MS< 5.3 Equation 2.5.2-8~~
~~logM0 Ă02.45 ĂĂ Ă ĔĹ ĂĔĹ Ă Ă~~
~~logM0 = 16.14 + 1.5MS MS > 6.8~~

~~Moment magnitudes were estimated from seismic moment for all events as a linear transformation of the logarithm of the seismic moment, M0, given by (Reference 269):~~

~~Mw = (2/3) log M0 – 10.7 Equation 2.5.2-9~~

~~in which M0 is in dyne-cm units (10-7 Nm).~~

~~A new linear relationship to compute MS from mb, valid in the interval 4.0 < mb < 6.0 and 3.1 < MS < 6.7, was applied by the following linear regression (Reference 254):~~

~~MS = 1.37 mb - 2.34 Equation 2.5.2-10~~

In this Subsection, the rationale for selecting moment magnitude (M_w) as the uniform magnitude scale for the Phase 2 earthquake catalog is discussed and the magnitude conversion process adopted for all events in the Cuba and Caribbean Phase 2 earthquake catalog is described in detail.

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Rationale for Selecting M_w as the Uniform Magnitude Scale for the Phase 2 Catalog

Seismologists performing current conventional probabilistic seismic hazard analyses, as well as development of ground motion prediction equations (~~e.g.,~~ References 300 and 344), prefer the use of M_w over other magnitude scales, including m_b scale, because it is a more direct indication of the seismic energy associated with an earthquake, particularly for both shallow and deep focus earthquakes with large fault dimensions and/or complex rupture mechanisms that occur in the Caribbean. The m_b magnitude scale saturates, or is progressively insensitive to, energy release beginning with magnitudes greater than ~~about~~ approximately 5.0 due to the difference in the period and the seismic-wave type used to determine the magnitude size. While the magnitudes of earthquakes within the CEUS region have generally and traditionally been adequately represented by the m_b scale, the largest events in the Caribbean are not. This rationale for selecting moment magnitude was the basis for its use in developing the Phase 2 earthquake catalog.

Also, the update of the Phase 1 earthquake catalog, as discussed in S~~s~~ubsection 2.5.2.1.2, was constrained to maintain the magnitude scale in m_b because both the EPRI-SOG seismicity catalog and recurrence characterization of the EPRI-SOG seismic sources use the m_b scale.

NUREG-0800 Section 2.5.2 and RG 1.206 specify that the earthquake catalog should include all earthquakes having Modified Mercalli Intensity (MMI) greater than or equal to IV, or magnitude greater than or equal to 3.0 that have been reported within 320 ~~km~~ kilometers (200 miles) of the site. Large earthquakes outside of this area that would impact the SSE (in NUREG-0800) or the GMRS (in RG 1.206) should be reported. The Phase 1 and Phase 2 catalogs were developed to meet these requirements. The magnitude scale is not explicitly specified in these requirements~~,~~ although, both documents later state that "magnitude designations such as m_b, M_L, M_s, M_w should be identified." There is no specification of the magnitude scale for the earthquake catalog given in RG 1.208.

The magnitude conversion relations between the moment magnitude scale and many other scales, such as m_b scale, show that the magnitudes less than about 4.5 (very short fault lengths) are assumed to be numerically equivalent to M_w and that the conversion relations are nonlinear at large magnitude values to reflect the saturation of some magnitude scales, specifically~~,~~ m_b scale (Reference 346). Therefore, in the development of the Phase 2 catalog, all small earthquakes of any magnitude scale less than 4.5 were assumed to be numerically equivalent to M_w. As a result of this assumption for small events, the selected threshold magnitude scale $M_w \geq 3.0$ for the Phase 2 earthquake catalog and m_b (or (E)mb) ≥ 3.0 for the Phase 1 earthquake catalog presents no inconsistency in terms of minimum size or minimum seismic energy of a given earthquake considered in the two catalogs. Therefore, under the process used to develop moment magnitudes for the Phase 2 catalog, all earthquakes of magnitude 3.0 and larger, regardless of characterization as moment magnitude or body-wave magnitude, are included in both Phase 1 and Phase 2 earthquake catalogs, and there is no impact on the number of earthquakes in the two earthquake catalogs associated with the different magnitude scales used in the two earthquake catalogs.

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Magnitude Conversion Process for Earthquakes in the Caribbean Region

The differences that exist among published seismotectonic region-specific magnitude conversion relations make the selection of appropriate relations for a given region important and, if such relations are not available, difficult. Seismic network operational histories are such that catalogs of events in a given region contain earthquakes located with different location programs. These programs use different station configurations and different crustal-velocity models with magnitudes calculated using different calibration. Therefore, conversions of diverse best estimates of magnitudes determined in different regions to a given uniform magnitude scale may show notable differences, ~~dependent~~ depending on tectonic setting (Reference 240).

In contrast to the CEUS tectonic environment considered for the Phase 1 earthquake catalog, the Caribbean region with its (1) different tectonic environments (e.g., plate boundary and near plate boundary shallow crustal faults and subduction zones), (2) different magnitude scales, and (3) different seismic network instrumentation and operational histories, required consideration of different global or regional magnitude conversion relationships for the Phase 2 earthquake catalog development.

~~In Order to~~ To contrast the nature of earthquakes from the Caribbean region to the CEUS region, a magnitude conversion process was developed to consider the various magnitude scales used in the original source catalogs considered in the development of the Phase 2 earthquake catalog, and these various magnitude scales were converted to M_w.

Among the various earthquake source catalogs used for compiling the Phase 2 catalog, there were 19 different magnitude types that needed to be converted to moment magnitude. These different magnitude scale conversions are discussed further below based on the following simplified process. First, magnitudes of any type less than 4.5, with reference to the Heaton et al. (Reference 346) correlation plot described below, were assumed to be equivalent to M_w directly. For magnitudes of any type of 4.5 and larger, the following simplified process was followed:

- **Moment magnitudes were already moment magnitudes, so no conversion was necessary.**
- **Surface-wave magnitudes M_s were converted to M_w considering the Ekstrom and Dziewonski relations (Reference 240) and the Kanamori relation (Reference 269).**
- **Body-wave magnitudes m_b were converted to M_s considering the Garcia et al. relation (Reference 254)~~,~~ and then the above process of conversion from M_s to M_w was followed.**
- **Intensity-based magnitudes in the Cuba catalog were considered equivalent to M_s magnitudes (Reference 254) and then the above process of conversion from M_s to M_w was followed.**

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- **All other magnitude types were considered equivalent to m_b and then the above process to convert from m_b to M_s to M_w was followed.**

The Heaton et al. (Reference 346) magnitude correlations, following similar work by Kanamori (Reference 347), plot various magnitude scales relative to M_w for a seismotectonic setting region (e.g., western U.S. region or other active plate boundary regions), more similar to the Caribbean than the CEUS region, allowing conversion of Caribbean earthquake magnitudes in other scales into moment magnitude. These magnitude-scale plots graphically show relationships between the moment magnitude scale and several other magnitude scales, applicable magnitude ranges,
and how they are nonlinear to reflect the saturation of some of the magnitude scales.

Following is a detailed summary of the approach that was used to provide specific magnitude scale conversions in order to estimate M_w for the Phase 2 earthquake catalog.

Specific Magnitude Scales Used in the Phase 2 Earthquake Catalog

The Phase 2 earthquake catalog developed for the Caribbean region contains 19 different measures of size for earthquakes that have occurred in notably different tectonic regions as compared to the CEUS region.

- **Moment magnitudes (M_w)**

The moment magnitude scale, which provides an estimation of total energy released in an earthquake, was the preferred magnitude scale in the Caribbean Phase 2 catalog under the rationale given above. Therefore, for all earthquakes in Phase 2 earthquake catalog that were originally reported in the M_w magnitude scale, these M_w values were directly included in the catalog.

- **Surface-wave magnitudes (M_s)**

The surface-wave magnitude (M_s) scale is commonly used for shallow events larger than M_s 5.0 (References 347 and 350) which, by definition, are earthquakes where surface waves may have been generated. Since the surface-wave magnitude gives the poorest results for small earthquakes or those deep or at intermediate depth, there are relatively few earthquakes of this type of magnitude scale in the Phase 2 catalog. For those reported earthquakes with M_s less than 4.5, these M_s magnitude scales were considered to be numerically equivalent to M_w. For M_s values equal to or greater than 4.5, the 1988 global surface-wave magnitude to average seismic moment (M_o) conversion relations of Ekstrom and Dziewonski (Reference 240) and then the seismic moment–to–moment magnitude conversion relation of Kanamori (Reference 269) was used to convert surface-wave magnitudes to M_w in the Phase 2 earthquake catalog development.

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- **Body-wave magnitudes (m_b)**

The Heaton et al. (Reference 346) m_b-M_w magnitude correlation plot suggests that body-wave magnitude (m_b) less than about 4.5 are consistent with M_w, and thus, they were assumed to be numerically equivalent to M_w for the Caribbean region. This consideration is also consistent with USGS Open File Report 97-464 (Reference 350) for body-wave magnitudes in the western US region.

As may also be seen in the Heaton et al. (Reference 346) magnitude correlation plot, there is an issue of saturation of the m_b scale beginning with magnitudes larger than ~~about~~ approximately 5.0. The m_b scale stops increasing with increasing earthquake size at about magnitude 6.4 corresponding to a moment magnitude of ~~about~~ approximately 7.5. Therefore, for m_b magnitudes of 4.5 and larger the magnitude conversion relation for m_b to M_s from the Garcia et al. study (Reference 254) was used, and then the M_s to M_w scaling, discussed above, was applied for these larger m_b values in the Caribbean Phase 2 catalog.

- **Intensity-based magnitudes (M_I and M_k) in the Cuba catalog**

The majority of earthquakes in the Cuba catalog have an estimate of intensity-based magnitude, M_I and M_k, as discussed in the Garcia et al. study (Reference 254). Both of these magnitude types are considered to be correlated to coda or duration magnitudes [see below]. For the magnitude conversion process, where there were no region-specific magnitude conversion relations for intensity-based magnitudes, as well as none for coda- or duration-magnitudes, to M_w, these M_I and M_k magnitudes were taken as equivalent to M_w for magnitudes less than 4.5, following Heaton et al. (Reference 346), and equivalent to M_s for magnitudes 4.5 and larger, following the Garcia et al. study (Reference 254). The M_s magnitude scale values were then converted to M_w~~,~~ as described above.

- **Local, Duration, and Coda magnitudes (M_L, M_d, DR and M_c)**

The local magnitude (M_L), duration magnitude (M_d) ~~[~~sometimes designated "DR" or "M_D" in the National Geophysical Data Center database (NGDC)~~]~~ database and coda magnitude (M_c) are three types of measurements for earthquakes that are used to determine the local magnitudes and are conventionally considered equivalent. The instrumental M_c and M_d are typically reported for small and moderate magnitude earthquakes less than ~~about~~ approximately 6.0, while it is found that M_L is also reported for larger earthquakes up to about 7.0. These three magnitude scales in the Phase 2 earthquake catalog, which are provided by different seismic networks with varying operational histories and different station calibrations, are comparable on average to M_w for magnitudes less than 4.5 in the Phase 2 earthquake catalog (References 346 and 350). Nuttli and Herrmann (Reference 351) report that M_L and m_b values are nearly equal in the western United States. Given the common equivalence of M_L, M_d, and M_c magnitudes~~,~~ and the Nuttli and Herrmann observation, these magnitudes when larger than 4.5 are considered equivalent to m_b and converted to M_w~~,~~ as detailed above.

- **Broad-band body-wave magnitudes (m_B).**

There are also some earthquakes larger than 6.0 in the Phase 2 catalog that are designated broad-band body-wave magnitude (m_B). The main advantage of m_B magnitude scale rather than M_s is its applicability to both shallow and deep earthquakes. These m_B magnitude-scale events in the Phase 2 catalog are considered to be equivalent to M_s over the applicable magnitude range of events between about 6.0 and 8.0 (References 346 and 347), and then converted to M_w~~,~~ as described above.

- **Intensity-based magnitudes ($M(I_o)$), not in the Cuba catalog**

These magnitudes are estimated from maximum intensity (I_o) using the Gutenberg-Richter (Reference 345) relationship, which correlates to local magnitude M_L. Therefore, these earthquakes are converted from M_L to M_w~~,~~ as described above.

- **Equivalent local and coda-duration magnitudes (m_l, m_2, fm, xm, MA, and m_t)**

The ~~Puerto Rico Seismic Network [~~PRSN~~]~~ earthquake catalog, which locally collects the events in the Caribbean region, has recorded earthquakes whose magnitudes are determined using different local magnitude relations (m_1 and xm), as well as different magnitude-coda duration relations (m_2 and fm) – the xm and fm magnitudes are determined using the earthquake location program Hypoellipse (Reference 348). An event less than magnitude 3.0, excluded from the Phase 2 catalog, is reported as a type MA magnitude, attributed to PRSN – it may be expected that this small magnitude is one of or an average of the other PRSN magnitudes. Also reported in the PRSN catalog are earthquakes from the Jamaica Seismic Network ~~[~~(JSN)~~]~~, which determines average coda magnitudes (m_t) based on the regression between standard m_b and log of the signal duration (Reference 352).

As for local, duration, and coda magnitudes described above when greater than 4.5 these magnitudes are considered equivalent to m_b and are converted to M_w.

- **Unspecified magnitudes (nk and MG)**

Finally, there are some earthquakes in the Phase 2 catalog with unknown magnitude scale labeled "nk" or " " (e.g., the computational method was unknown and could not be determined from published sources)~~,~~ as well as an unspecified magnitude scale labeled "MG" (e.g., magnitudes either have been reported by the contributor without listing the type [e.g., "MG 3.5"] or have been computed using procedures~~,~~ which are not defined by the magnitude types routinely reported). These types of earthquakes were considered to be equivalent to m_b for small ($3 \leq M_w < 4.5$) and moderate ($4.5 \leq M_w < 6$) earthquake magnitudes in the Phase 2 catalog. Lamarre and Shah (Reference 349) have plotted the unspecified magnitude scales versus M_L for the NGDC database used in the Phase 2 earthquake catalog, and have indicated that it is very closely approximated by the M_L and m_b for earthquakes in magnitude range less than about 5.0. Taken as equivalent to m_b, these magnitudes were converted to M_w~~,~~ as described above.

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Since the types of data used in determination of these magnitude scales are very different from region to region (e.g., observational errors and intrinsic variations in source properties), it is important to establish tectonically-similar regional magnitude scale correlations (Reference 347). Therefore, it should be emphasized that this magnitude conversion process was not incorporated into Phase 1 earthquake catalog that includes all events in the CEUS region with a notably different tectonic environment as compared to the Caribbean region (Section 2.5.1).

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The following references will be added to FSAR subsection 2.5.2.7 in a future COLA revision.

344. Chiou, B., R. Darragh, N. Gregor, and W. Silva (2008). NGA Project Strong-Motion Database, Earthquake Spectra v.24, pp.23-44, 2008.

345. Gutenberg, B. and C. ~~F.~~ Richter (1956). Earthquake M~~m~~agnitude, I~~i~~ntensity, E~~e~~nergy and A~~a~~cceleration. Bulletin of the Seismology Society of America, Vol~~v~~. 46, pp 105-145, 1956.

346. Heaton, T., F. Tajima and A. W. Mori (1986). Estimating G~~g~~round M~~m~~otions U~~u~~sing R~~r~~ecorded A~~a~~ccelerograms. Surveys in Geophysics, Vol~~v~~.8, p 25-83, 1986.

347. Kanamori, H.~~ (1983).~~ Magnitude S~~s~~cale and Q~~q~~uantification of E~~e~~arthquakes. ~~in~~ S. Duda~~, S.J.~~ and K. Aki (eds.), Quantification of Earthquakes. Tectonophysics, Vol~~v~~. 93, p185-199.

348. Lahr, J.~~C. (1999)~~, HYPOELLIPSE: a C~~c~~omputer P~~p~~rogram for D~~d~~etermining L~~l~~ocal E~~e~~arthquake H~~h~~ypocentral P~~p~~arameters, M~~m~~agnitude, and F~~f~~irst-M~~m~~otion P~~p~~attern: U.S. Geological Survey Open-File Report 99-23, version 1, 1997~~119 p~~.

349. Lamarre, M. and ~~Shah,~~ H. ~~C~~Shaw~~.~~, ~~(1988).~~ Seismic H~~h~~azard E~~e~~valuation F~~f~~or S~~s~~ites in California: Development of an E~~e~~xpert S~~s~~ystem. Report No. 85. 1988~~180p~~.

350. Mueller, C., M. Hopper, and A. Frankel (1997). Preparation of earthquake catalogs for the National Seismic Hazard Maps—Contiguous 48 States: U.S. Geological Survey Open-File Report 97–464, 36 p.

351. Nuttli, I~~O. W~~. and R.~~ B.~~ Herrmann (1982). Earthquake M~~m~~agnitude S~~s~~cales. J. Geotech. Eng. Div. ASCE, Vol~~v~~.108, p 783-786, 1982.

352. Wiggins-Grandison, M.~~ D. (2001).~~, Preliminary R~~r~~esults from the N~~n~~ew Jamaica Seismograph N~~n~~etwork. Seismological Research Letters, ~~v~~Vol.72, p525-537, 2001.

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ASSOCIATED COLA REVISIONS:

FSAR Subsection 2.5.2.4.4 will be revised in a future COLA revision as follows:

2.5.2.4.4 New Seismic Source Characterizations

To complement the updated EPRI seismic source model described above, three new seismic source characterizations are included for analysis. These three new source characterizations are:

- Supplemental seismic source zones that fill the area of the site region beyond the area covered by the original EPRI source model (Subsection 2.5.2.4.4.1).
- New, post-EPRI characterization of the Charleston seismic source (Subsection 2.5.2.4.4.2).
- New, post-EPRI characterization of seismic sources located in the Cuba area and the North America-Caribbean plate boundary region (Subsection 2.5.2.4.4.3).

An additional post-EPRI model is the USGS National Seismic Hazard Mapping Project (NSHMP) (Reference 300), which characterizes seismic sources throughout the continental United States using multiple classes of earthquake source models. While the NSHMP source model is described below, source parameters from this model are not included in the updated PSHA for the Turkey Point Units 6 & 7 site. The general approach used by the USGS for modeling distributed seismicity in the CEUS is based on gridded, spatially smoothed seismicity in large background zones. Seismic sources within the ~~Central and Eastern United States~~ (CEUS) most relevant to the Turkey Point Units 6 & 7 site are modeled with: (1) a regional uniform background source model dividing the Extended Margin of the CEUS from the Craton; (2) special zones accounting for variability in catalog completeness, seismicity, maximum magnitude, and b-value, such as the uniform source zones for the Eastern Tennessee and New Madrid seismic zones; and (3) finite fault sources, such as those included for the New Madrid and Charleston seismic sources.

The 2008 NSHMP earthquake sources are depicted in Figure 2.5.2-~~258~~ 276. Significant changes from the 2002 NSHMP model of seismic hazard in the CEUS (Reference 251) include: (1) uncertainty in the maximum magnitude (Mmax) assigned to Mmax zones (e.g., e~~E~~xtended m~~M~~argin); (2) revised geometry of the Charleston seismic source zones; and (3) revised magnitudes, rates, and geometry for the New Madrid seismic source. As a result of these updates, the 2008 NSHMP characterizes Mmax for the Extended Margin and Craton as weighted distributions ranging between M7.1 - 7.7 and M6.6 - 7.2, respectively. The two areal zones defining the Charleston source are both assigned Mmax distributions of M6.8 - 7.5 with a recurrence interval of 550 years, unchanged from the 2002 NSHMP. The USGS NSHMP Charleston seismic source update is discussed in ~~FSAR~~ Subsections 2.5.2.4.4.2.2 and 2.5.2.4.4.2.3.

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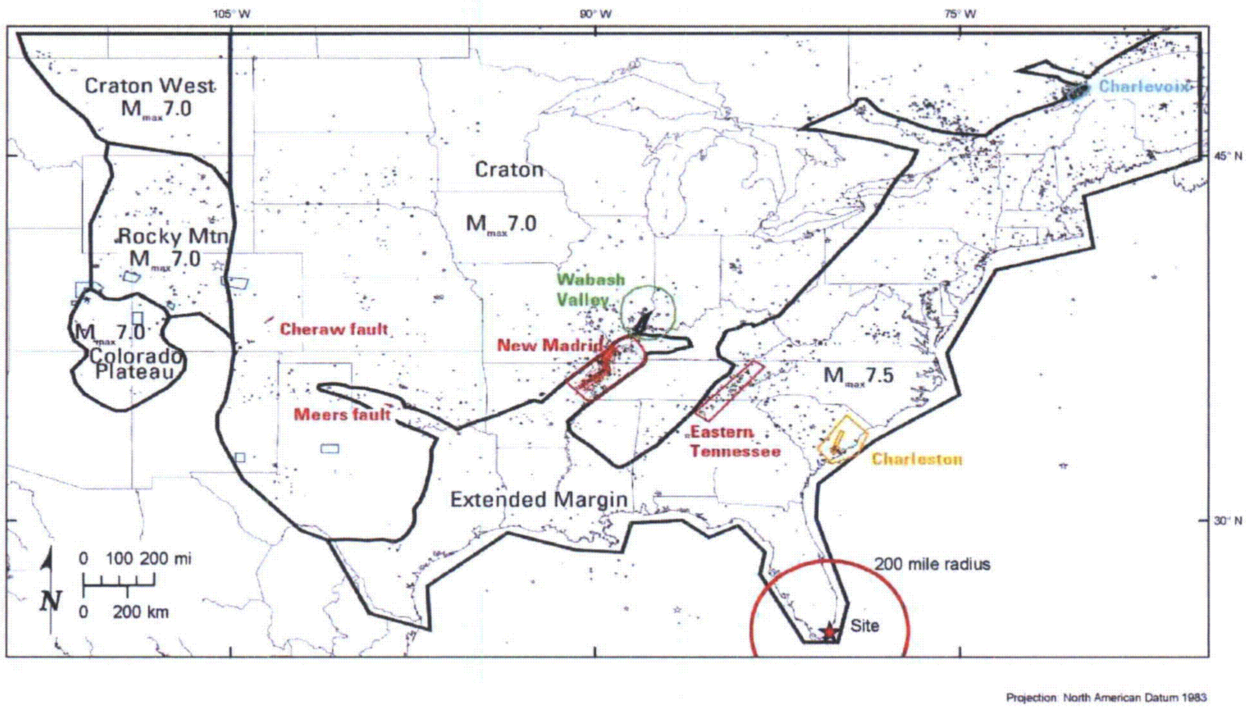
2.5.2.4.4.1 Supplemental Source Zones

The following new figure will be included in a future COLA revision.

Figure 2.5.2-276 ~~USGS National Seismic Hazard Map Earthquake Sources~~Seismic Sources from the U.S. Geological Survey's 2008 National Seismic Hazard Mapping Project



Source: ~~Petersen et al. 2008 FSAR~~ Reference 300

Attachment 3

Mark-ups for the Associated COLA Revisions for 2.5.3 RAIs

(Total Pages - 6)

Legend of changes on the attached RAI mark-ups:
Red text indicate the changes that were provided in the revised response to the RAI by FPL Letter L-2013-306
Green text indicates changes in COLA Revision 5 from the revised RAI response

2.5.3 Roadmap

RAI Number	***Associated COLA Revisions (Red Text and black strike through)***		***Explanation of changes from RAI Response to COLA Revision 5 (Green Text, e.g., FPL Initiated Changes, i.e., technical editing, FPL additional work,)***	***Comments***
	COLA Revision	Revision Number		
02.05.03-1	No	N/A		
02.05.03-2	Yes.	5	In the second paragraph of the RAI response, revised text for FSAR Subsection 2.5.3.7, the additional sentence added to the end of the paragraph, were added as a result of work performed by FPL on non-tectonic deformation to expand and revise text as a result of an April 25, 2013 public meeting. Remaining green text changes are editorial in nature and were made to be consistent with the FSAR style or technical wording additions or corrections based on a final FPL review.	
02.05.03-3	Yes	5	Due to a misplacement of a file, the most current revision of revised response was not used when generating the revised response. The COLA content utilized the correct revision.	
02.05.03-4	Yes	5	Green text change is editorial in nature and was made to be consistent with the FSAR style.	

Marked-up FPL Revised Response
to NRC RAI No. 02.05.03-2 (eRAI 5875)

ASSOCIATED COLA REVISIONS:

Reference 790 in FSAR Subsection 2.5.1.3 will be revised as follows in a future COLA revision:

790. ~~Uchupi, E., The Atlantic Continental Shelf and Slope of the United States:*Topography*, Professional Paper 529, U.S. Geological Survey, 1968. C~~ **Uchupi, E., Shallow structure of the Straits of Florida: *Science*, ~~v~~Vol. 153, No. 3735, pp. 529-531, 1966.**

The second paragraph in FSAR Subsection 2.5.3.1.2 will be revised as follows in a future COLA revision:

In addition to the geologic mapping described above, the U.S. Geological Survey has published a compilation of all known or suggested Quaternary faults, liquefaction features, and possible tectonic features in the Central and Eastern United States (References 203 and 235) (Figure 2.5.3-201). **These compilations did not extend into the Bahamas or Cuba, and therefore do not depict faults in these regions. Within the boundaries of these compilations,** ~~These compilations do not identify any~~ **no** Quaternary tectonic faults or tectonic features **are identified** ~~with~~in the site region or site area. However, one potential Quaternary feature, Grossman's Hammock, is located approximately 20 miles northwest of the site, but a ground-penetrating radar study provides evidence that the feature has no tectonic offset (Reference 217); ~~FSAR~~ Subsection 2.5.3.2 describes this feature in detail. The U.S. Geological Survey studies (References 203 and 235) classify Grossman's Hammock as a non-tectonic feature (Figure 2.5.3-201).

The text in FSAR Subsection 2.5.3.7 will be revised as follows in a future COLA revision:

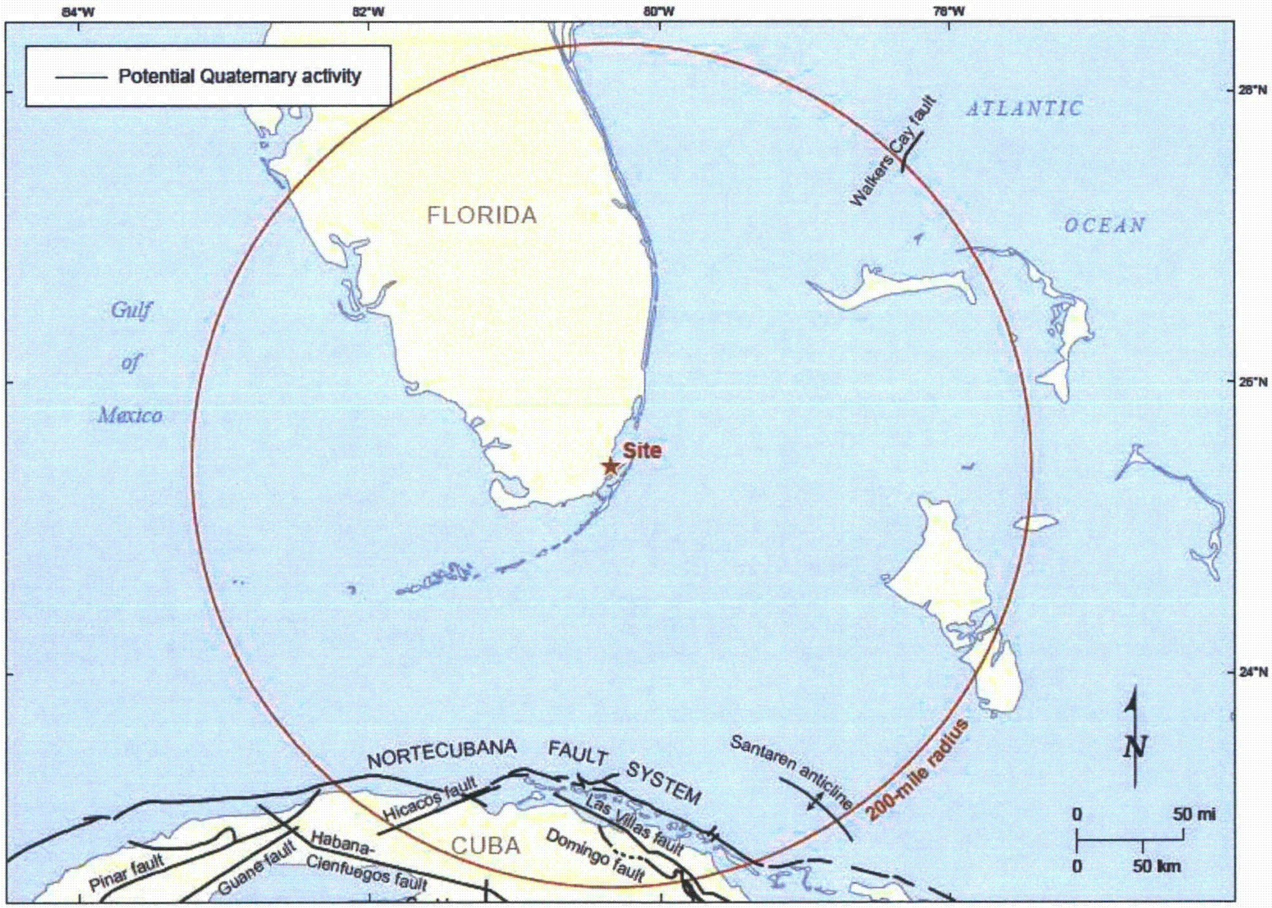
2.5.3.7 Designation of Zones of Quaternary Deformation in the Site Region

Results of the subsurface exploration program at the site indicate continuous, horizontal stratigraphy that precludes the presence of Quaternary faults, folds, or structures related to tectonic deformation at the site (Figure 2.5.1-335). There are no zones of Quaternary deformation associated with tectonic faults requiring detailed investigation within the site area (Figure 2.5.1-335). Field reconnaissance, review, and interpretation of aerial photography, and review of published literature performed, do not reveal any evidence for Quaternary tectonic deformation, including paleoliquefaction, within the site, site area, or site vicinity. Within the site region, seismicity and potential Quaternary deformation are restricted to the **faults within the** Cuba areal source zone, approximately ~~160~~ **140** miles south of the site**, and possible deformation associated with the Walkers Cay fault and Santaren anticline (Figure 2.5.3-205).** No sand blows or paleoliquefaction features have been identified in the published literature for the site region. **Karstic dissolution of limestone is a source of non-tectonic Quaternary deformation found in Florida and the Bahamas within the site region (Subsection 2.5.3.8.2.1 and 2.5.4.4.5).**

FSAR Figure 2.5.3-205 "Potential Quaternary Tectonic Structures in the Site Region" will be added to Subsection 2.5.3 in a future COLA revision as indicated below:

Marked-up FPL Revised Response
to NRC RAI No. 02.05.03-2 (eRAI 5875)

Figure 2.5.3-205 Potential Quaternary Tectonic Structures within the Site Region



~~**Figure 2.5.3-205. Potential Quaternary Tectonic Structures within the Site Region**~~

~~**Source: Modified from: References 2.5.1- 477, 443, 770, 494, 448, 474 and 439**~~

Marked-up Revised Response
to NRC RAI No. 02.05.03-3 (eRAI 5875)

ASSOCIATED COLA REVISIONS:

The first paragraph in FSAR Subsection 2.5.3.2 will be revised as follows in a future FSAR revision:

Field reconnaissance, review and interpretation of aerial photography and review of published literature did not reveal any evidence for **active** tectonic deformation within the site vicinity or site area. No **active** faults or geomorphic features ~~indicative of~~ **related to active** faulting have been mapped ~~at the surface~~ **in the site vicinity, site area, or the site** (Figures 2.5.1-334, 2.5.1-336, 2.5.1-337, 2.5.1-338, 2.5.1-339, 2.5.1-340, 2.5.1-341, and 2.5.1-342) ~~in the site vicinity, site area, or the site~~. **Although a** ~~**sinistral**~~ **basement fault has been interpreted** ~~**postulated**~~ **to exist** ~~**northwest of the site**~~ **within the site vicinity (Figure 2.5.1-253), there is no evidence to suggest that this buried pre-Cretaceous fault is active or represents a surface faulting hazard (Figures 2.5.1-261** and **2.5.1-263)** ~~**no faults buried at depth within the site vicinity are expected to deform the surface**~~ **(Subsection 2.5.1.1.1.3.2.1). Therefore, no capable faults are known to exist within the site vicinity.** In addition, no seismic activity has been reported within the site vicinity (Subsection 2.5.2), and bedding is horizontal and undisturbed (Subsection 2.5.1.2.3). No salt domes, Quaternary volcanic features, or glacial sources of deformation occur in the site vicinity (Figures 2.5.1-201 and 2.5.1-237) (Subsections 2.5.3.8.2.1, 2.5.1.1.2.1.1, 2.5.1.1.1.2.1.1, 2.5.1.2.4, and 2.5.1.2.3). Non- tectonic deformation features in the site area are interpreted to be “potholes” caused by surficial dissolution (Subsections 2.5.1.2.4 and 2.5.4.4.5).

Marked-up Revised Response
to NRC RAI No. 02.05.03-4 (eRAI 5875)

ASSOCIATED COLA REVISIONS:

The last paragraph of Subsection 2.5.3.2 will be revised as follows in a future version of the FSAR.

The second feature beyond the site vicinity investigated as part of geologic field reconnaissance includes possible faults identified from borehole data in the McGregor Isles area near Ft. Myers, 120 miles northwest of the site. Based on gamma-ray logs from several wells, Sproul et al. (Reference 230) interpret faulting of pre-upper Hawthorn (Miocene) strata. In spite of their interpretation that overlying upper Hawthorn and younger strata are unfaulted, Sproul et al. (Reference 230) suggest possible geomorphic indicators of faulting. **Sproul et al. (Reference 230) noted a bend in the coastline near the westward projection of a few of the subsurface faults and that a stream between two of the faults is aligned subparallel to the faults.** However, despite the landscape being heavily modified by urban development, field reconnaissance and inspection of aerial photography reveal no evidence for faulting at the surface, **and published studies identified no surficial faulting in the area (Reference 240).**

A new reference will be added to Subsection 2.5.3.9 in a future version of the FSAR.

240. Scott, T. M., and Missimer, T. ~~M.~~, *The Surficial Geology of Lee County and the Caloosahatchee Basin*, Florida Geological Survey Special Publication, Issue 49, p. 17-20, 2001.

ASSOCIATED ENCLOSURES:

None