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UPDATED SEISMIC HAZARD ANALYSES FOR NUCLEAR PLANTS IN THE CENTRAL AND EASTERN US

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INTRODUCTION

Updated seismic hazard analyses are being conducted for nuclear power plants (NPPs) in the central and eastern US (CEUS) under a project funded by nuclear utilities through the Electric Power Research Institute. The purpose of the project is to update seismic hazard estimates using updated ground motion equations for the CEUS. These equations use ground-motion models and earthquake ground motion data collected recently from stable continental regions in central and eastern North America (CENA). As part of the project, seismic hazard calculations were conducted at 7 test sites, to evaluate the updated ground motion model and compare results to hazard estimates using previously published ground motion equations.

UPDATED GROUND MOTION EQUATIONS

In the last decade, seismic hazard estimates for nuclear power plant license applications in the CEUS have used ground motion equations published by EPRI (2004, 2006). Since the publication of these equations, important research on ground motions in CENA has been published, and numerous earthquake ground motions have been recorded in CENA. For example, the Mineral, Virginia earthquake of August 23, 2011 (**M** 5.8) produced a number of recordings, and the transportable USArray network recorded many small earthquakes. An important part of the data collection and evaluation was to remove site-specific effects on ground motion, in order to convert ground motion records to rock conditions. This was done using data on shear-wave velocity obtained from surface measurements at many recording sites. Details of the data collection and conversion process are given in Salomone et al. (2013).

The EPRI (2004, 2006) ground motion model was updated as part of this project, using the same structure but revising ground motion estimates and associated weights. The EPRI (2004, 2006) ground motion model had 3 clusters of estimates for background sources (called general, non-rift sources, or background sources) and an additional cluster for sources of large earthquakes (called non-general, rift sources). This cluster structure was maintained, and the cluster best-estimate equations, and alternative equations, were updated to reflect more recent research and empirical data. The research addresses topics such as the earthquake stress parameter appropriate for CENA earthquakes, the effect of rupture dimensions on nearby ground motions, the shape of the earthquake source spectrum, and attenuation of ground motion at distances near 100 km (and whether the Mohorovičić discontinuity in the Earth's crust plays a role in attenuation), and the role and value of parameter κ in affecting ground motion. Details of the model update process are given in Salomone et al. (2013).

The project was conducted as a SSHAC Level 2 project, per the recommendations of SSHAC (1997). Researchers were contacted and assembled at workshops to learn their latest interpretations, and the EPRI (2004, 2006) models were updated within the cluster structure. Weights on alternative clusters, and weights on equations within clusters, were estimated based (in part) on comparisons of model estimates to empirical data recorded in CENA. These data were converted to rock conditions, as noted above, in order to compare to rock ground motion estimates. In this way, the alternative ground motion clusters, the alternative equations within each cluster, and the weights on these alternatives, represented the center, body, and range of the technical defensible interpretations (see for example USNRC, 2012b)

Following EPRI (2004, 2006), ground motion estimates were made for “mid-continent region” seismic travel paths and for “Gulf region” seismic travel paths, the latter reflecting travel paths near the Gulf of Mexico. The effect of the Gulf region on ground motion attenuation was reevaluated, as was the geometry of the Gulf region. The general observation is that ground motions in the Gulf region are lower than ground motions for the mid-continent region, when the earthquake magnitude and distance are the same, and when local site conditions are the same. A separate set of equations was developed within the same ground motion cluster structure, to reflect this difference. Details of the Gulf region definition are given in Salomone et al. (2013).

These updates to the ground motion model are herein collectively referred to as the “Update” model. The EPRI (2004, 2006) model is referred to as the “EPRI-0406” model.

SEISMIC SOURCES AND THEIR CHARACTERISTICS

The seismic sources used in the seismic hazard calculations were developed under a separate project sponsored by the Electric Power Research Institute, the US Nuclear Regulatory Commission, and the US Department of Energy (CEUS, 2012). A brief description of those seismic sources, and their effect on seismic hazard compared to alternative seismic sources, is given in McGuire, Toro, and Kassawara (2013). Thus the seismic hazard results shown here represent the combined effect of the new seismic source model and the updated ground motion model.

SEISMIC HAZARD CALCULATIONS

A previous study (CEUS, 2013) calculated seismic hazard at 7 test sites in the CEUS using the EPRI (2004, 2006) equations. The 7 test sites were chosen to represent a range of seismic hazard conditions in the CEUS (representing a range of contribution to hazard from background sources and from sources of large, infrequent earthquakes). Seismic hazards were calculated at the same 7 test sites under the current project using the Update model, for comparative purposes. All seismic hazard calculations at the 7 test sites were made for hard rock conditions.

Figure 1 compares contribution to total mean hazard for peak ground acceleration (PGA) by seismic source at the test site located at Chattanooga, Tennessee. This figure shows that background sources are the dominant contributor to PGA hazard, but that the New Madrid Fault Source (NMFS) also has an important contribution. The Update model is plotted with solid curves, the EPRI-0406 model is plotted with dashed curves. For PGA, the total mean hazard curves are similar, but the Update model indicates somewhat less hazard for the NMFS than the EPRI-0406 model.

Figure 2 compares contribution to total mean hazard for 1 Hz spectral acceleration (SA) by seismic source at Chattanooga. This comparison indicates that the Update model gives lower hazard than the EPRI-0406 model, both for background sources and for the NMFS. Note that both the Update model and the EPRI-0406 model use 3 clusters of equations to represent ground motions for background sources, and 4 clusters of equations to represent ground motion for the NMFS.

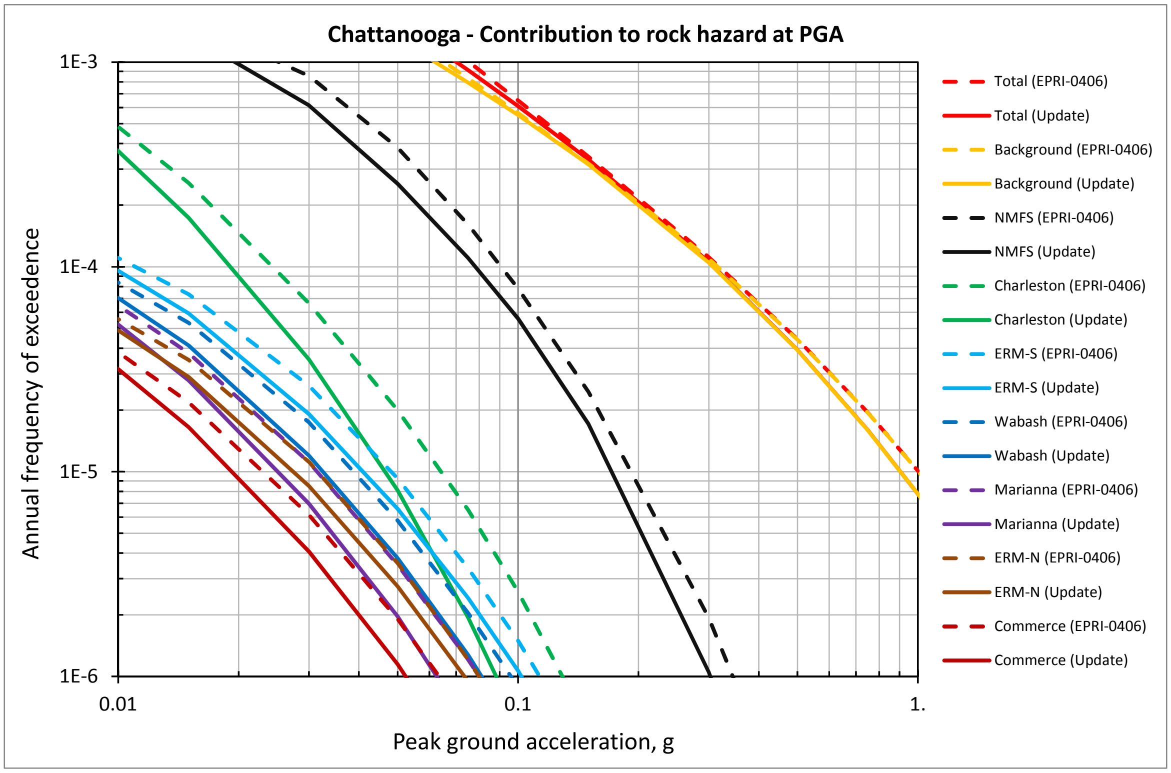

Figure 1: Contribution by source to PGA mean rock hazard at Chattanooga

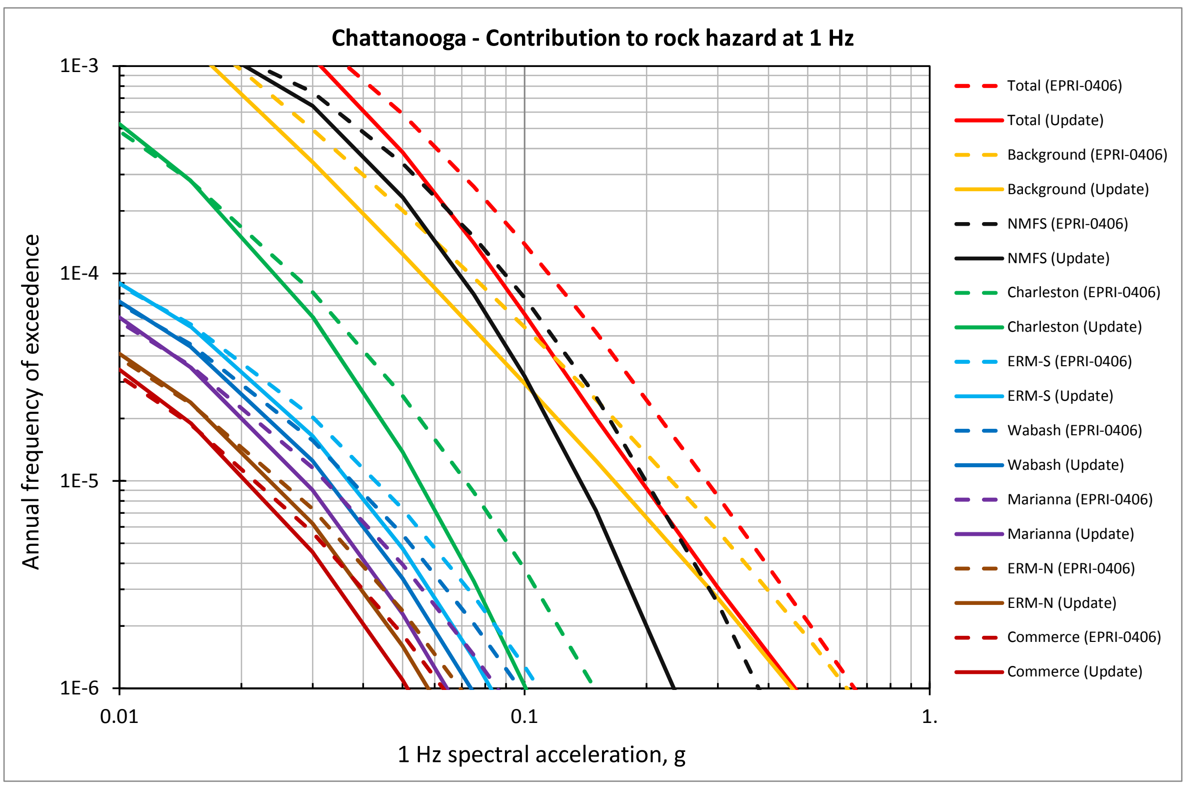

Figure 2: Contribution by source to 1 Hz mean rock hazard at Chattanooga

Seismic hazards can be compared for a range of spectral frequencies using uniform hazard response spectra (UHRS), and Figure 3 shows such spectra for the Chattanooga site for UHRS corresponding to 10^{-4} and 10^{-5} annual frequencies of exceedence. These spectra are plotted at the 7 spectral frequencies for which ground motion equations were available in the EPRI-0406 model, and which were investigated with the Update model: 100 Hz (taken as equivalent to PGA), 25 Hz, 10 Hz, 5 Hz, 2.5 Hz, 1 Hz, and 0.5 Hz. The observation made in Figure 1 regarding PGA hazard estimates being similar for the Update model and the EPRI-0406 model also applies to the UHRS in Figure 3. At other spectral frequencies (25 Hz and lower), the Update model indicates lower UHRS amplitudes, and this is consistent with the seismic hazard comparison shown in Figure 2 for 1 Hz SA.

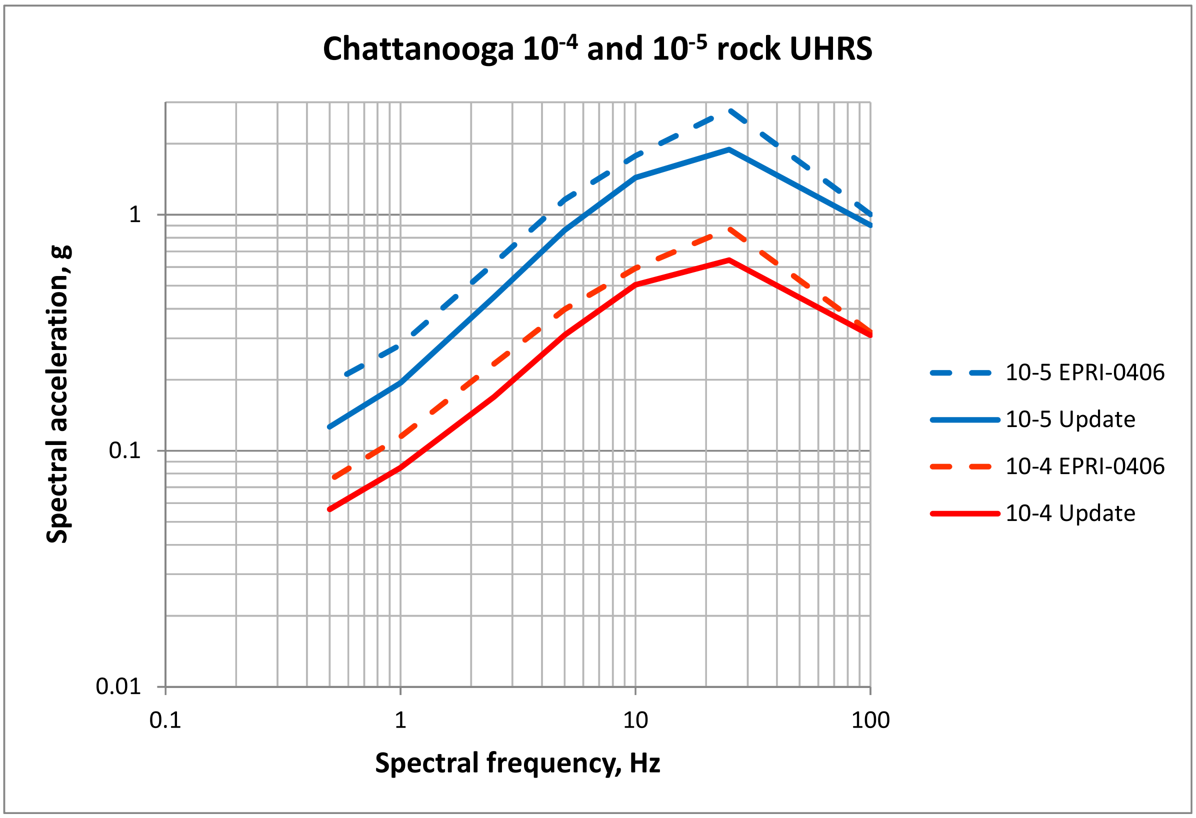

Figure 3: 1E-4 and 1E-5 rock UHRS for Chattanooga

Qualitatively, a similar comparison to that shown in Figure 3 for Chattanooga was obtained at most of the other test sites. That is, the Update model does not greatly affect PGA hazard estimate for 10^{-4} and 10^{-5} annual frequencies of exceedence, compared to the EPRI-0406 model. However, the Update model indicates lower UHRS amplitudes at other spectral frequencies (25 Hz and lower).

Figure 4 compares contribution to total mean hazard for peak ground acceleration (PGA) by seismic source at the test site located at Houston, Texas. Solid curves show hazard contributions for the Update model, dashed curves show contributions for the EPRI-0406 model. Houston is in the Gulf region, and as a result, several changes have occurred between the EPRI-0406 model and the Update model. First, for background sources, the Gulf equations are used for both models, and Figure 4 indicates that Gulf estimates of ground motion have increased for the Update model, compared to the EPRI-0406 model.

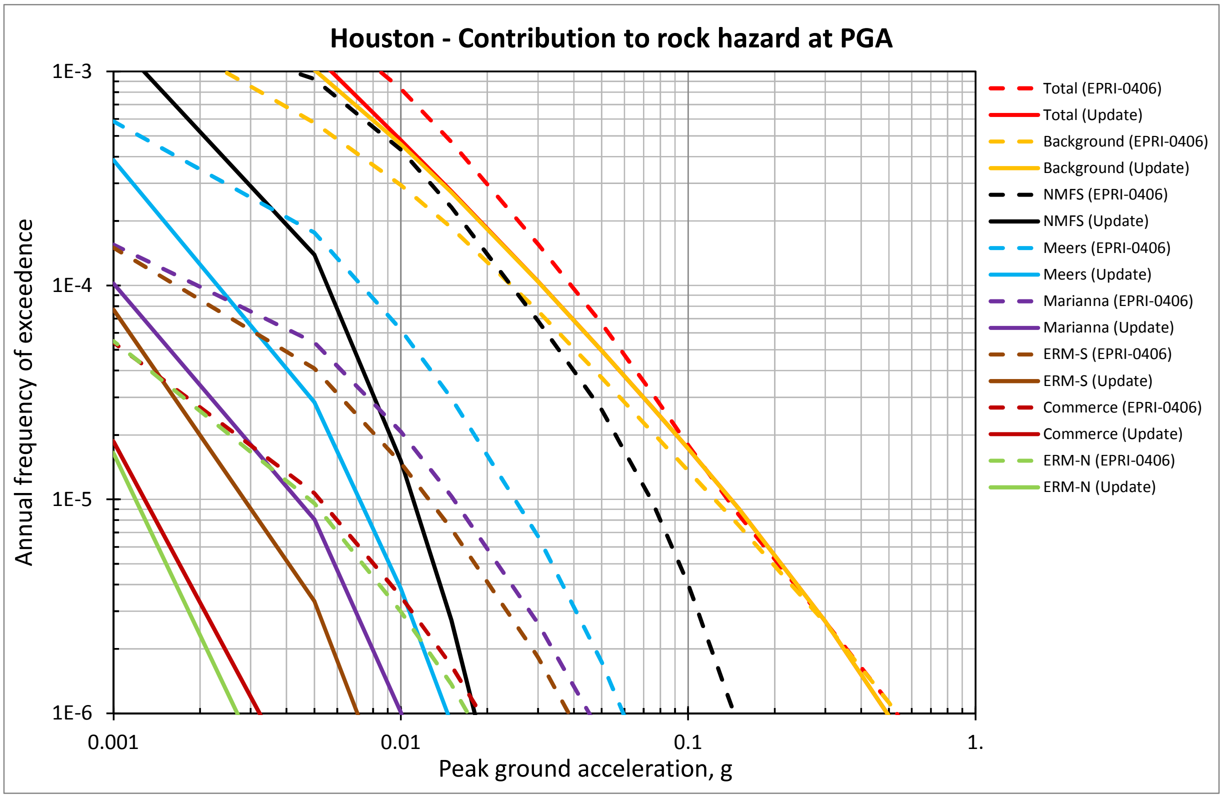

Figure 4: Contribution by source to PGA mean rock hazard at Houston

Second, a redefinition of the geometry of the Gulf region was stated in the Update model; the new Gulf region now includes most of the Mississippi embayment. As a result, seismic travel paths between the NMFS and Houston are entirely within the Gulf region, so Gulf equations have been used to calculate the hazard shown for the Update model in Figure 4. In the EPRI-0406 model's definition of the Gulf region geometry, the seismic travel path from the NMFS to Houston was approximately equal between the mid-continent and Gulf regions, so the mid-continent equations were used to characterize NMFS hazard at Houston (these equations indicated higher hazard). As a result of this redefinition of the Gulf region geometry, the PGA hazard at Houston with the Update model is lower than the PGA hazard with the EPRI-0406 model.

As a result of these two changes, the PGA mean hazard at Houston from the Update model is lower than the hazard from the EPRI-0406 model at the PGA amplitude corresponding to 10^{-4} annual frequency of exceedence. At high PGA amplitudes, the two hazard estimates are more similar, and they are about equal at the PGA amplitude corresponding to 10^{-5} annual frequency of exceedence.

Figure 5 shows the contribution by seismic source to 1 Hz SA hazard at Houston for the Update model and the EPRI-0406 model. At this spectral frequency, the NMFS dominates the hazard, and the use of the Gulf equations in the Update model gives lower hazard than the use of the mid-continent equations in the EPRI-0406 model, as discussed above regarding Figure 4.

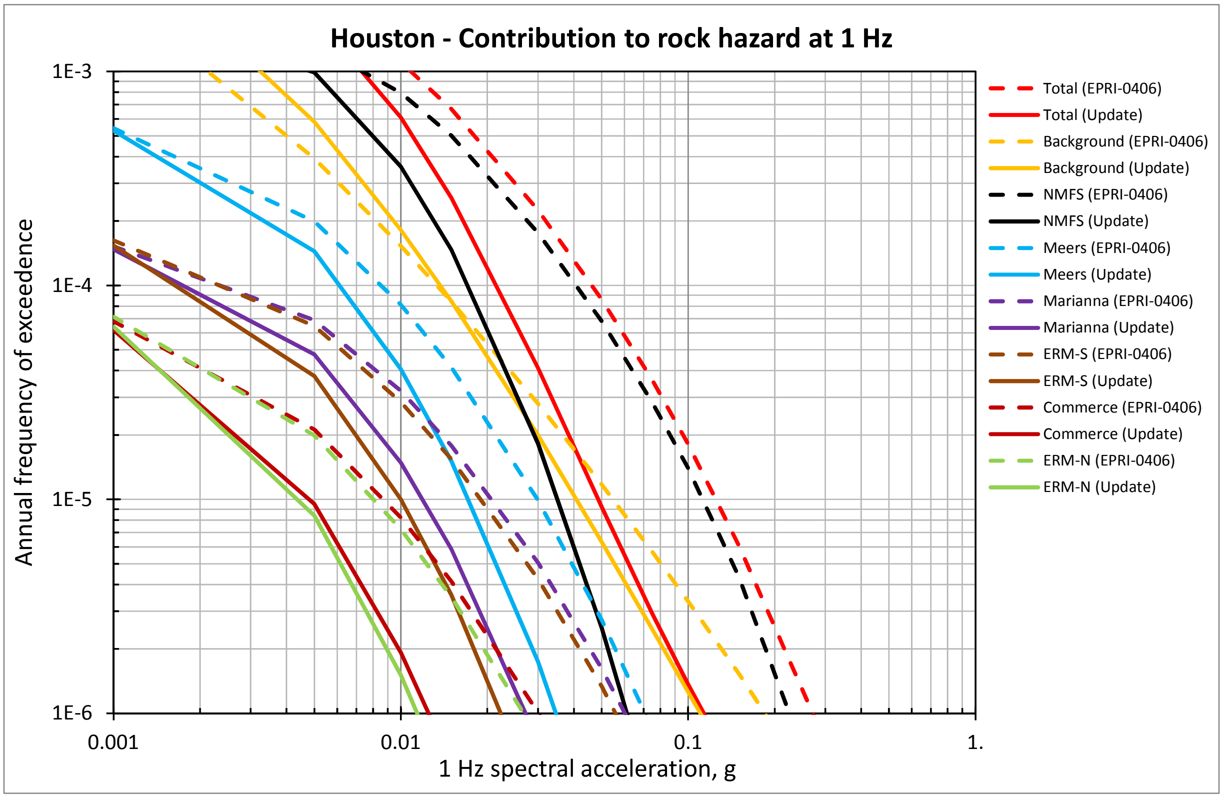

Figure 5: Contribution by source to 1 Hz mean rock hazard at Houston

Figure 6 compares 10^{-4} and 10^{-5} UHRS for the Houston site for the 2 models. This comparison indicates that the 10^{-4} UHRS for the Update model lies below the 10^{-4} UHRS for the EPRI-0406 model at all spectral frequencies. For the 10^{-5} UHRS, the Update model lies below the EPRI-0406 model except at PGA, where the spectra are about the same. These results are consistent with the total mean hazard curves shown for PGA and 1 Hz SA in Figures 4 and 5. Note that the reasons for the differences are more complicated for the Houston site than for other sites, because of the effect of the Gulf Region equations and the Gulf region geometry, as discussed above.

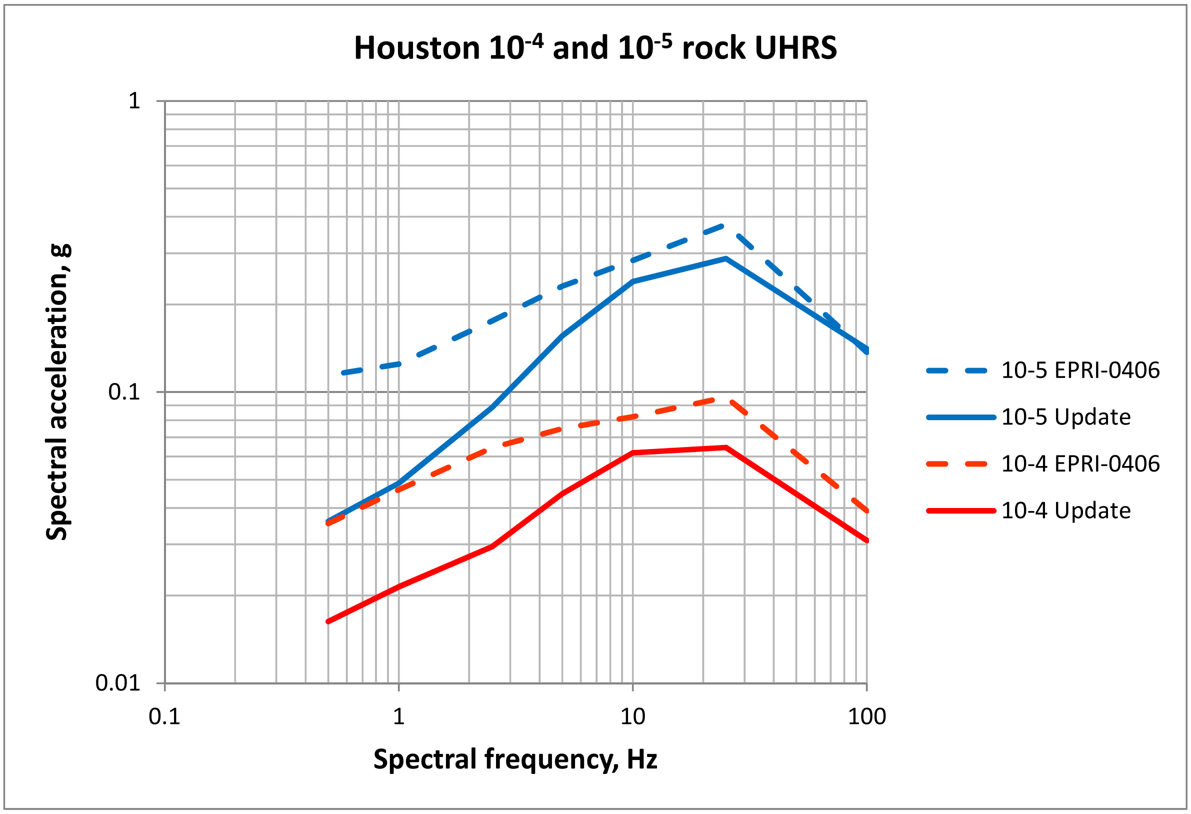

Figure 6: 1E-4 and 1E-5 rock UHRS for Houston

CONCLUSION

On-going studies of seismic hazard at nuclear power plants in the CEUS require the most up-to-date, well-founded models of ground motion equations and seismic sources. The current study by EPRI updates ground motion equations for the CEUS from the EPRI (2004, 2006) studies. These earlier equations have been used for nuclear power plant licensing applications in the CEUS, and have been accepted by the US Nuclear Regulatory Commission. The updated equations use moment magnitude as the earthquake size measure, which is the same magnitude scale use to characterize earthquakes in the recent seismic source characterization for the CEUS (EPRI, 2012) for RLME and background sources.

The updated ground motion model has been examined by calculating seismic hazard at a number of test sites in the CEUS, as illustrated here. This examination indicates that the updated model can be used for evaluation of nuclear power plant seismic hazard with confidence. This model will allow further studies to be made of ground motion effects on nuclear power plant risk with the best-available estimates of seismic hazard, in order to provide an informed response to regulatory requests (USNRC, 2012a).

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