ELECTRIC POWER RESEARCH INSTITUTE

EPRI (2004,2006) Ground Motion Model (GMM) Review Project

Nuclear Regulatory Commission
Public Meeting
August 16, 2012

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HIGHLIGHTS

- Provide review slides with SSHAC-required Phase 1 documentation;
- Present and Discuss PM, TI Team and PPRP Recommendation Regarding Phase 2;
- Task 2: Review Status and Conclusions of Ground-Motion Database, Review of New CEUS Ground Motion Prediction Equations (GMPEs), and Resource Expert and Proponent Interviews;
- Review Status and General Observations from Task 3: Obtain Shear Wave Velocity Measurements at Recording Stations;
- Discuss Results for Task 4: Test EPRI (2004, 2006) Ground Motion Model (GMM);
- Review Project Schedule and Discuss Path Forward

Decision Point 2 Questions

- Is the EPRI (2004, 2006) Ground – Motion Model (GMM) based on data, models and methods compiled and evaluated from 2002 to 2004 consistent with current (2012) data, models and methods?

- Should the EPRI (2004, 2006) GMM be updated before using it to calculate GMRS at existing nuclear power plants in response to the NRC RFI 50.54(f) letter dated March 12, 2012?

- Does the preponderance of evidence obtained from Phase 1 require that Phase 2 be completed to assess the seismic hazard differences obtained when using the old and updated EPRI (2004, 2006) GMM?

Basis for Recommendation

- Ground motion experts, who developed seven (7) of the thirteen (13) ground motion prediction equations (GMPEs) used in the EPRI (2004, 2006) GMM, recommended that their GMPEs be updated with newer models developed during the last ten (10) years.
- There are three new GMPEs developed by ground motion experts during the past ten (10) years that should be evaluated and possibly integrated into an update of the EPRI (2004, 2006) GMM.
- A new ground motion database for the Central and Eastern North America (CENA) is now available with nearly 28,000 earthquake recordings. Eighty percent (80%) of the earthquake records are from earthquakes that occurred after the development of the EPRI (2004, 2006) GMM in 2004.
- Comparison of these new data to the predictions by the EPRI (2004) GMM indicates that updating the EPRI (2004, 2006) GMM is warranted to better support the NTTF Recommendation 2.1 effort.

EPRI (2004, 2006) Ground-Motion Model

Table 3-5
Ground Motion Attenuation Model Weights in Each Cluster

Cluster No.	Model Type	Models	Weights[1]
1	Spectral, Single Corner	Hwang & Huo (1997)	0.037
		Silva et al. (2002) – SC-CS	0.192
		Silva et al. (2002) – SC-CS-S	0.148
		Silva et al. (2002) – SC-VS[1]	0.560
		Toro et al. (1997)	0.029
		Frankel et al. (1996)	0.034
2	Spectral, Double Corner	Atkinson & Boore (1995)	0.714
		Silva et al. (2002) DC	0.154
		Silva et al. (2002) DC-S	0.132
3	Hybrid	Abrahamson & Silva (2002)	0.336
		Atkinson (2001) & Sadigh et al. (1997)	0.363
		Campbell (2003)	0.301
4	Finite Source/Greens Function	Somerville et al. (2001) [1]	1.0

[1]The model weights have been rounded to three decimal places.

Task 2 Results: Literature Reviews and Interviews

- **Models No Longer Recommended by Developers:**

- Cluster No.1: Spectral, Single Corner:
  - Silva et al. (2002) – SC-CS
  - Toro et al. (1997)
  - Hwang&Huo (1997) (in part)

- Cluster No. 2: Spectral, Double Corner
  - Atkinson&Boore (1995)
  - Silva et al. (2002) DC

- Cluster No. 3: Hybrid
  - Abrahamson&Silva (2002)
  - Atkinson (2001)&Sadigh et al. (1997)
  - Campbell (2003)

- Cluster No. 4: Finite Source/Greens Function
  - None

New Candidate Models

- Atkinson-Boore (2006 with 2011 revisions)
- Atkinson (2008 with 2011 revisions)
- Pezeshk et al. (2011)
- Silva et al. (2003):
  - nearly identical to Silva et al. (2002)
  - Silva still sees value in these models, except for constant-stress, no saturation versions

USGS (2008)

Table 3. Weights for CEUS attenuation relations.

Single corner—finite fault	Weight
Toro and others (1997)	0.2
Silva and others (2002)—constant stress drop w/ saturation	0.1
Single corner—point source with Moho bounce	
Frankel and others (1996)	0.1
Dynamic corner frequency	
Atkinson and Boore (2006) 140 bar stress drop	0.1
Atkinson and Boore (2006) 200 bar stress drop	0.1
Full waveform simulation	
Somerville and others (2001) for large earthquakes	0.2
Hybrid empirical model	
Campbell (2003)	0.1
Tavakoli and Pezeshk (2005)	0.1

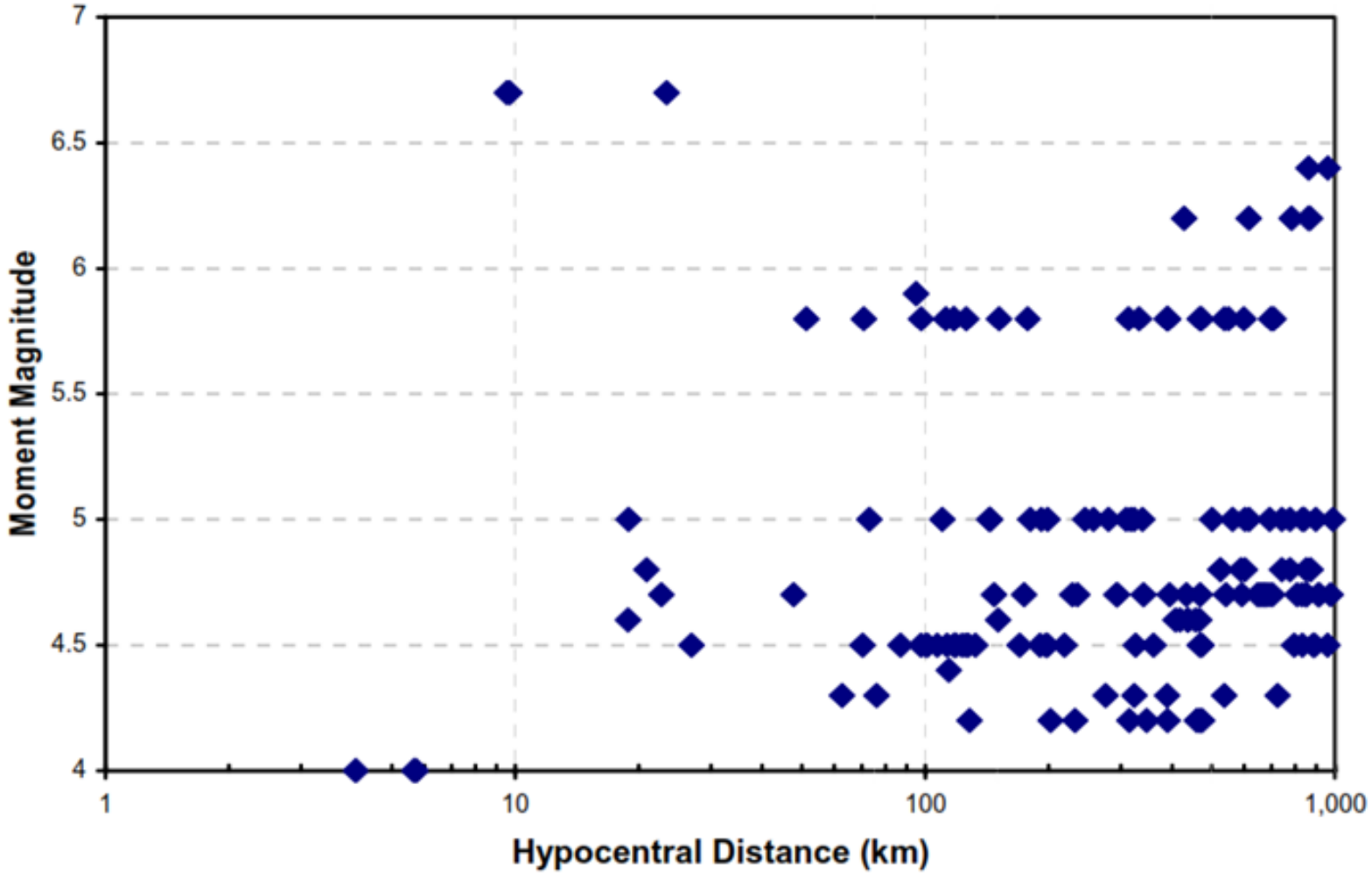
Task 2 Results: Summary

- Three (3) new ground motion prediction equations (GMPEs) are available
- Predictions are similar among the three for M5 and not too different for M7
- No new single–corner models
  - Should keep some of them (Frankel & Silva recommendations) but could down-weight if large residuals
- <u>Proposal (mainly for Task 5)</u>
  - AB06' → 2-corner stochastic (replaces AB95)
  - A08' and PZT11 → hybrid (replace AS02, A01;S97, C03)

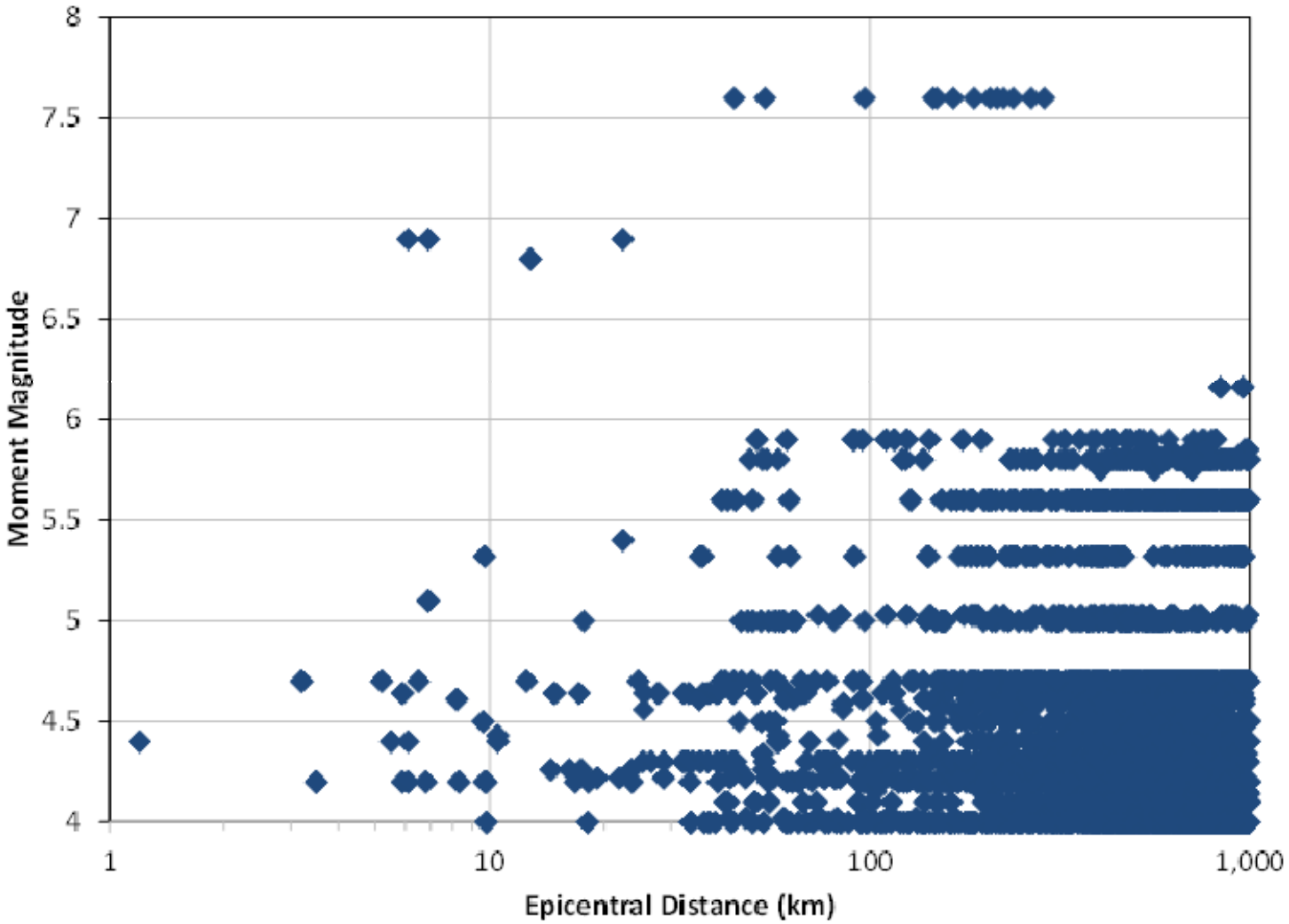
REVIEW: NGA-EAST DATABASE

- Data and metadata from earthquakes in CENA including some recent earthquakes:
  - **M4 and greater with any records within 1000km**
  - **M2.5 to M4 with five or more recordings within 100km**
- Number of records is nearly 28,000
- Each record has a flag indicating its quality
- Includes notable earthquakes not in EPRI (2004) study:
  - **2008 M5.3 Mt. Carmel, IL**
  - **2010 M5.0 Val des Bois, Quebec**
  - **2011 M5.8 Mineral VA earthquake (about 300 recordings) and one M4.5 aftershock**
  - **2011 M5.6 Sparks Oklahoma**
- Eighty Percent (80%) of the records are from earthquakes that occurred since 2004

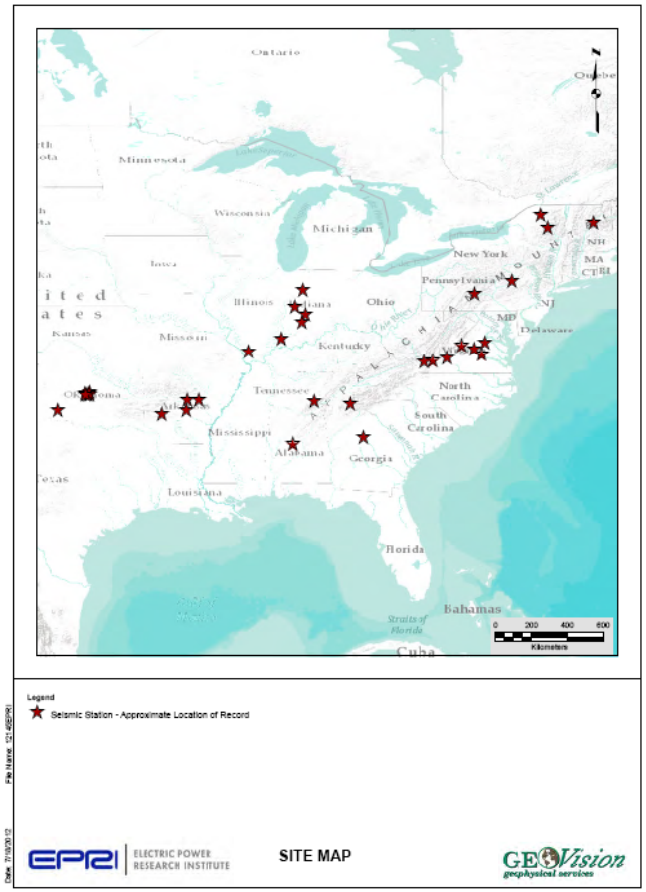
REVIEW: EPRI (2004) GMM: MAGNITUDE-DISTANCE PLOT



REVIEW: MAGNITUDE-DISTANCE PLOT – NGA-EAST



Task 3: Shear Wave Velocity Measurements Site Map



RECOMMENDATION

- It is appropriate to update the existing EPRI (2004, 2006) GMM to incorporate current data, models and methods before it is used to calculate GMRS at existing nuclear power plant sites. The updated EPRI (2004, 2006) GMM should be the “appropriate” EPRI (2004, 2006) GMM referred to in the NRC RFI 50.54 (f) letter dated March 12, 2012.

What's Next in Short-Term

- Receive NRC Response regarding Phase 2 (August 21, 2012)
- Proceed with Task 5, Update the EPRI (2004, 2006) GMM, and Phase 2 as discussed in WM#5 (August 22, 2012)
- Send Decision 2 letter to NRC (August 24, 2012)
- Send Invitations to Resource Experts and Proponents for Feedback Workshop (August 24, 2012)
- Receive Shear Wave Velocity Measurement Report (August 31, 2012)
- Discuss date for Closure Briefing in February 2013

Phase 1
SSHAC-Required Documentation

REVIEW: OVERVIEW

Background:

- The EPRI (2004, 2006) Ground Motion Model (GMM) Review Project will provide industry information necessary specifically for an informed response to the NRC Request for Information (RFI) to Title 10 of the Code of Federal Regulation 50.54(f) Recommendation 2.1 of the Near-Term Task Force (NTTF) Review of Insights from the Fukushima Dai-Ichi Accident dated March 12, 2012.

- The project will provide information for developing site-specific ground motion response spectra (GMRS) for existing nuclear power plant sites and other seismic regulatory issues pending completion of the NGA-East Ground Motion Model.

- The industry position is to review and, if necessary, update the EPRI (2004, 2006) GMM: This position is prudent in light of guidance in NUREG-2117 (2012), input from ground motion experts and seismologists contacted from October 2011 to March 2012 and new data, models and methods that have become available since the SSHAC Level 3 EPRI (2004) workshops were held in 2002.

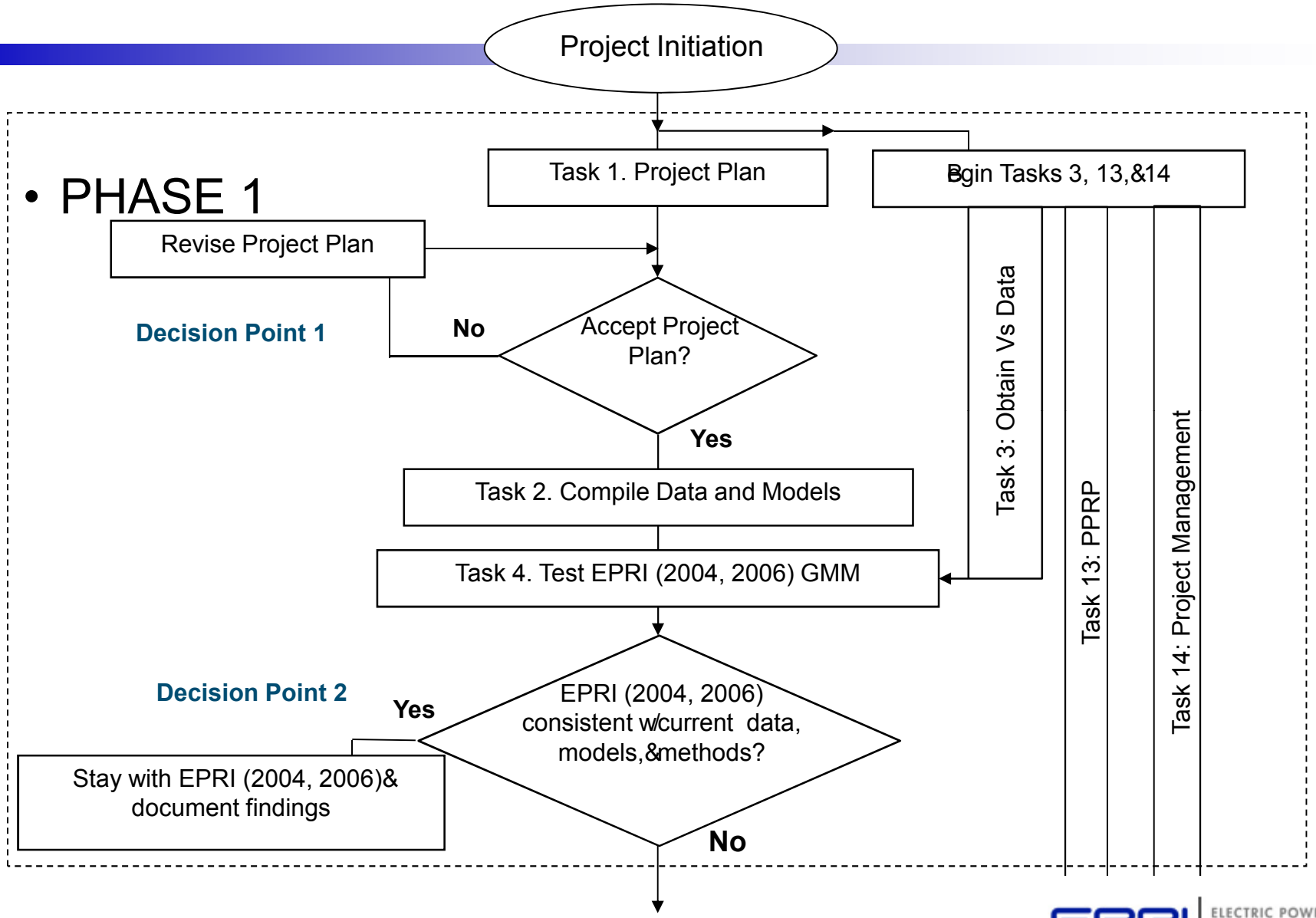
Purposes:

  - Review and Update, if appropriate, the EPRI (2004, 2006) GMM for the need of calculating GMRS for existing nuclear power plant sites in response to the NRC RFI of the NTTF recommendation for seismic using an approach that can be accepted by the NRC
  - Increase the accuracy of input to compute ground motion response spectra (GMRS) required in NTTF Recommendation 2.1 for seismic

Review: Status

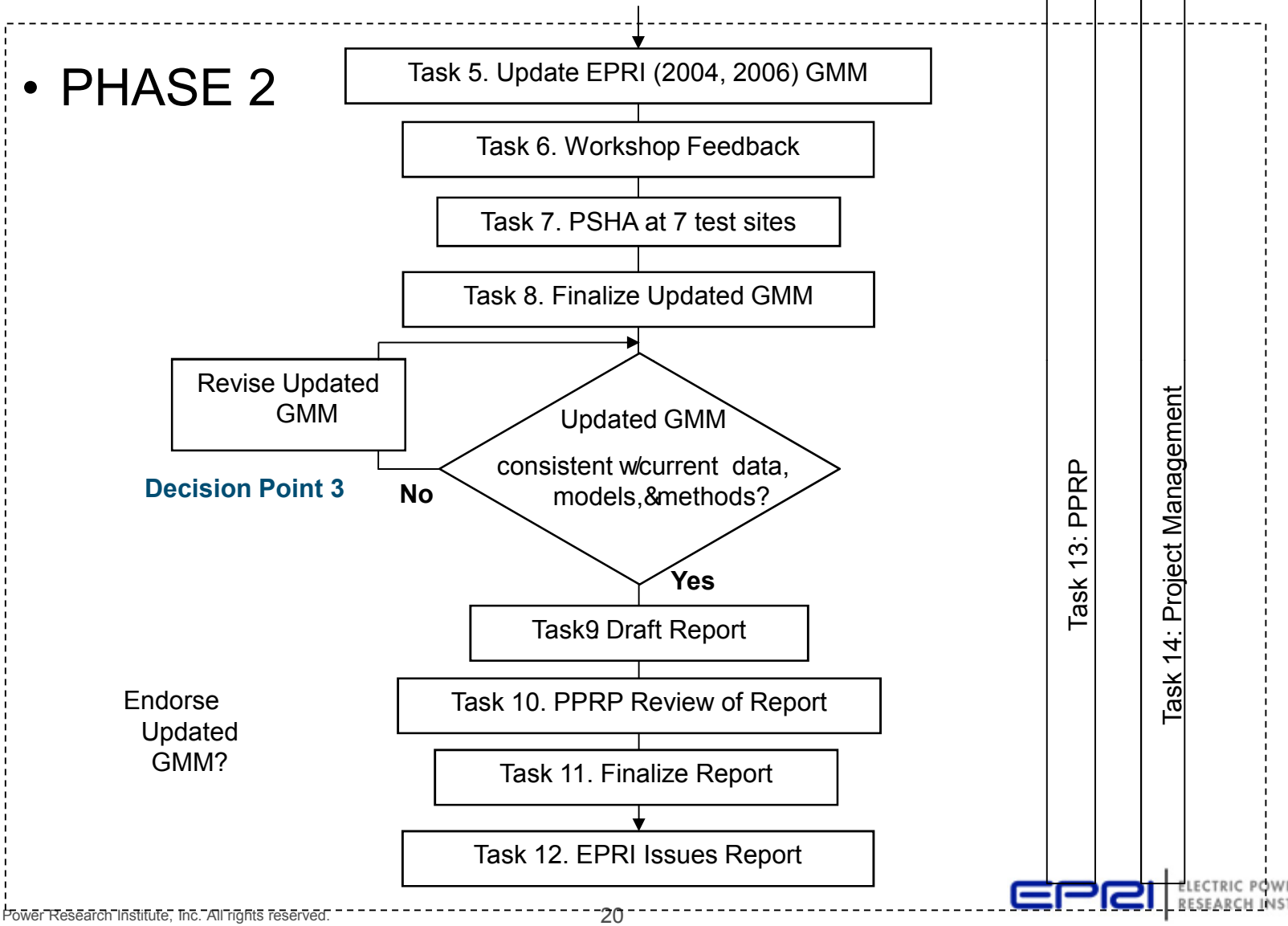
- Incorporate NRC comments into Project Plan (Completed – May 7, 2012)
- **Working Meetings:**
  - Working Meeting #1 (Conference Call) (Completed - March 8, 2012)
  - Working Meeting #2 (Completed – April 26, 2012)
  - Working Meeting #3 (Completed - May 24, 2012)
  - Working Meeting #4 (Completed - June 27, 2012)
  - Working Meeting #5 (August 14, 2012)
- **PM and TI Team Conference Calls:** June 13, 2012; June 20, 2012, July 2, 2012; July 10, 2012; July 17, 2012; July 27, 2012; August 2, 2012 and August 3, 2012 (Project Team)
- Publish EPRI (2004, 2006) GMM Review Project Plan as EPRI Technical Update (May 2012) Completed June 18, 2012)
- Shear Wave Velocity Measurements at Recording Stations (Completed field program July 12, 2012 – 33 recording stations plus two overlapping recording stations; Received all preliminary Vs data on August 7, 2012; Obtained NGA-East data – Completed - June 11, 2012)
- Obtain NGA-East Ground Motion Database (Version 2.2) from NGA-East Project (Completed May 31, 2012)
- Identify Ground Motion Prediction Equations (GMPEs) developed after 2002 (Completed)

REVIEW: Project Plan: FLOW CHART



REVIEW: Project Plan: Flow Chart (continued)

- PHASE 2



REVIEW: Work Plan Status and Schedule Showing Target Dates

- **PHASE 1**

- Task 1: Project Plan (April 2012)
  - Decision Point 1 – May 2012
- Task 2: Obtain GM Database and Identify New GMPEs (July 2012)
- Task 3: Obtain Shear Wave Velocity Measurements (July 2012)
- Task 4: Test EPRI (2004, 2006) GMM (August 2012)
  - Decision Point 2 – August 2012

REVIEW: Work Plan and Schedule (continued)

- **PHASE 2**

- Task 5: Update the EPRI (2004, 2006) GMM (October 2012)
- Task 6: Interaction with Technical Community at USGS Workshop (October 2012)
- Task 7: Calculate Seismic Hazard at Seven (7) Test Sites (December 2012)
- Task 8: Finalize EPRI (2013) GMM (February 2013)
  - Decision Point 3 – February 2013

- Tasks 9-11: Document Project in Report (January – March 2013)
- Task 12: Issue EPRI (2004, 2006) GMM Review Project Report (April 2013)

REVIEW: Important Industry Milestone

- Complete GMRS Calculations and Subsequent Screening (September 2013)

REVIEW: INDUSTRY DUE DILIGENCE

Contact Type	Date	Participants
Conference Call	November 8, 2011	G. Atkinson, J. Bailess, J. Hamel, R. Kassawara, K. Keithline, J. Marrone, S. McDuffie, R. McGuire, M. Petersen, L. Salomone, J.C. Stepp, G. Toro, B. Youngs,
Interviews	October 26, 2011	N. Abrahamson
	November 2, 2011	M. McCann
	November 3, 2011	W. Silva
Meeting	November 30, 2011	A. Frankel, C. Goulet, R. McGuire, M. Moschetti, C. Mueller, M. Petersen, S. Rezaeian, L. Salomone, J.C. Stepp, G. Toro,
Conference Call –Project "Kickoff" Call	March 8, 2012	N. Abrahamson, J. Ake, W. Arabasz, S. Bozkurt, M. Chapman, J. Hamel, R. Kassawara, J. Kimball, R. McGuire, C. Mueller, C. Munson, R. Quittmeyer, L. Salomone, J.C. Stepp,

REVIEW: HIGHLIGHTS FROM DUE DILIGENCE CONTACTS

- EPRI (2004) GMM workshops in 2002; sigma component updated beginning in 2005;
- New CENA Ground Motion Database available;
- New Ground Motion Prediction Equations (GMPEs) available since 2002
  - Atkinson, 2004a, 2004, 2008; Atkinson and Boore, 2006, 2011; Atkinson and Kraeva, 2010; Atkinson and Morrison, 2009; Atkinson et al, 2007, 2011; Boatwright and Seekins, 2011; Boore et al, 2010; Boore, 2012; Campbell, 2004, 2009; Pezesch et al, 2011; Sonley and Atkinson, 2006; Tavakoli and Pezesch, 2005; Zandich and Pezesch, 2010.
- New significant earthquakes since 2002 (e.g.,2011 M 5.8 Mineral VA earthquake; 2011 M 5.6 Sparks OK; 2010 M 5.0 Val des Bois Quebec; 2008 M 5.3 Mt. Carmel IL.)
- One hybrid GMPE in EPRI (2004, 2006) GMM has unphysical behavior at long distances
- Should take into account that some GMPEs do better in certain magnitude distance ranges;
- Modification of existing four (4) clusters may be necessary to account for new information, new models, and new data;
- Calculation of sigma should take into account large datasets from other regions and new insights on sigma; new information may result in different sigma for small and large magnitude earthquakes;
- Correlations between ground motion parameters need to be considered.

Task 2 and Task 3 Results

REVIEW: Task 2 - Literature Reviews

Citation		Status
Atkinson, 2004a		Completed
Atkinson, 2004b		Completed
Atkinson, 2008		Completed
Atkinson, 2012		Completed
Atkinson and Boore, 2006		Completed
Atkinson and Boore, 2011		Completed
Atkinson and Kraeva, 2010		Completed
Atkinson and Morrison, 2009		Completed
Atkinson and Ward, 2007		Completed
Atkinson et al, 2007		Completed
Atkinson et al, 2011		Completed
Batwright and Seekins, 2011		Completed
Boore et al, 2010		Completed
Boore, 2012		Completed
Campbell, 2004		Completed
Campbell, 2009		Completed
Pezeshk et al, 2011		Completed
Sonley and Atkinson, 2006		Completed
Tavakoli and Pezeshk, 2005		Completed
Zandieh and Pezeshk, 2010		Completed

REVIEW: Task 2 - Interviews

- N. Abrahamson; Completed June 21, 2012
- G. Atkinson; Completed July 6, 2012
- D. Boore; Completed June 26, 2012
- K. Campbell; Completed June 20, 2012
- C. Cramer; Completed July 3, 2012
- A. Frankel; Completed July 31, 2012
- S. Pezeshk; Completed June 26, 2012
- W. Silva; Completed July 17, 2012
- P. Somerville; Completed July 9, 2012

Task 2: Another Way to Look at GMPEs: Key Assumptions

- Geometric decay within 70 km: R^{-1} or $R^{-1.3}$
  - Most new models (ASB06' and PZT11) have $R^{-1.3}$
- Magnitude scaling
  - All new models imply constant or decreasing stress parameter
  - Silva no longer support models without decreasing stress or saturation
- Saturation at Short Distances
  - All three models have WUS saturation
- Can't mix and match models: remember need for consistency

TASK 3: SHEAR WAVE VELOCITY MEASUREMENT GENERAL OBSERVATIONS

- Shear wave velocity for hard rock sites are, in general, below the reference rock velocity of 2800 m/s; Some recording stations had shear wave velocities at about the reference rock velocity at depths greater than 30 m (e.g. PN.PFBLN - Indiana and US.WMOK - Oklahoma).

- Velocity inversions occurred at some sites; Shear Wave Velocity of Layer 1 in the profile can be higher than Layer 2.

- Information on the depth of seismograph emplacement were obtained for the recording stations.

- The geology at the recording stations can be highly variable; Lateral velocity variation is an important issue at many sites; Future investigations may require more testing arrays.

- Different array locations, anisotropy and depth of water table assumed can cause differences when making shear wave velocity measurements.

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