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ATTACHMENT A

To: Lawrence Salomone [Via e-mail on June 3, 2008]
Kevin Coppersmith
CEUS SSC Project TI Team

From: CEUS SSC Project PPRP

Subject: Key Issues for CEUS SSC Relevant to Workshop #1

By this memorandum we are transmitting the PPRP's identification of some key tectonic and data evaluation issues for assessment of a seismic source model for the Central and Eastern United States. The intent is to aid the Project TI Team in planning Workshop #1. PPRP members in their informed resource expert role identified the key tectonic and data evaluation issues summarized in this memorandum. Thus, at this point the items herein represent thoughtful views rather than prescriptive recommendations by the PPRP. Some elaborations of individual PPRP members' inputs are enclosed.

Seismotectonic Model – A state-of-knowledge understanding of the mechanisms [processes that explain the occurrence of earthquakes in time and space] involved in the occurrence of earthquakes within the study region is a fundamental requirement for the assessment and characterization of seismic sources. Important issues related to elements of the model include:

- The origin, direction, and strength of ambient stress,
- The potential influence of variations in tectonic structure and crustal material properties on variations in the stress field,
- The time-frame over which the stress field can be considered stationary,
- Current knowledge base for age of tectonic faulting and the correlation of age of tectonic faulting with tectonic domains and tectonic history, and
- Properties of the intermediate crust at depths where most earthquakes nucleate and the spatial correlation with historic and instrumental seismicity.

Definition of Earthquake Sources – A systematic approach and procedure for defining earthquake sources would contribute to the consistency and transparency of the assessment. An optimum approach would be to develop a matrix of criteria that would be used to perform a weighted integrated assessment of the state of knowledge regarding observed tectonic structures, tectonic structure domains, knowledge about the age of tectonic faulting, knowledge about the material properties of the crust, and knowledge about seismicity rates in the context of the seismotectonic model for defining and characterizing tectonic structure-specific sources, area tectonic domain sources, and tectonic based background sources.

For both the development of a state of knowledge seismotectonic model for the study region and for the assessment of earthquake sources, the vertical and horizontal resolution of gravity and magnetic anomaly data for the CEUS is an important issue. These data are particularly important for evaluating the material properties of the crust and for determining the depth extent of tectonic features.

Assessment of Maximum Earthquake Magnitude – The approach to assessing maximum magnitudes for earthquake sources is perceived to be a significant issue. Development of current knowledge together with systematic procedures for assessing maximum magnitude based on tectonic characteristics of an earthquake source [structure-specific source, area source, or background source] are needed.

Characterization of New Madrid and Charleston Seismic Zones – A fundamental issue relates to the interpreted repeat occurrence of large earthquakes in the CEUS [specifically, associated with the New Madrid and Charleston seismic zones] within the past few thousand years without evidence of substantial deformation in post-Cretaceous time in the near-surface rocks. The body of observed data and interpretations [paleoliquefaction mapping and interpretations] that form the basis for these interpretations should be critically evaluated. A thorough understanding of the uncertainty in both the observations and interpretations is perceived to be a fundamental requirement. Equally importantly, interpretations of these data that postulate localized high rates of seismic strain release within the recent past in the absence of observed significant deformation require explanation in the context of a viable tectonic model.

Enclosures
1. William J. Hinze elaborated inputs
2. Jeffrey K. Kimball elaborated input
3. Jon P. Ake elaborated input

To: Carl Stepp, Walter Arbasz; PPRP
From: William J. Hinze
Subject: Hazard-Significant Seismic Site Characterization Issues
Date: May 29, 2008

The following outlines some thoughts on the hazard-significant seismic site characterization issues that may be considered during Workshop #1 of the CEUS SSC. The list is exclusive of consideration of the study's seismicity catalog and ground motion considerations.

The list includes issues of varying importance and level of detail. No attempt has been made to establish a priority ranking. Some are described as statements while others are more definitively considered as questions.

There are a variety of ways to subdivide the issues. I have chosen a four-fold division of *Earthquake Mechanisms*, *Earthquake Stresses*, *Earthquake Sources*, and *Earthquake Parameters*. Mechanism concerns potential processes leading to the origin of earthquakes, stresses involves the nature and origin of stresses that cause the structural development of the crust leading to earthquakes, sources considers the identification and bounding of local and regional seismic sources, and parameters relates to characteristics of the earthquakes in the identified seismic sources.

Earthquake Mechanisms – As in other intraplate terranes the mechanisms involved in the origin of earthquakes in the CEUS are not well known. Nonetheless numerous mechanisms have been suggested and considered in seismic hazard analysis (20 were identified in the EPRI/SOG study). They are generally based on spatial or temporal variations in prevailing stress field or spatial changes in the strength of the brittle crust. It is not necessary to establish the mechanism for earthquakes of the CEUS to perform a seismic hazard analysis, but the results of the analysis are much more credible and thus more stable when mechanisms for the activity can be identified.

- Numerous mechanisms have been identified for the origin of earthquakes in the CEUS including zones of weakness (e.g., tectonic faults, ancient plate boundaries, meteorite impact sites); inhomogeneities in crustal lithology; stress concentrations due to storage of strain energy associated with fault offsets or curvature, localized intrusions of the crust, and variations in crustal composition, thickness, and temperature; and elastic rebound of the lithosphere. The credibility of proposed earthquake mechanisms for intraplate earthquakes in the CEUS needs study and analysis.
- A fundamental issue relates to the occurrence of major earthquakes in the CEUS within the past few thousand years without evidence for substantial deformation in post-Cretaceous time in the topography and near-surface rocks of the region. This paradox should be evaluated considering for example that the major earthquake activity is very young, is episodic with recurrence times measured in tens or hundreds of million years, migrates over broad regions of the CEUS, or is mechanically decoupled from the observed surface sedimentary rocks.

- Another issue relating to earthquake mechanisms is the manner in which the mechanisms vary with spatial scales, magnitude, foci depth, etc.

Earthquake Stresses – Understanding the origin, direction, and strength of ambient stresses that cause strain leading to earthquake activity is important to the credibility and stability of seismic hazard analysis. Issues that relate to earthquake stresses in the CEUS include:

- The origin of stresses observed in the CEUS was largely related to ridge-push tectonic forces in the 1980's seismic hazard analysis. The importance of these forces is now open to question. Thus it is important to consider the origin of these forces and the resulting implications to seismic hazard analysis of the CEUS.
- Measurements of the azimuth of the observed stress field vary somewhat over the CEUS. The source of these variations should be considered. They may vary simply due to errors in measurement, but they may also have other origins including stress deflections as a result of local geologic structure and lithology and depth and stresses of local origin.
- Temporal changes in stress may take place at a range of time scales. Changes may occur in periods of thousands to hundreds of thousands of years due to elastic rebound of the earth due to Pleistocene glaciations and deglaciation especially in the northern part of the CEUS and loading of the crust by sediment concentrations in deltas at the shoreline of the continent or at time scales of minutes or hours due to the passage of seismic waves. The latter "far-field" triggering of earthquake activity with major earthquakes has been noted in recent years and should be evaluated in the CEUS.
- If major seismicity migrates over the CEUS the current seismic activity in some regions may simply be due to aftershocks. Thus it should be of interest to determine whether earthquakes in these regions, e.g., the New Madrid seismic zone, are Poissonian in nature or follow the aftershock law.

Earthquake Sources – A significant amount of effort has been put into identifying and bounding the seismic zones of the CEUS by mapping historical and pre-historical earthquake epicenters. These zones can be classified as either local or regional.

Local seismic zones (special seismic zones of the USGS) are restricted to a limited geographic region that has been the subject of relatively intense seismic activity in historic time. They are not related to the magnitude of the observed earthquakes. Generally they are marked by occurrence of relatively low magnitude earthquakes (< 5), but others such as the New Madrid seismic zone and the Charleston (SC) zone are noted for infrequent (order of hundreds to thousands of years) high magnitude earthquake(s) of the order of 7 and frequent smaller magnitude quakes. Analyses of the geology, geophysics, and Seismicity of these zones attempt to identify a source structure controlling the extent of the zone and its characteristic earthquakes.

Regional earthquake zones (seismotectonic zones or uniform background zones of the USGS) are broad expanses of the CEUS that are subject to infrequent, widely dispersed earthquake activity that have magnitudes commonly less than 5. They are not identified with any particular local structure but may be related to a specific crustal terrane based on age, tectonic history, and structure and composition. Identification of local and regional seismic zones leads to the following issue questions:

- What criteria identify local and regional seismic zones and their geographic limits?
- Seismic source zones are volumes rather than an area as depicted in surface maps. Accordingly surface geology, seismic activity, and geophysical data are used to define the character of source zones at depth. Geophysics is the primary investigative tool because of the paucity of earthquake data and the limited information derived from surface geology. As a result a significant issue is the resolution, both vertical and horizontal of geophysical methods, particularly of the extensively used regional gravity and magnetic anomaly data of the CEUS. This is particularly important in evaluating the ability to obtain information on the depth extent and surface area of fault faces.
- What is the significance of deep crustal expression in identifying seismic zones and their characteristics?
- Is the continental/oceanic transition (boundary) zone in both the Atlantic Ocean and the Gulf of Mexico a seismic zone?
- Smoothing of seismic source zones can be used to recognize that the specific boundaries of zones are seldom known to a high degree of accuracy because of insufficient information or inadequate resolution of the methodologies used to define them. Should smoothing be used and if so what criteria should be used to define the smoothing method?
- Although more is known about the New Madrid seismic source zone than any other seismic zone in the CEUS, several issues remain concerning its potential seismic hazard. For example, what is the origin of the zone of diffuse epicenters that is separated from but parallels the Reelfoot rift to the northwest? Why is there no such similar zone to the southeast? What is the origin and seismic hazard significance of linear trends of epicenters that parallel the Reelfoot rift north of the main seismic flux? Why does the axis of the rift have more seismic activity than the bounding fault margins?
- Should crustal structures that are potential zones of weakness oriented favorably for reactivation in the current regional stress field be identified as seismic source zones even if they have little or no record of historical or pre-historical earthquake activity? This should include basement structures that have been reactivated in Phanerozoic time as evidenced in sedimentary structures.
- Identified continental rifts that show evidence of tectonic activity in Mesozoic era to recent times are the source of roughly one-half the historical earthquake activity in the CEUS. What differentiates these rifts from older rifts as local seismic source zones?
- Are cross-structures to rifts capable of mechanically decoupling rifts so that local seismic zones can be restricted to only a portion of the rift bounded by the cross structure? Related to this is the question of the extension of the New Madrid seismic zone into the Wabash River Valley seismic zone.

- What establishes the potential seismicity of ancient (Precambrian faults) that are oriented favorably for reactivation in the current stress field?
- Should similar crustal geological features that are recognized in geophysical and geological data and that are roughly oriented in the same azimuth be considered a similar seismic hazard regardless of the historical seismic record? Are differences in the historical seismic record of these features simply a result of low Seismicity and long recurrence periods?

Earthquake Parameters of Local and Regional Seismic Zones –
The more active seismic zones of the CEUS provide useful information on the earthquake characteristics of the region. However, the low seismic flux limits this information leading to several important issues regarding the credibility of predicted earthquake parameters. These issues include the following:

- Aftershock sequences are observed following some of the more major earthquakes in the CEUS, the nature of these sequences can provide important information on the nature of the sources and the seismic strain.
- The temporal pattern of earthquakes of varying magnitude in a seismic zone are important to defining recurrence intervals and can be useful in defining maximum magnitudes anticipated in the zone. These patterns require definition and are particularly important in identifying the maximum magnitudes of earthquakes in zones. The problem of maximum magnitude is especially problematic in regional seismic zones.
- Pre-historical earthquakes identified by paleoseismology techniques have an important role in assessing the seismic hazard of the CEUS. However, there are numerous problems associated with the use of paleoliquefaction features including their recognition as associated with a particular earthquake event and calibrating them to the magnitude of the event.
- Earthquake wave attenuation is generally assumed to be constant over the CEUS. However, there are significant variations in crustal thickness, composition, and structure over this region and seismic anisotropy exists. As a result attenuation of seismic energy may vary across the area.
- “Slow” earthquakes are now identified in some regions. Do these occur in intraplate regions such as the CEUS and if so what are their impact on seismic hazards and what are their relation to ordinary earthquakes?
- Earthquake foci over the CEUS are at depths not exceeding a few tens of kilometers. Is the depth of foci an important parameter in identifying the origin of earthquakes and identifying seismic zones and their potential hazard?

Excerpts from Memo by Bill Hinze to PPRP Dated May 12, 2008
Relevant to Planning of CEUS SSC Workshop #1

Upon reflecting on issues and discussions at the CEUS SSC meeting on May 8, 2008 I have had some thoughts that I wish to share with Panel. Most of them are a result of asking myself how the credibility of the results of the study can be increased. . .

Data needs and related resource experts.

- The 300 km rind of data surrounding the study area should include the area to the west and south of 105^o W. This includes a seismically active region of for example the Rio Grande rift, the Rocky Mountain front, and northwestern Mexico. These will become more important in the future to central US nuclear facilities.
- The resource experts that will be invited to Workshop #1should be encouraged to discuss the metadata for the germane data sets, but they should also be encouraged to identify where appropriate the types of geologic sources that are portrayed in the data sets with examples, the horizontal and vertical resolution of the data, precision and accuracy, and the limitations of the data set. If possible they should also discuss competing data sets and their relative merits.
- There are several other data sets that should be made available to the TI team in addition to those listed in the draft plan. These should include derived data sets which emphasize particular attributes of the data. A map should be furnished with the location of crustal refraction and reflection profiles including those in the 320 km rind in Canada. The deep seismic reflection profiles will be more of a problem than the refraction profiles but review of COCORP, GLIMPCE, USGS, etc. data sets should capture the vast majority of the available profiles. These profiles that were generally not available at the time of the EPRI SOG study should be most useful in defining and characterizing seismic source zones. Note that current gas exploration renaissance in the Appalachian Mountains includes new reflection profiling that could be valuable to the SSC if they were available for the public sector.
- I learned . . . at the May 8th meeting that GPS data are not to be included in the data available to the TI team. . . . Neglecting [GPS] data at least to the point of evaluating their precision is a potentially serious error that will decrease the credibility of the findings of the SSC.
- It is likely in the analysis of data that there may be the need for additional data sets that will assist in interpretation and analysis beyond those identified prior to the study. Minimal resources should be made for adding a few additional data sets during the progress of the study.
- Mapping of prehistoric earthquakes by paleoliquefaction data is an important component of the SSC study. However, mapping of

paleoliquefaction features should also include maps which show stream valleys, etc. that have been mapped and show no liquefaction features although the surface materials are amenable to paleoliquefaction. Negative evidence is important as well as positive evidence in this situation.

- We were told at the May 8th meeting that no data would be assembled for higher resolution studies within the 40 km range around the sites selected for intensive analysis. Yet the reflection data within these regions would be used where available. Experience suggests that interpretation of seismic reflection profiles are enhanced, often significantly, by being integrated with potential field and other geophysical data. I suggest that the decision regarding the omission of higher resolution data in the specific study areas be reconsidered. Use of these data where available will decrease uncertainties.
- Unless stratigraphic studies of the sedimentary formations of the CEUS can be shown to be important to seismic properties (e.g., attenuation) there is no apparent compelling reason for exerting a good deal of effort on these studies.

Key Issues That Require Evaluation for Assessment of the CEUS Seismic Source Model as Input for Planning Workshop #1
Jeff Kimball, May 29, 2008

The issues are listed followed by a table which could be used to cross link the issues to the database. While I have not attempted to comprehensively fill out the table, review of the issues indicates that database focus may need to be adjusted to include more focus on paleoliquefaction data and seismic source dimension data {source inversions, stress drop}.

High Priority Seismic Source Issues:

1. Relationship between moment magnitude and source dimension such as source area or fault length.
2. Treating seismic sources as point sources versus extended sources. Needs consistency with ground motion modeling; larger {M>6} events should be treated as extended sources.
3. Seismic source approach to areas of low seismicity. Should large "open" sources be considered {extended margin, craton}?
4. Magnitude distribution approach, such as characteristic magnitude distribution versus truncated exponential magnitude distribution; when to use which approach.
5. Magnitudes assigned to earthquakes found via paleoliquefaction evidence.
6. Approach to establishing maximum magnitude for regions of low seismicity.

Other Seismic Source Issues:

1. New Madrid – source boundaries, approach to modeling faults, fault orientation.
2. New Madrid – assessing uncertainty in timing of paleoearthquakes.
3. Charleston – source boundaries, approach to modeling faults, fault orientation.
4. Charleston – assessing uncertainty in timing of paleoearthquakes.
5. Wabash Valley – source boundaries, approach to modeling faults, fault orientation.
6. Wabash – assessing uncertainty in timing of paleoearthquakes.
7. Identification of tectonic features and impact of seismicity; when features are identified but seismicity is not smoothed does this default to "smoothed seismicity"?
8. USGS smoothed seismicity versus EPRI approach to smoothing – which to use and why.
9. Areas of low seismicity – lower limit on maximum magnitude given implied source dimensions?

Seismic Source Related Issues		
	Key Issue	Database
General Issues	1. Relationship between moment magnitude and source dimension such as source area or fault length.	Earthquake source inversions, stress drop.
	2. Treating seismic sources as point sources versus extended sources. Needs consistency with ground motion modeling; larger {M>6} events should be treated as extended sources.	Workshop #2?
	1. New Madrid – source boundaries, approach to modeling faults, fault orientation.	GSG, paleoliquefaction data

	Key Issue	Database
Fault Source Issues	2. Charleston – source boundaries, approach to modeling faults, fault orientation.	GSG, paleoliquefaction data
	3. Wabash Valley – source boundaries, approach to modeling faults, fault orientation.	GSG, paleoliquefaction data
Area Source Issues	1. Seismic source approach to areas of low seismicity. Should large "open" sources be considered {extended margin, craton}?	Workshop #2?
	2. Identification of tectonic features and impact of seismicity; when features are identified but seismicity is not smoothed does this default to "USGS smoothed seismicity"?	GSG; Should we request sensitivity studies to address this issue {USGS vs. EPRI}?
Earthquake Occurrence – Magnitude Distribution Issues		
	Key Issue	Database
General Issues	1. Magnitude distribution approach, such as characteristic magnitude distribution versus truncated exponential magnitude distribution; when to use which approach.	Workshop #2?
	2. Magnitudes assigned to earthquakes found via paleoliquefaction evidence.	Critical review of published data, but this data should be compiled.
	3. Approach to establishing maximum magnitude for regions of low seismicity.	Seismicity catalog. Workshop #2?
	4. USGS smoothed seismicity versus EPRI approach to smoothing – which to use and why.	Should we request sensitivity studies to address this issue {USGS vs. EPRI}?
Specific Issues	1. Areas of low seismicity – lower limit on maximum magnitude given implied source dimensions?	Workshop #2?
	2. New Madrid – assessing uncertainty in timing of paleoearthquakes.	New Madrid Paleoliquefaction data
	3. Charleston – assessing uncertainty in timing of paleoearthquakes.	Charleston Paleoliquefaction data
	4. Wabash – assessing uncertainty in timing of paleoearthquakes.	Wabash Paleoliquefaction data

GSG = geologic, seismologic, geophysical data.

Key Issues for CEUS SSC Project
Jon Ake
6/1/2008

1. Source characterization for regions other than New Madrid, Wabash Valley and Charleston. Two end member scenarios are the very large zones (extended margin vs craton etc.) defined in the USGS approach and numerous very small zones defined in the EPRI-SOG study. If very large zones are used it implies little understanding of the seismotectonic differences across large areas. Conversely, the smaller zones often lack a sufficient number of earthquakes to allow for a stable estimate of rate.
2. The approach to use for computing rates using "gridded seismicity". There at least two alternative approaches being used currently, the penalized likelihood EPRI model and the kernel smoothing approach used by the USGS. These probably need to be viewed as two proponent models and we need to evaluate the impact of the differences. There are also questions that need to be addressed with respect to the degree of smoothing applied (correlation distance in the kernel approach and Wa and Wb in the EPRI formulation).
3. The approach to be used for definition of maximum magnitude in source zones (i.e. not New Madrid, Charleston, Wabash Valley). Again there are several models available that should be considered. This is an area where the data set for estimating magnitude from paleo-liquefaction evidence probably needs to be reviewed to ensure there is not a systematic bias in the resultant magnitudes.
4. To ensure that appropriate source dimensions are assigned we need to re-examine the source scaling in the CEUS. This needs to be done for the revised ground motion models as well. Assigning source dimensions based on a WUS model is clearly inappropriate.
5. A detailed examination of hypocentral depths (and associated uncertainties) in the CEUS. This will need to be used with heat flow and potential field data to evaluate limits on seismogenic thickness.
6. Source boundaries for Wabash, Charleston, New Madrid etc. Will the boundaries be "hard" and no ruptures be allowed to extend outside, or will they be "soft" where the ends of fault ruptures may extend outside the source zone?
7. The uncertainty in the timing of paleoearthquakes needs to be evaluated more fully as this issue is "co-mingled" with any assessment that might be made relative to cluster models for sources like New Madrid.
8. Seismicity catalog updates. The need to compile the best possible catalog is a very high priority. The discussion in the Draft Project Plan (DPP) on this issue is very good. The need to convert the available data to moment magnitudes is discussed in the DPP, the techniques that will be applied to the historical data as well as the instrumental data is something that needs to be carefully considered.