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Subject: Response to *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Participatory Peer Review Report on Workshop No. 2* dated March 10, 2009.

Dear Carl and Walter,

Thank you for your letter summarizing the Participatory Peer Review Panel's review of Workshop No. 2 for the CEUS SSC project. The letter reflects a clear understanding of the purposes of the workshop in the context of the SSHAC Level 3 process. In the spirit of a participatory peer review process, we welcome timely, insightful, and constructive reviews and suggestions that will assist the Project Manager and TI team in steering the project toward a successful conclusion. One mechanism for that interaction is this correspondence between the PPRP and the project management.

To provide the PPRP with insights into our intentions relative to the specific recommendations made in the letter, we provide below a response to the recommendations that have been underlined in your letter to draw attention to their priority. We also value the perspectives provided in other parts of the letter and these will be given serious consideration during the course of the project activities leading up to and including Workshop No. 3.

1. Need for a Tectonic Framework*: The range and complexity of alternative hypotheses and interpretations presented at WS-2 reinforce our previous recommendations concerning the need, first, to evaluate an overall tectonic framework for the study region and, second, to properly incorporate this evaluation into the CEUS seismic source model assessment. We consider a transparent evaluation of uncertainty to be a necessary element of the tectonic framework evaluation. The tectonic framework should have a universal role in the seismic source model assessment. This would establish the approach and scale for the seismic source model assessment, and it would provide a transparent, consistent assessment (weighting) of the complex alternative interpretations and hypotheses that constitute the current state of knowledge of the technical community.*

We agree with the PPRP's recommendation that a Tectonic Framework be developed for the CEUS SSC project and this topic has been the subject of considerable focus by the TI team and staff over the past several months. To avoid narrowing the concept to include only a consideration of tectonic features, the project has used the term "Conceptual SSC Framework" to describe the process that is being used to identify and characterize seismic sources for the project. Over the course of three working meetings, the TI team and staff have reviewed the criteria that will be used to identify seismic sources, the process that will be used to identify and

evaluate the data, the manner in which the criteria will be applied, and the means of documenting the evaluations in tables and text. These processes are being summarized in a document that will become a chapter in the project report. The concepts will be discussed at the PPRP meeting in May.

We observed that some proponent interpretations regarding seismic sources and the origin of the seismicity in the CEUS pointed to the significance of evaluating the geological and seismological characteristics of the entire lithosphere—including the upper brittle crust, the ductile lower crust, and the upper mantle. Geological and geophysical evidence indicates that these various zones of the lithosphere are laterally heterogeneous, which could have profound impact on the seismicity of the brittle upper crust. As a result, we recommend that the TI Team should include the attributes of the entire lithosphere in their evaluation of the tectonic framework and their seismic source model assessment.

As witnessed by the identification of resource experts with expertise in lithospheric modeling at WS2, the TI team and staff are aware of the potential importance of this type of data. Inasmuch as researchers have made assessments of the potential implications of their modeling of deeper mantle processes to seismicity within the seismogenic crust, the TI team and staff will make every effort to include this information in the considerations for identifying seismic sources.

2. Approach to Seismic Source Assessment and Scale:

a) "Granularity" of Seismic Source Model (i.e., the scale of uniform scrutiny): During the workshop, geological structures ranging in scale from very local to continental-scale were described and discussed. We recommend that the TI Team provide early assurance, through assessment criteria that are explained and justified, that a systematic approach and procedure are being used for defining and assessing seismic sources in terms of scale. These assessment criteria will facilitate subsequent use of the model for a site-specific PSHA at any site in the study region. The assessment criteria should be at a level of detail that appropriately incorporates the state of knowledge of the sources and the current understanding of their inherent complexity. Using the criteria, one should be able to distinguish specific sources that have significant, identifiable, and relatively consistent seismic hazard potential. This systematic approach should be applied consistently across the study region.

It is agreed that the "granularity" of the seismic source model and characterization effort is important and needs to be defined on a consistent basis for the entire study region. The Conceptual SSC Framework being used on the project begins with identifying the criteria that call for identifying a unique seismic source: variations in maximum magnitude, variations in recurrence rate, variations in future earthquake characteristics (e.g., depth, style of faulting), and significant variations in tectonic feature characteristics. It is acknowledged that the product of the CEUS SSC project is a *regional* seismic source model that can be applied at any location within the CEUS. As such, it includes variations in seismic source criteria that would lead to hazard-significant variations across the study region. It is also recognized that the CEUS SSC product will not include the detail that would be required for a site-specific application, say for inclusion in a PSHA conducted for power plant licensing. Per regulatory guidance (e.g., Regulatory Guide 1.208), those site-specific applications would need to consider possible refinements that might be needed to the CEUS SSC seismic source model in light of local

geologic or seismologic investigations. It may be that a more refined model is possible at a few locations (e.g. New Madrid, Charleston) and we propose to use this refinement rather sacrificing the detail for the sake of a common level of "granularity."

b) Approach to Smoothing: We observed that there was little discussion or consideration of uncertainty involved in smoothing recorded seismicity versus deductive seismic source assessment, and there was no evaluation of alternative smoothing parameters. We consider this to be an important part of the assessment for the CEUS seismic source model and we recommend greater attention to the issue of smoothing and corresponding documentation.

The focus of the workshop was on alternative interpretations of various datasets and conceptual models. The notion of smoothing has a conceptual basis as well (i.e., degree of spatial stationarity in rates), which was addressed by those talks related to stationarity (e.g., Kafka talk on statistical analysis of past and future patterns of seismicity; multiple talks related to possible spatial migration of seismicity in New Madrid area). The audience at the workshop was not familiar with the mechanics of smoothing, and the mechanics of smoothing (e.g., kernel types, smoothing distances, etc.) were not discussed at the workshop. These details are recognized by the TI to be important and are the focus of attention by the TI team. We anticipate that alternative approaches will be used and captured in the SSC model.

3. Integrated Evaluation of Paleoliquefaction and Interpretations of Paleo-Fault Displacements:

a) Uncertainties in age dating: Multiple proponent experts discussed their interpretations of evidence for recent fault movement or the dating of geologic surfaces related to the formation of paleoliquefaction features. The proponents did not sufficiently describe the uncertainties in the age dating within their respective studies, and as such, the overall quality and reliability of this information is in question. The TI Team should strive to better understand the overall quality of these studies and develop a cohesive understanding of how the results can and cannot be used to establish recurrence information for various seismic sources. We recommend that the TI Team perform an integrated analysis of the body of paleoseismic investigation results in the vicinity of the New Madrid Seismic Zone using appropriate statistical methods. The study should incorporate uncertainty in the interpretations, to the extent that the uncertainty is described in or can be reasonably interpreted from the study results, in order to better correlate event times and rates of activity.

It is agreed that the ongoing studies of paleoseismicity in the New Madrid region are important and uncertain. The presenters at the workshop were encouraged to discuss uncertainties in the ages, locations, and sizes of paleo-earthquakes; some experts were more adept than others at describing their uncertainties. One of the responsibilities of the TI team and staff is to develop seismic source models that consider the present level of knowledge and uncertainties in the larger technical community. It is recognized that the seismic source models will provide a snapshot in time in this regard and that new data and information will continue to be developed in the future. Our focus, then, will be to incorporate the center, body, and range of views in the technical community on the recurrence models and rates in the New Madrid region. Given the

present level of knowledge and uncertainties, it is likely that the "appropriate statistical methods" will be quite simple and will not entail unwarranted sophistication.

b) Size of paleoearthquakes: Paleoliquefaction is widely accepted to be a useful basis for assessing a seismic source model for the CEUS region; it is likely to gain even more importance in the future. The new approaches presented at WS-2 for assessing uncertainty in the observed data and interpretations and for using the interpretations for estimating the size of causal earthquakes have great promise and should be pursued in the future. At present, the uncertainties resulting from both the current and the newly presented method are poorly constrained. We recommend that particular care be taken in estimating magnitude and in assigning corresponding uncertainties. We further recommend that the lack of evidence of paleoliquefaction not be used to determine maximum magnitude.

We agree that the methods for assessing the magnitudes of paleo-earthquakes are still under development and that limited data have been developed that allow more quantitative methods to be applied consistently throughout the CEUS. For example, the geotechnical characterization that would lead to more confident magnitude estimates, as discussed by Drs. Green and Olsen, is only available in a limited number of cases at the present time. Hence, the magnitude estimates for paleo-events reported in the literature will be reviewed with care. We plan to factor appropriate uncertainty estimates of the size of paleo-earthquakes into the assessment of maximum magnitudes. We agree that the lack of evidence of paleoliquefaction needs to be interpreted with considerable caution, and there are no plans to use that evidence to place limits on maximum magnitudes.

c) Time-dependent models: Given the importance of paleoliquefaction studies for evaluating the New Madrid and Charleston seismic zones, the TI Team should make a fundamental decision whether the incorporation and use of time-dependent recurrence models should be pursued. While this topic came up during the workshop, there was no discussion focused on what weight should be given to time-dependent recurrence models. It was not clear how the TI Team would assess the views of the technical community on this issue.

The notion of time-dependent earthquake behavior in the New Madrid and Charleston seismic zones has been proposed by the technical community[1] and, therefore, must be seriously considered for inclusion by the TI team and staff. In addition, it has been used in several COLA applications. A variety of approaches exist for incorporating time-dependent behavior into a classical PSHA (i.e., one that is based on Poissonian temporal behavior), should we decide to do so. It is assumed that the CEUS SSC product will provide input to a PSHA that could be used to assess hazard for nuclear facilities having a design life of approximately 50 years. It would be in

[1] Recent examples include:
James S. Hebden, J. S. and Stein, S., 2009, *Time-dependent seismic hazard maps for the New Madrid seismic zone and Charleston, South Carolina, areas*: Seismological Research Letters, 80(1):12-20
Li, Q., Liu, M., and Stein, S., 2009, *Spatiotemporal Complexity of Continental Intraplate Seismicity: Insights from Geodynamic Modeling and Implications for Seismic Hazard Estimation*: Bulletin of the Seismological Society of America; v. 99; no. 1; p. 52-60
Calais, E. and Stein, S., 2009, *Time-Variable Deformation in the New Madrid Seismic Zone*
Science, March 13, 2009; 323(5920): 1442 - 1442.

this context that time-dependent recurrence models would be incorporated, should the TI team and staff judge this to be an important mechanism for capturing the views of the larger technical community.

4. Documentation of how alternative views are used*: At WS-2 a wide range of proponent views within the scientific community were presented about a number of important seismic source related issues. It is clear that, when assessed in detail, most CEUS locations are complex, with heterogeneities playing an important role in creating the data observed in the field. The TI Team needs to document how alternative views are accounted for in the assessment of the seismic source model to be presented in May 2009.*

We agree that any given seismic source or region of interest within the CEUS will potentially have a number of datasets that pertain to the spatial and temporal aspects of the source characteristics. The TI team and staff are fully aware of the responsibility to document in the project report all of the data and information sources that were used in the assessment. Doing so will allow future readers to understand how the views of the larger technical community were considered in the evaluation process.

5. The hypothesis of late aftershocks: *During the workshop, a proponent, using chiefly qualitative evidence, offered the view that much of the contemporary seismicity observed in the CEUS represents late aftershock activity of prior moderate to large earthquakes. If this view is used by the TI Team as a working hypothesis, it should first be critically examined. Standard seismological and statistical tools exist for verifying whether observed contemporary seismicity can plausibly be related to prior earthquakes, consistent with aftershock decay models such as the modified Omori model or Ogata's epidemic-type aftershock sequence (ETAS) model. Modern aftershock sequences in the CEUS, for example, can provide Omori parameters that can be used to test the hypothesis of long-lived aftershock sequences in the region.*

The term "aftershock" was used in a variety of ways at the workshop, including some ways that would imply very long-lived sequences of earthquakes that occur decades to centuries following the "main shock." The TI team and staff agree that this issue must be viewed with caution and with care. Likewise, the treatment of the seismicity catalog for purposes of earthquake recurrence analysis (i.e., de-clustering) will also require that we consider the issue.

6. Temporal Clustering*: One uncertainty that was briefly discussed is whether the New Madrid seismic source zone is coming out of a cluster in terms of short repeat times for larger earthquakes. Some proponents cited GPS data that indicate little if any measurable strain in the New Madrid seismic zone region over the past 20 years, and one proponent presented geologic evidence that could be interpreted to indicate a history of clustering with very long geologic time intervals between clusters. The available data and overall lack of understanding of the mechanisms that may drive a clustering model for the New Madrid seismic source zone warrant caution about the supposition that a clustered sequence of higher recurrence behavior is ending.*

As noted by several of the resource experts at the workshop, the notion of temporal clustering of earthquake behavior has been postulated based on geologic and seismic evidence at a number of localities within stable continental regions. It is true that the present state of knowledge does not

provide insights into the physical mechanisms for this phenomenon, although attempts have been made (e.g., migrating strain localization, evolution of zones of weakness). The lack of understanding of the causative mechanism for temporal clustering adds uncertainty. Nevertheless, temporally-clustered behavior continues to be reported and must be considered in our evaluations. Likewise, some members of the larger technical community favor a temporal model in which the 1811-1812 earthquakes marked the end of a temporal cluster and the absence of evidence for contemporary strain accumulation is cited as evidence for the model. We agree that this model warrants caution in considering the manner in which it will be evaluated for incorporation into the CEUS SSC model.

***7. SSHAC process issues**: Under SSHAC guidelines, the makeup of the TI team has implications for ownership issues relating to the seismic source model and subsequent hazard results. As evident during the workshop, there are blurred boundaries between the TI Team specified in the CEUS SSC organization chart and the TI Staff. The working "TI Team" appears to consider itself a larger group than listed in the Project Plan. The makeup of the "TI Team" in terms of individuals who will be responsible for ownership of the SSC inputs should be clarified.*

We also note that in the SSHAC framework there conventionally is a distinction between the TI (or TI Team) and the hazard analyst. In the CEUS SSC project this distinction is blurred with Robin McGuire having a dual role as a member of the TI Team and as one of the key analysts responsible for computing hazard at seven demonstration sites. This is not a conflicting role and indeed adds strength to the project. We suggest, however, that this circumstance be explained in the final project report.

During the course of discussions about the project activities, the term TI Team was used to indicate the working team that is evaluating the data and developing the seismic source model. This terminology is not consistent with the organization chart in the Project Plan. More accurately, the evaluations and development of the seismic source model is being conducted by the TI Team and the TI Staff. On the second point, the circumstance will be explained in the final project report.

Thanks again for the insightful review comments, and we are convinced that they will assist us in developing a better product. If you have any questions regarding this letter, please feel free to contact us.

Sincerely,

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