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May 14, 2008

Mr. Nilesh Chokshi
Division of Site and Environmental Reviews
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: EPRI White Papers in Support of New Plant Applications

Project Number: 689

Dear Mr. Chokshi:

Based on the outcome of the February 13th meeting between the NRC staff and the industry's Seismic Issues Task Force, the industry took an action to develop three white papers to resolve outstanding generic issues. These documents were prepared with support from the Electric Power Research Institute (EPRI). The three final white papers are enclosed for NRC staff review.

The first white paper, Guidance for Updating Accepted Existing Seismic Source Models, Given New Data or New Information, provides guidance on how to update seismic source models. This document is designed to provide a roadmap and guidance for applicants who encounter new data or information as part of the update of seismic source components of accepted existing PSHA models. The document describes the types of information that would require further evaluation and a process for conducting the evaluation and incorporating the results into the PSHA models as necessary.

The second document, White Paper on Seismic Hazard in the Eastern Tennessee Seismic Zone (ETSZ), is a generic sensitivity analysis to evaluate the impact of new information on the ETSZ. This sensitivity study is an example of how to apply the guidance provided in the first white paper. The study has been performed to evaluate a generic site within the ETSZ to address questions regarding the effects of new interpretations of existing data within the region from two additional studies. The conclusions of this white paper support the basis for no adjustments to the ETSZ as currently documented in the ESP and COL applications submitted to date.

The third document, White Paper on Influence of Dames & Moore Interpretations for Seismic Hazard Studies in the Southeastern US, was performed at the request of the NRC. This sensitivity study evaluates the specific effects of modifying the seismic source model (probability of activity) of the

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Dames and Moore Earth Science Team (EST) as originally developed under the EPRI SOG. This is one interpretation out of six EPRI-SOG teams for the Central Eastern United States (CEUS), and is an example of the broad range of diverse, informed scientific opinion that is sought in a large seismic hazard project. Until data are collected that render such opinions invalid, or until the EPRI-SOG study is updated by another study of similar breadth and scope, the Dames & Moore interpretation should continue to be considered one valid interpretation among six.

For these reasons, and because the potential change in Dames & Moore P_a values results in estimated changes to mean hazard and to mean seismic core damage frequency that are insignificant, this study validates the ESP and COL applications submitted to date that use the original P_a values for the Dames & Moore team.

We appreciate your review of these documents and look forward to answering any questions you may have at our upcoming meeting on May 23. If you have any questions, please contact Leslie Kass (lck@nei.org; 202-739-8115) or me.

Sincerely,

Adrian P. Heymer

Enclosure

c: Dr. Rebecca Karas, U.S. Nuclear Regulatory Commission
Dr. Clifford Munson, U.S. Nuclear Regulatory Commission
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White Paper on

Guidance for Updating Accepted Existing Seismic Source Models, Given New Data or New Information

Prepared for

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May 13, 2008

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I. INTRODUCTION

The motivation for this white paper is to provide additional material and information for support of ongoing efforts by the Nuclear Energy Institute (NEI) and the Nuclear Regulatory Commission (NRC) to resolve open generic seismic issues and to develop guidance acceptable to the NRC for meeting the requirements of the seismic regulations. A meeting between the NRC and NEI on February 13, 2008 held to further this effort identified the need for more detailed guidance on acceptable procedures and evaluations for determining whether updating of *Accepted PSHA Models*[1] is required. NEI took the action to prepare this white paper to provide a basis for establishing an appropriate level of more detailed procedure and evaluation guidance. The purpose of this paper is to provide additional detailed procedure and evaluation guidance for determining whether new data[2] or new information[3] (e.g., new evaluations of seismic sources or new probabilistic seismic hazard studies) require updating the seismic source component of an accepted existing PSHA model. The focus of the proposed guidance is on the seismic source component of accepted PSHA models, as the ground motion component for sites located in the central and eastern United States recently has been updated[4]. The procedures and evaluations for updating accepted existing seismic source models described below may be used to elaborate the guidance currently contained in Regulatory Guide (RG) 1.208.

II. OVERVIEW OF RG 1.208 GUIDANCE FOR UPDATING ACCEPTED EXISTING SEISMIC SOURCE MODELS

General discussion and general guidance for updating seismic source models that have been previously reviewed and accepted by the NRC can be found in several locations in RG 1.208.

- Regulatory Position 2.1 - Evaluation of New Seismic Sources

  "For sites in the CEUS, existing databases may be used to

[1] Accepted PSHA Model is adopted from Regulatory Guide 1.208, Appendix A. (The complete definition is given in this paper.) PSHA Model is used in this document to be equivalent to the more commonly used term "Seismic Hazard Model".

[2] New data are data that have become available subsequent to the NRC's acceptance of the accepted PSHA model under consideration.

[3] New information is used in this paper to mean interpretations of PSHA models that have become available subsequent to the NRC's acceptance of the PSHA model under consideration. See Section III for discussion.

[4] EPRI TR-1009684: "CEUS Ground Motion Project Final Report", 2004.

identify seismic sources to perform PSHA. Previously unidentified seismic sources that were not included in these databases should be appropriately characterized and sensitivity analyses performed to assess their significance to the seismic hazard estimate. The results of investigation discussed in Regulatory Position 1 should be used, in accordance with Appendix C to this regulatory guide, to determine whether the seismic sources and their characterization should be updated. The guidance in Regulatory Positions 2.2 and 2.3 (below) and the methods in Appendix C to this regulatory guide may be used if additional seismic sources are to be developed as a result of investigations."

In the context of this position statement "existing databases" should be interpreted to include accepted existing seismic source models. RG 1.208 Appendix C, which is referred to for guidance to determine whether a previously accepted seismic source model should be updated, primarily contains additional guidance for data compilation. Appendix C.3, included in full below, provides general guidance on new elements and parameters that should be evaluated using new data to determine whether accepted existing seismic source assessments require updating. But the guidance lacks details on procedures and evaluations acceptable to the NRC for determining whether an accepted existing source model requires updating (see Appendix C.3, below).

- Regulatory Position 2.2 - Use of Alternative Seismic Sources

"When existing methods and databases are not used or are not applicable, the guidance in Regulatory Position 2.3 should be used for identification and characterization of seismic sources. The uncertainties in the characterization of seismic sources should be addressed. "Seismic sources" is a general term that is equivalent to capable tectonic sources.

Identification and characterization of seismic sources should be based on regional and site geological and geophysical data, historical and instrumental seismicity data, the regional stress field, and geological evidence of prehistoric earthquakes. Investigations to identify seismic sources are described in Appendix C to this regulatory guide. The bases for the identification of seismic sources should be described. A general list of characteristics to be evaluated for seismic sources is presented in Appendix C."

This regulatory position provides guidance for development of a site-specific seismic source model for sites when an accepted existing seismic source model is not available or is not used as the starting basis. It points to Regulatory Position 2.3 and also to Appendix C for guidance on the scope of data to be evaluated for the development of a site-specific seismic source model, and to Appendix C.3 for a list of source model parameters that should be evaluated and characterized.

- Regulatory Position 2.3.1 - Characterizing Seismic Potential When Alternative Methods and Databases Are Used

The relevant part of Regulatory Position 2.3.1 is the following:

"For sites in the CEUS, the seismic sources and data accepted by the NRC in past licensing decisions may be used as a starting point, along with the data gathered from the investigations carried out as described in Regulatory Position 1."

Regulatory Position 2.3.1 restates a portion of Regulatory Position 2.1 with minor differences

- Appendix C.3 - Evaluation of New Information Obtained from the Site-specific Investigations

"The first step in reviewing the new information obtained from the site-specific investigations with previous interpretations is determining whether the following existing parameters are consistent with the new information: (1) the range of seismogenic sources as interpreted by the seismicity experts or teams involved in the study, (2) the range of seismicity rates for the region around the site as interpreted by the seismicity experts or teams involved in the studies, (3) the range of maximum magnitudes determined by the seismicity experts or teams, and (4) attenuation relations. The new information is considered not significant and no further evaluation is needed if it is consistent with the assumptions used in the PSHA, no additional alternative seismic sources or seismic parameters are needed, or it supports maintaining the site mean seismic hazard."

Appendix C.3 identifies the seismic source model parameters that should be evaluated to determine whether new data and information indicate that they need to be modified. Detailed guidance is lacking on procedures acceptable to the NRC for performing the evaluations as well as on acceptable criteria for determining whether assessments of new data require updating of elements or parameters of an accepted existing seismic source model.

- Appendix A - Definitions

<u>Accepted PSHA Model</u> "An accepted PSHA model is a method of conducting a Probabilistic Seismic Hazard Analysis (including the seismic sources and ground motion equations) that has been developed using Senior Seismic Hazard Analysis Committee (SSHAC) guidelines and that has been reviewed and accepted by the NRC in the past either for generic application (e.g., the 1989 studies by LLNL and EPRI, with the inherent seismic source description for the CEUS) or as part of an ESP or COL application. Accepted PSHA models are starting points for developing probabilistic seismic hazard calculations for new ESP or COL applications, yet must be updated with new information on seismicity, geology, geophysics, and ground motion equations, as appropriate for a site that is being reviewed. The term accepted PSHA model should not be assumed to imply that the model can be used without updates or reviews as discussed RG 1.208."

The term "PSHA Model" as defined in RG 1.208 is consistent with the term "Seismic Hazard Model" that is more generally used by the seismic hazard community. The definition provides the important guidance that an Accepted PSHA Model is one that 1) has been developed implementing the SSHAC guidelines and 2) has been reviewed and accepted by the NRC for generic application or as part of a past site-specific ESP or COL application. This definition clearly accepts the EPRI/SOG generic regional seismic source model as a starting basis for performing new site-specific PSHAs for sites located in the CEUS.

III. DISTINCTION BETWEEN DATA AND INFORMATION

The terms "data" and "information" are used in both their normal meanings and somewhat interchangeably in the guidance provided in RG 1.208. No clear distinction is made between "new data" and "new information" for determining whether accepted existing seismic source models require updating. An example of the uses of these terms in their normal meanings is in RG 1.208 (B. DISCUSSION).

"Geological, seismological, and geophysical investigations are performed to develop an up-to-date, site-specific, earth science database that supports site characterization and a PSHA. The results of these investigations will also be used to assess whether new data and their interpretation are consistent with the information used in

probabilistic seismic hazard studies previously accepted by the NRC."

Here the term data is used in its normal meaning in scientific discourse and interchange: physical data obtained from investigations that may be used as the basis for calculations or as the basis for evaluations or interpretations. The term information is used here consistent with its normal more general meaning, to refer to totality of the data, data evaluations, interpretations and assessments that are captured in a seismic hazard model previously accepted by the NRC.

An example of the interchangeable use of the terms "data" and "information" is given in Appendix C.1, first paragraph.

"..... Geological, seismological, and geophysical investigations provide the information needed to identify and characterize source zone parameters, such as size and geometry, and to estimate earthquake recurrence rates and maximum magnitudes. The amount of data available ...."

Data, data evaluations, and data interpretations all can reasonably be considered to be "data" for the purpose of providing regulatory guidance and may be evaluated and treated the same for determining whether updating of accepted existing seismic source models is required. In contrast to new data, new information such as a new seismic hazard model that is the product of an integrated assessment of data using a selected SSHAC assessment process (e.g., as indicated in the given definition for an *Accepted PSHA Model*) involves different evaluation procedures for determining whether the information requires updating of an accepted seismic hazard model. The different evaluation procedures are needed independently of whether the new PSHA model is based on old data, i. e., data that were assessed for development of the accepted existing PSHA model or incorporates assessment of new data. Similarly, new information such as PSHA studies that do not meet the standard for an *Accepted PSHA Model* require still different procedure and evaluation guidance.

The examples given above illustrate the need to make a distinction between new data and new information for the purpose of developing guidance on procedures and evaluations to be followed for determining whether accepted existing seismic sources require updating.

IV. PROPOSED GUIDANCE FOR PROCEDURES AND EVALUATIONS FOR UPDATING ACCEPTED EXISTING SEISMIC SOURCE MODELS

RG 1.208 provides general guidance, as discussed above, for determining whether an accepted existing seismic source model requires updating, given new data or new information. As stated in the introduction to this paper, discussions during the meeting between the NRC and NEI on February 13, 2008 identified the need for more specific guidance than currently is contained in RG 1.208 on acceptable procedures and evaluations to determine whether accepted existing seismic sources require updating. Proposed more detailed procedure and evaluation guidance is described in the remainder of this paper.

A. Procedure and Evaluation Guidance for New Data

<u>Updating the Database for a Site Region</u>

Updating the geology, seismology and geophysics databases for a site region must be performed for every ESP or COL application. RG 1.208 Regulatory Position 1 together with Appendix C provides adequately detailed guidance for satisfying this requirement. The updated database, including the updated earthquake catalog for the site region must be evaluated to determine whether any element or parameter of an accepted existing seismic source model for the site requires updating.

<u>Proposed Procedure and Evaluation Guidance for New Data</u>

RG 1.208 provides clear guidance that accepted existing seismic source models, including the EPRI/SOG generic CEUS seismic source model and any site-specific seismic source models that have been reviewed and accepted by the NRC, may be used as the starting basis for development of a site-specific seismic source model for a new application. But more detailed specific procedure and evaluation guidance is needed to facilitate orderly review. Well-structured procedure and more detailed evaluation guidance for determining whether the updated database for a site region requires an accepted existing seismic source model to be modified is provided in RG 1.165, Appendix E.3. The guidance in Appendix E.3 is generally consistent with the more general guidance provided in RG 1.208 and it is clear that the intent of the guidance for performing this evaluation contained in the two regulatory guides is the same.

The evaluation guidance below presented as a three-step procedure, is consistent with procedures that have been followed and evaluations that have been performed for the preparation of seismic sections of recent ESP and COL applications to determine whether new data required accepted existing seismic source models to be modified. Except for the addition of Step 1, the guidance described in these steps has been adopted from RG 1.165 Appendix E.3 with modification as appropriate to reflect current state of practice for developing site-specific performance goal-based ground motion response spectra (GMRS).

Step 1: The purpose of Step 1 is to develop site-specific generic rock GMRS and sensitivity results using the accepted existing seismic source model. These results will be used for comparison with the results of subsequent steps of the proposed evaluation procedure to determine whether any updating of the site-specific GMRS is needed. The site-specific generic rock GMRS[5] is an acceptable basis for this comparison. Site-specific generic rock GMRS computations for a new application (a Greenfield site or new units at an existing operating plant site) should be based on hazard at 10^{-4} and 10^{-5} annual exceedance frequencies obtained using the site-specific accepted existing seismic source model. Sensitivity evaluations should be in enough detail to illustrate the sensitivity of the generic rock GMRS to elements and parameters of the accepted existing seismic source model and to serve as benchmark results for comparison with the affect of any changes in elements or parameters of the model that may result from evaluations of new data or new information as described in the following steps.

Step 2: This step consists of evaluating new data and determining whether elements or parameters of the accepted existing seismic source model should be modified. The proposed evaluations are consistent with the general guidance contained in RG 1.208 Appendix C.3. For performing a PSHA for an ESP or COL application, RG 1.208 guidance is to start with an accepted existing seismic source model. Data that have become available in the site region subsequent to the NRC's review of the accepted seismic source model must be evaluated and assessed to determine whether any element or parameter of the accepted existing model should be modified. Consistent with the definition of "*Accepted PSHA Model*" given in RG 1.208, a SSHAC Level

[5] Generic Rock for the CEUS is defined as rock having defined properties that were used to develop the EPRI 04 Ground Motion Model.

2 or a higher level assessment process is appropriate for evaluating any new data and for assessing any new seismic source model parameters for comparison with those of the accepted existing seismic source model used in Step 1. A SSHAC Level 2 assessment is considered appropriate because it assures appropriate thoroughness, assessment rigor, and level of documentation for development of a site-specific seismic source model and determination of a site-specific GMRS for nuclear facilities.

In a Level 2 process an experienced Technical Integrator (TI) team performs the evaluations and uncertainty assessments. The Level 2 evaluation and assessment process includes comprehensive consultations with scientists and seismic hazard experts who are informed about the new data, including authors of published studies and seismic source characterization experts. The goal of the TI's evaluations is: 1) to develop a comprehensive understanding of the quality of any new data or interpretations of new data in the site region, 2) to capture the range of informed experts' understandings of the degree of scientific support for any new data interpretations, and 3) to weight any new data or interpretations properly accounting for informed experts' understanding of the credibility of the new data and interpretations in the context of the informed scientific community's understanding of regional tectonic and earthquake processes. The assessments performed by the TI address uncertainty in the new data, the uncertainty in scientific support for any interpretations of the new data considering the level of uncertainty in the data and in models used, and importantly, addresses whether the new data or any interpretations of the new data are inconsistent with the informed scientific community's understanding of the fundamental regional tectonic and earthquake processes. Thus, the SSHAC Level 2 process assures a fully balanced assessment in which the TI performs as the integrator and assesses uncertainty that properly captures the range of understanding of the informed experts. Additionally, a Level 2 assessment requires full documentation of the evaluation process and of the bases for the assessments.

If after completing the evaluations and assessments as described in this step it is determined that assessed parameters based on new data are within the range of parameters of the accepted existing seismic source model (for example, the updated earthquake catalog does not result in an increase in the earthquake activity rate or contain earthquake magnitudes larger than the maximum magnitude of the assessed maximum magnitude distribution for an element of the seismic source model), the accepted existing seismic source model may be used as in Step 1 for determination of the GMRS for the site of interest and no additional evaluations are required.

If after completing the evaluations and assessments of new data as described in this step it is determined that the new data have been adequately vetted and have broad acceptance in the informed community, elements or parameters of the accepted existing seismic source model should be modified consistent with the results of the Level 2 assessment and this updated seismic source model should be used for sensitivity evaluations as described in Step 3 of this procedure to determine whether it results in a significant increase in the generic rock GMRS at the site.

Step 3: This step consists of sensitivity evaluations to determine whether any increase in the site-specific generic rock GMRS obtained using the updated seismic source model from Step 2 is significant with respect to seismic risk. These evaluations may be made using the site-specific generic rock GMRS since the GMRS properly incorporates the slopes of the hazard curves between 10^{-4} and 10^{-5} annual exceedance frequencies. Any changes in the generic rock GMRS should be determined by comparing the generic rock GMRS obtained using the modified site-specific seismic source model developed in Step 2 with the generic rock GMRS obtained in Step 1. For this comparison, when a site of interest is located far away from seismic zones such as the New Madrid and Charleston Seismic Zones that contribute to the hazard at distant sites, a simplified composite source geometry representing alternative assessments of seismic sources for these seismic zones may be used. In addition sensitivity evaluations should be performed as in Step 1 to determine the sensitivity of the generic rock GMRS to the modified elements or parameters of the site-specific accepted existing seismic source model. The significance of any increase in site-specific generic rock GMRS should be based on a risk informed criterion. A sensitivity analysis resulting in less than a 20% cumulative change in the mean annual frequency of exceedance of the GMRS defined in Step 1 is sufficiently small as to not warrant revision of the GMRS. Such a change has only a minor effect on the achieved performance goal and is accommodated by the conservatism built into the performance goal methodology. The Design Factors (DF) used to define the GMRS from the UHRS are conservatively biased such that the achieved Frequency of Onset of Significant Inelastic Deformation (FOSID) levels are on average 20% less than target level of $1\text{x}10^{-5}$/yr. In addition, Seismic Core Damage Frequency (SCDF) levels are a factor of 2 to 10 times less than FOSID levels; therefore, a sensitivity study resulting in a 20% cumulative change in the mean annual frequency of exceedance of the GMRS would not warrant revision of the GMRS[6].

B. Procedure and Evaluation Guidance for New Information

New information such as new seismic source assessments developed to support PSHAs for non-nuclear facilities, for research, or for demonstration purposes should require separate procedures and additional evaluations that are not described in RG 1.208. The procedures should include evaluations that consider the purpose of the seismic source assessment, the SSHAC level implemented for conducting the assessment, the scope and completeness of documentation, and whether the assessment included evaluations of new data not previously evaluated for assessment of the accepted existing seismic source model. Seismic source assessments for PSHAs that support seismic design evaluations for facilities such as bridges and the normal building inventory do not have the overall public safety assurance requirements of nuclear facilities. These evaluations normally employ a SSHAC Level 1 assessment procedure or alternatively, may rely substantially or completely on a procedure such as spatial smoothing of historical seismicity. For a Level 1 assessment, the analyst performs a literature review and develops a seismic source model for the site of interest. While a Level 1 assessment is expected to incorporate the uncertainty of the informed scientists and seismic hazard assessment experts, normally it does not involve the level of rigor and documentation required for higher level SSHAC assessments that are required for nuclear facilities. Also, while a simplified evaluation may involve interactions between the analyst and informed scientists and hazard assessment experts, the evaluations typically are not structured following the SSHAC guidelines. While these assessments are accepted for PSHAs that support building codes, which do not require definition of hazard at very low annual exceedance frequencies, they do not satisfy the defined requirements for an *Accepted PSHA Model* contained in the RG 1.208 guidance.

An applicant should evaluate such new information and document the evaluation in enough detail to support orderly review by the NRC staff.

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[6] Robert P. Kennedy. "Risk (Performance-goal) Based Approach for Establishing the SSE Design Response Spectrum for Future Nuclear Power Plants", Appendix A in R. McGuire 2005. "Assessment of a Performance-Based Approach for Determining the SSE Ground Motion for New Plant Sites, V1: Performance-Based Seismic Design Spectra", EPRI TR-1012044, Electric Power Research Institute, Palo Alto, CA.

The scope of documentation should include the purpose of the seismic source evaluation, the evaluation procedures used, the level of documentation, and any other information that would support informed review of the application. If such evaluations include new data that were not evaluated as part of the assessment of the accepted existed seismic source model, such new data should be evaluated following the procedure and evaluation guidance described in Steps 1 through 3 above.

New seismic sources developed using a fully implemented SSHAC Level 2 assessment process or higher are expected to satisfy the requirements for nuclear facility application. The assessment performed for development of such new seismic sources may or may not include evaluations of new data not previously evaluated for characterizing the accepted existing seismic source model. The procedures and evaluation for these cases should be as follows:

1) When the new seismic source assessment using a SSHAC Level 2 process or higher does not include evaluations of new data not previously evaluated for assessment of the accepted existing seismic source model, the new seismic source assessment should be combined with the accepted existing seismic source model giving it weight equal to a single additional seismic source assessment team. For example, when the EPRI SOG seismic source model (which is constituted of six expert teams' models) is the accepted existing seismic source model, the new seismic source assessment will become the seventh team and each of the seven teams will be equally weighted. This model becomes the updated site-specific seismic source model for the site. The evaluations described in Step 3 above are then made using this updated site-specific seismic source model.

2) When the new seismic source assessment using a SSHAC Level 2 process or higher does incorporate evaluations of new data, the applicant should independently evaluate the new data as described in Step 2 above. If after completing the evaluations and assessments described in Step 2, it is concluded that the accepted existing seismic source model should be modified, the model should be updated as supported by the Level 2 assessment performed by the applicant. This updated site-specific seismic source model should be used together with the appropriately weighted new seismic source assessment to perform the evaluations described in Step 3 above. The appropriate weight for combining the new seismic source with

the applicant's updated site-specific seismic source model will be determined by the degree to which the new source assessment satisfies the procedure and documentation requirements for a full SSHAC Level 2 assessment or higher.

When a new seismic source assessment potentially affects multiple nuclear plant sites, a generic sensitivity evaluation may be performed assuming a geographic location for a hypothetical site that maximizes the affect of the new source assessment. This generic sensitivity assessment can be used for the multiple potentially affected sites.

White Paper on

Seismic Hazard in the Eastern Tennessee Seismic Zone

Prepared for

Electric Power Research Institute

By

Risk Engineering, Inc.

Boulder, Colorado

May 12, 2008

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INTRODUCTION

This study examines the seismic hazard at a site located in the Eastern Tennessee Seismic Zone (ETSZ) and examines the sensitivity of hazard at that site to different assumptions on seismicity in the region. As background, the Electric Power Research Institute (EPRI, 1989) conducted a large study of seismic hazard in the central and eastern US (CEUS) in the 1980s—known as the EPRI-SOG study since it was funded by the Seismicity Owners Group—that has become the starting point for recent assessments of seismic hazard for current nuclear plant license applications. Several updates of the EPRI-SOG study have been made in recent license applications to account for new information, particularly for the New Madrid seismic zone and for the Charleston, South Carolina regions, both of which have experienced large earthquakes in historical times.

The ETSZ has been included in two additional studies, the first a study conducted by Lawrence Livermore National Laboratory (LLNL, 2002) herein termed the "TIP study" (it was designated the Trial Implementation Project), and the second a study conducted by Geomatrix (2004) herein termed the "DSS study" (it was designated the TVA Dam Safety Study). The 6 Earth Science Teams that participated in the original EPRI-SOG study identified the ETSZ as a possible source of earthquakes, with varying credibility ascribed to a local source representing that seismicity. Over all the various EPRI-SOG interpretations, the maximum magnitude possible for the ETSZ was given a wide distribution that, on the moment magnitude scale **M**, represented values of $\mathbf{M}_{max}$ from 4.5 to 7.5, with a mean value of about 6.0 (see Figure 1, taken from Ref. 3). The TIP and DSS studies developed their own evaluations of the ETSZ and also assigned a broad range of maximum magnitudes to this zone, from $\mathbf{M}_{max}$ 5.25 to 8.25 (see Figure 1). The mean $\mathbf{M}_{max}$ value for both the TIP and DSS studies is about 6.6.

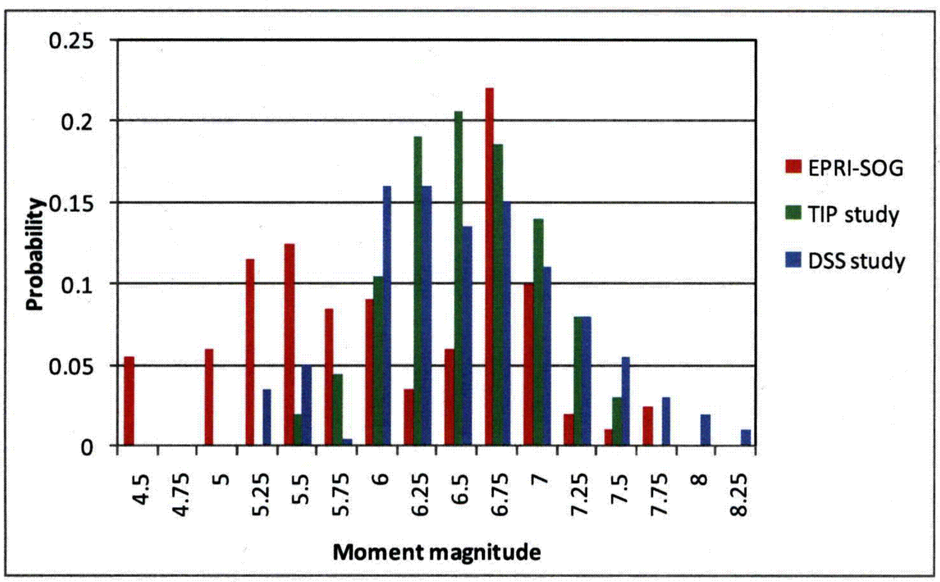

Figure 1: $\mathbf{m}_{max}$ distribution (in terms of M scale) for ETSZ, derived from Ref. 3.

The largest historical earthquake recorded in the ETSZ is less than 5.0, and no evidence of large paleo-earthquakes has been documented in the ETSZ, so values of $\mathbf{M}_{max}$ must be inferred from geology, tectonics, and analogies with other regions throughout the world. Such inferences are subject to large uncertainties, resulting in the broad range of values shown in Figure 1.

In order to determine the effect of alternative interpretations of $\mathbf{M}_{max}$ for the ETSZ on seismic hazard from the EPRI-SOG study, one must examine and evaluate how the EPRI-SOG study should be updated to account for new information. For example, the alternative $\mathbf{M}_{max}$ values for the ETSZ might themselves be very influential on seismic hazard at a site close to or within the ETSZ, but if the total hazard at that site is dominated by some other source and the ETSZ contributes a small fraction of the total hazard, changes caused by alternative $\mathbf{M}_{max}$ values would have a minor effect. Also, the EPRI-SOG study was a multi-million dollar, multi-year effort involving 20-25 earth scientists evaluating earthquake sources, and the resulting interpretations should not be completely discarded in favor of alternative interpretations that do not necessarily represent a consensus of scientific opinion.

With this perspective, updating the ETSZ interpretations must also include updating the catalog of seismicity in the CEUS since the EPRI-SOG study. The EPRI-SOG catalog of earthquakes included events through 1984, and most comparisons of seismicity rates indicate that, if anything, mean seismicity rates in the ensuing 23+ years have decreased.

Thus the overall path followed by this study has the following tasks:

Task 1: Update seismicity catalog. Several regional catalogs are used to extend the EPRI-SOG catalog from 1984 to 2006, the most recent year for which complete data are available.

Task 2: Modify seismicity rates and m_{max} values of EPRI-SOG teams. The seismicity parameters and m_{max} values of seismic sources used to represent the ETSZ are modified to reflect the updated seismicity catalog and to parallel the interpretations of maximum magnitudes used in the TIP and DSS studies.

Task 3: Determine sensitivity to alternative interpretations. The seismic hazard using the modified parameters is compared to the hazard with the original EPRI-SOG parameters to quantify the effect of any change in seismic hazard on ground motions that might be used for seismic design.

Task 4: Perform integration using alternative interpretations and determine significance. If the sensitivity from Task 3 indicates that the alternative assumptions are potentially significant, determine how the alternative assumptions might be incorporated into a seismic hazard analysis in a balanced way. As stated above, it would not be appropriate to completely discard the interpretations of a major, multi-year study to adopt alternative assumptions that are not based on new data or on widely accepted scientific interpretation. Once the alternative assumptions are incorporated in a balanced way, determine the impact on seismic hazard and evaluate whether the alternative assumptions are significant.

The remainder of this report describes the application of these tasks to the ETSZ and the conclusions regarding seismic hazard.

UPDATED SEISMICITY CATALOG

The region in the CEUS that was examined for updated seismicity is shown in Figure 2. This region was selected because it encompasses all seismic sources used to depict the ETSZ for the 6 EPRI-SOG teams (see the next section). Updating the seismicity parameters for these sources requires an updated earthquake catalog for the entire region covered by any of these seismic sources.

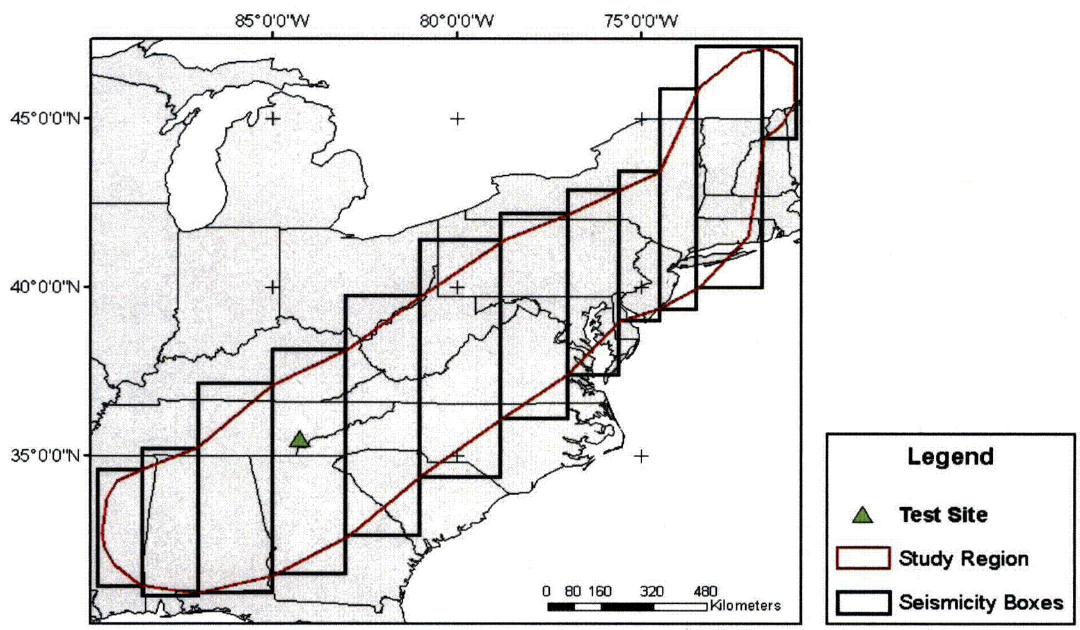

Figure 2. Study region for updated earthquake catalog (shown in red), and longitude-latitude boxes used to collect earthquakes for analysis.

Four regional earthquake catalogs were compiled to develop a composite catalog for the entire region shown in Figure 2. In all cases, earthquakes with $m_b \geq 3$ in the study region were used. These four catalog sources were:

Southeastern US Seismic Network. The Virginia Tech Seismological Observatory (VTSO) compiles the Southeastern US Seismic Network (SEUSN) Bulletins, which contain earthquakes from 1977 through 2005. These bulletins are available from the VTSO website. An additional file contains earthquakes in 2006. Non-seismic events (mine blasts, explosions) have been removed from these catalogs. Figure 3 shows the region where the SEUSN is considered "authoritative" by the Advanced National Seismic System (ANSS).

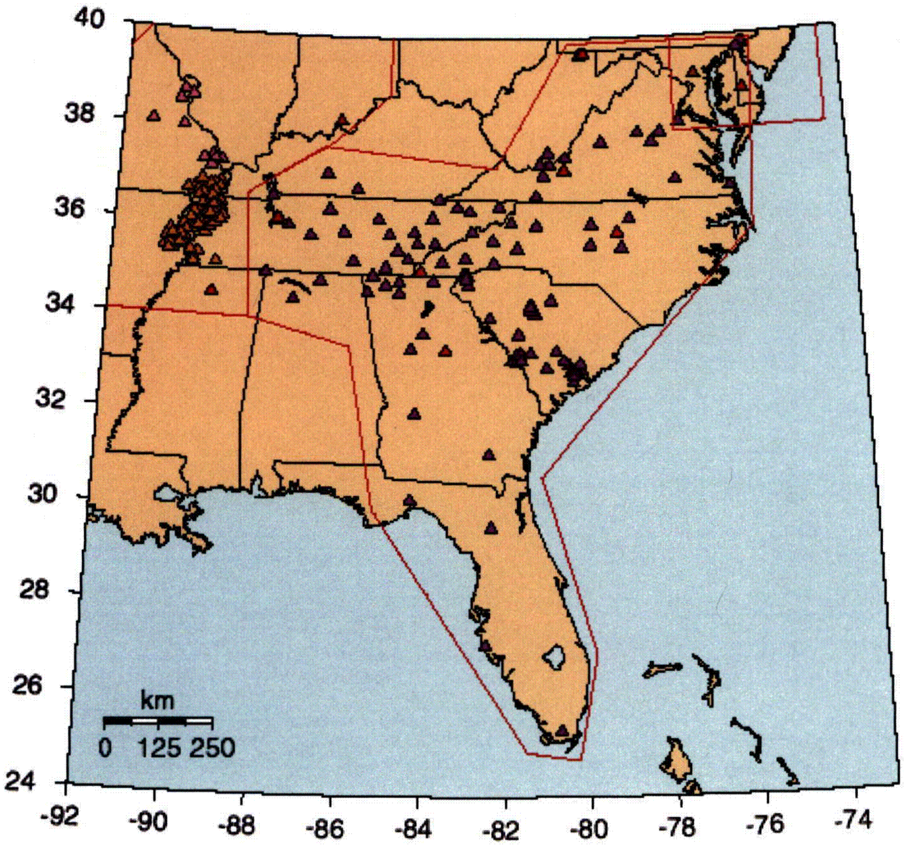

Figure 3. Region where SEUSN is considered authoritative by ANSS (from ANSS website). Blue triangles are SEUSN seismic stations, other triangles are stations run by other networks.

Lamont-Doherty Cooperative Seismographic Network. The Lamont-Doherty Earth Observatory, part of Columbia University, operates the Lamont-Doherty Cooperative Seismographic Network (LCSN). The LCSN catalog can be downloaded from the LCSN website, giving earthquakes from 1970 to present. Earthquakes from 1985—2006 were used in the current study. Figure 4 shows the region where the LCSN is considered "authoritative" by the Advanced National Seismic System (ANSS).

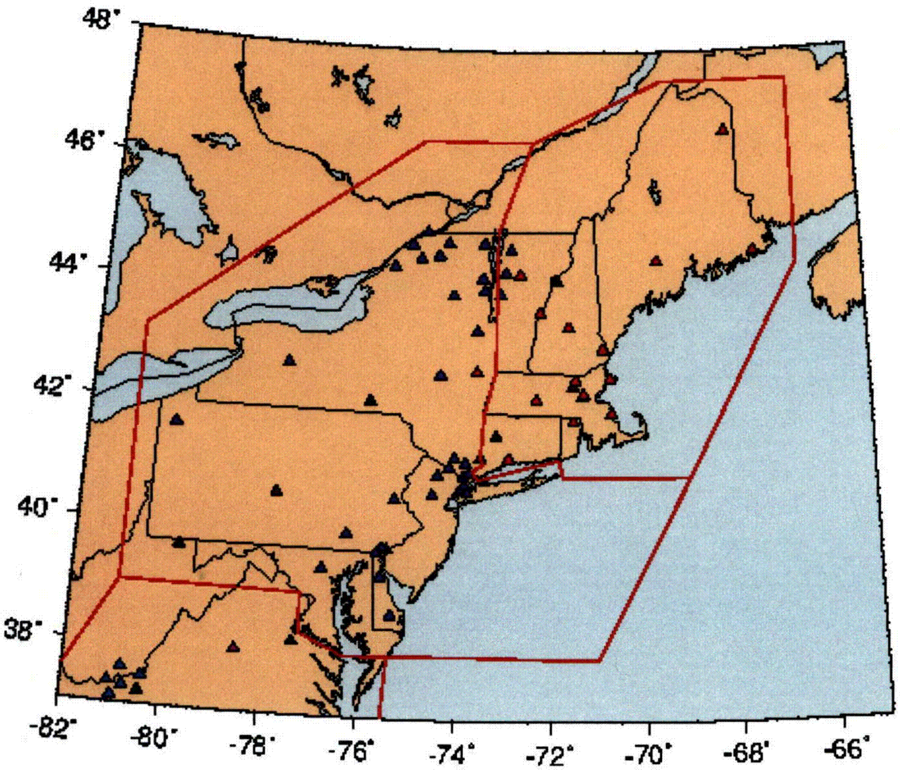

Figure 4: Regions for which LCSN (in New York, Pennsylvania, and adjacent states) and NESN (in New England) are considered authoritative by ANSS (from ANSS website). Blue triangles are LCSN seismic stations, red triangles are NESN seismic stations, other triangles are stations run by other networks.

New England Seismic Network. The New England Seismic Network (NESN) is operated by Weston Observatory, part of Boston College. Weston Observatory publishes quarterly bulletins for the NESN data, which are available from the Weston Observatory website. Separate catalogs are available for the years 1568-1990, 1990-1999, and 2000-2005. Quarterly bulletins are available to augment the catalog for 2006. Note that the first 2 catalogs overlap for the year 1990, and the locations and magnitudes contained in the 1st catalog for the year 1990 are preferred.

National Earthquake Information Center. The US Geological Survey/National Earthquake Information Center (NEIC) publishes a monthly Preliminary Determinations of Epicenters (PDE) listing. This list is the most complete computation of hypocenters and magnitudes done by the USGS NEIC. It is normally produced a few months after the events occur. The publication is called "Preliminary" because the "final" computation of hypocenters for the world is considered to be the Bulletin of the International Seismological Centre (ISC), which is produced about two years after the earthquakes occur. NEIC is considered the default authoritative source for earthquakes outside the local network regions shown in Figures 3 and 4. The NEIC catalog was used to supplement the other 3 catalogs in central and southern Alabama, and in eastern Kentucky and western West Virginia.

Earthquakes with $m_b \geq 3$ in the four catalogs were assembled, duplicates and dependent events (foreshocks and aftershocks) were removed with preference on duplicate events going to the seismic network considered to be authoritative by ANSS (as shown in Figures 3 and 4). The only exception was that in central and southern Alabama, the locations and magnitudes of the SEUSN were adopted over those of the NEIC catalog, based on the advice of network operators (Chapman, personal communication, 2008). To identify duplicates and dependent events, the algorithm of Gardner and Knopoff (1974) was used as a flag, and all flagged events were individually examined. The result was a catalog of 136 earthquakes in the study region from 1985-2006 with $m_b \geq 3$ that can be used to extend the EPRI catalog. Figure 5 shows earthquakes from the original EPRI-SOG catalog and the additional 136 earthquakes identified in the study region. Figure 5 also shows the location of the test site used for seismic hazard calculations described below.

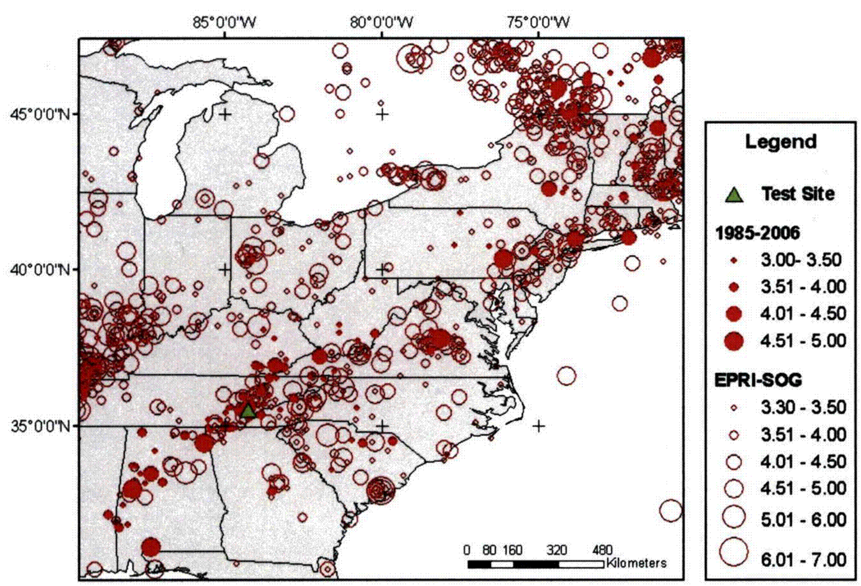

Figure 5: Original EPRI-SOG earthquakes, and earthquakes in the extended catalog.

MODIFICATION OF SEISMICITY RATES AND M_{max} VALUES.

The EPRI-SOG team sources representing seismicity in the region of the ETSZ were updated to calculate revised seismicity parameters using the extended earthquake catalog. These updated sources are listed in Table 1 with their probabilities of activity (P_a).

Table 1. EPRI-SOG team sources representing the ETSZ and related background zones.

Team	Source	Name	P_a	Comment
Bechtel	BEC-24	Bristol trends	0.25	ETSZ source
	BEC-25	NY-AL lineament	0.30	ETSZ source
	BEC-25A	Altern. for 25	0.45	ETSZ source
Dames & Moore	DAM-04	Appalachian fold belt	0.35	ETSZ source
	DAM-4A	Kink in fold belt	0.65	ETSZ source
Law Engineering	LAW-17	Eastern basement	0.62	ETSZ source
	LAW-217	Background for 17	0.38	Background
Rondout	RND-13	So. NY-AL lineament	1.0*	Adjacent source
	RND-25	So. Appalachians	0.99*	ETSZ source
	RND-27	TN-VA border zone	0.99*	Adjacent source
Woodward-Clyde	WCC-31	Blue Ridge comb.	0.024	ETSZ source
	WCC-31A	Blue Ridge comb.—Altern.	0.211	ETSZ source
	WCC-BG	Background	0.765	Background
Weston	WGC-24	NY-AL Clingman	0.90	ETSZ source
	WGC-103	So. Appal. background	0.10	Background

*-- Rondout source RND-25 overlays most of the ETSZ, see Figure 9. P_a was taken as 1.0 for all three sources. The two adjacent sources were treated conservatively here as though they also represent the ETSZ.

Maps of each team's seismic sources listed in Table 1 are shown in Figures 6-11. Note that the notch in Figure 7 for Dames & Moore sources 4 and 4A is covered by source DAM-05, which is not modeled here. Note also that many EPRI-SOG sources extend well outside the ETSZ, and increasing $\mathbf{M}_{max}$ values in those areas would produce conservative estimates of seismic hazard that are not justified by the TIP and DSS studies. Also, many EPRI-SOG teams sources adjacent to the ETSZ have not been modeled here, because the focus is on the ETSZ, and therefore the sets of sources shown in Figures 6-11 would not be appropriate for a site located outside the ETSZ.

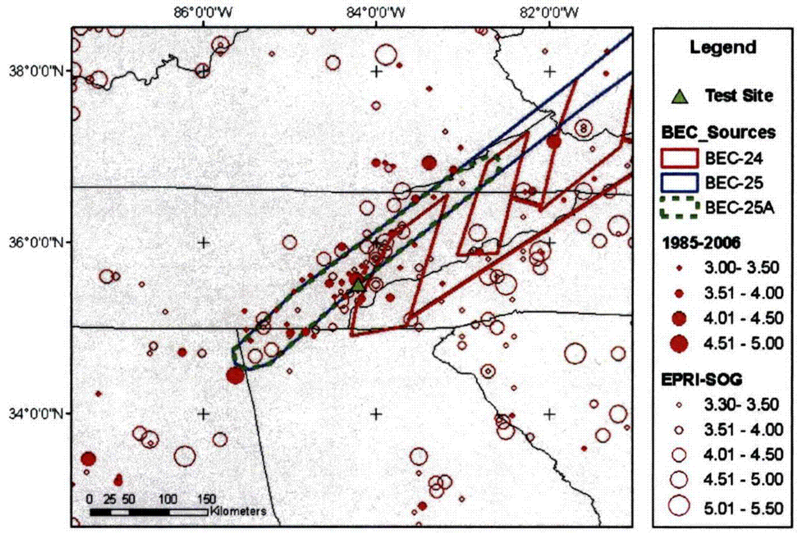

Figure 6: Map of Bechtel team seismic sources and historical seismicity.

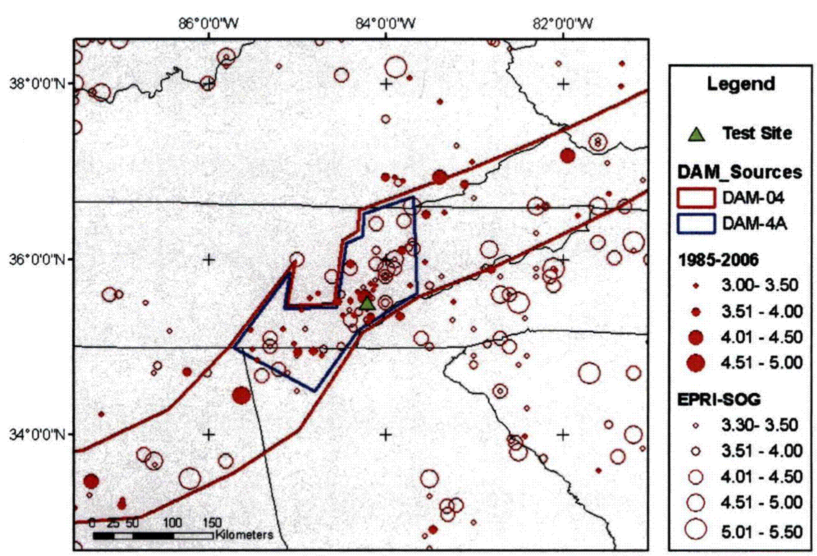

Figure 7: Map of Dames & Moore team seismic sources and historical seismicity.

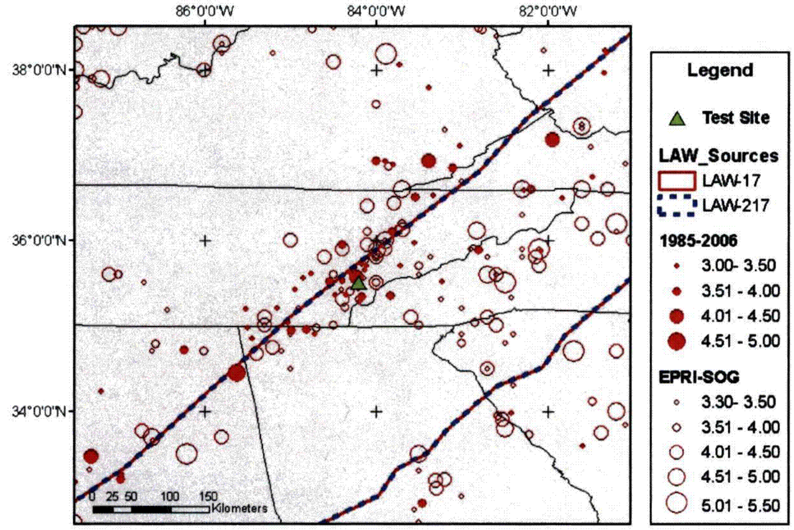

Figure 8: Map of Law team seismic sources and historical seismicity.

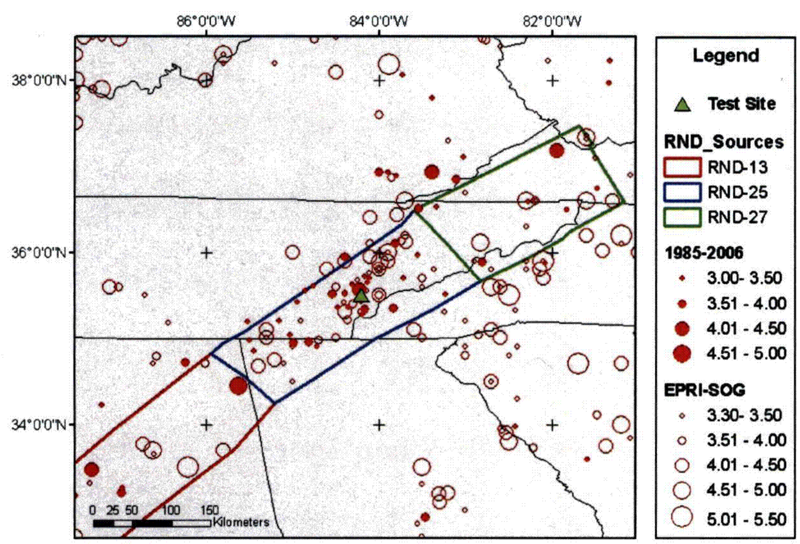

Figure 9: Map of Rondout team seismic sources and historical seismicity.

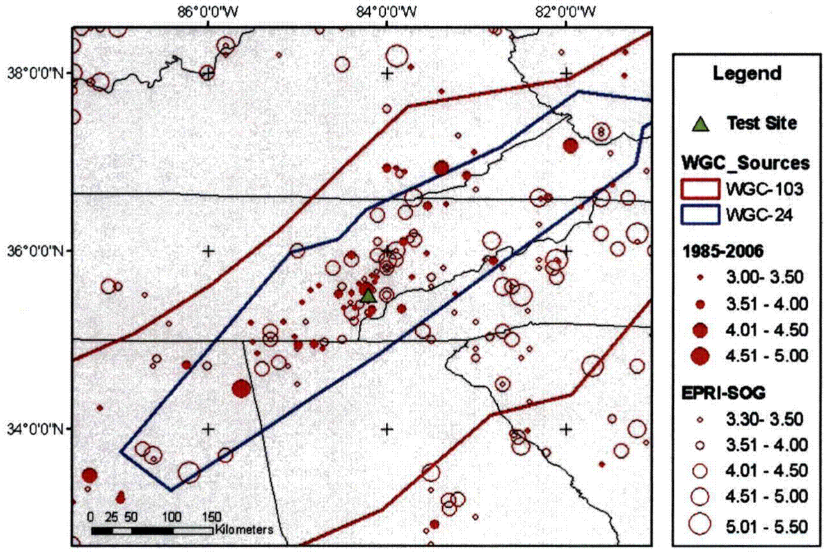

Figure 10: Map of Weston team seismic sources and historical seismicity.

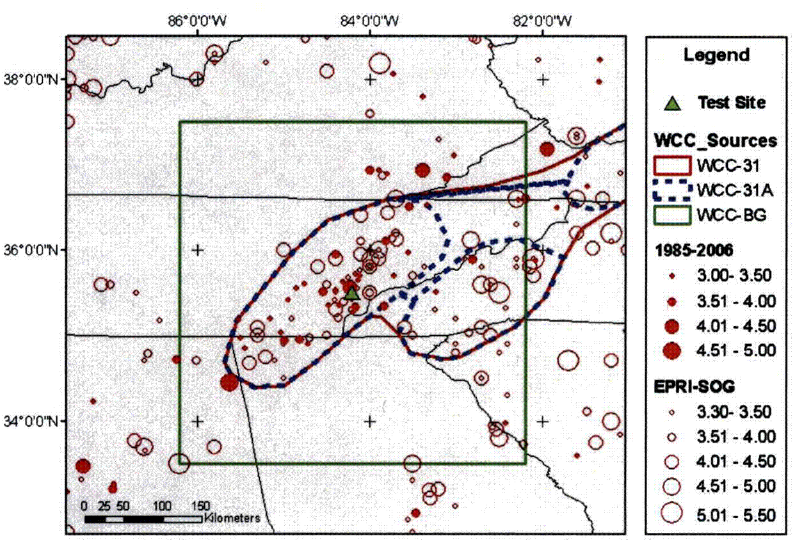

Figure 11: Map of Woodward-Clyde team seismic sources and historical seismicity.

Smoothing assumptions on seismicity parameters for all sources are summarized in Ref. 5, and these smoothing assumptions were used with the EPRI-SOG computer program EQPARAM to calculate updated seismicity parameters using the extended catalog.

Maximum magnitude values were updated using the probability mass functions shown in Figure 1, which are reproduced in Figure 12 for just the TIP and DSS studies. The values in Figure 12 are in terms of moment magnitude **M**, and the seismicity of the EPRI-SOG sources is described by body-wave magnitude m_b, so a conversion was necessary between the two scales. Three published conversion equations were used for this purpose: Atkinson and Boore (1995), EPRI (1993), and Frankel et al (1996). These conversion equations are reasonably consistent for **M** between 4.5 and 8, as shown in Figure 13, and an equally weighted average of the 3 equations was used for magnitude conversion.

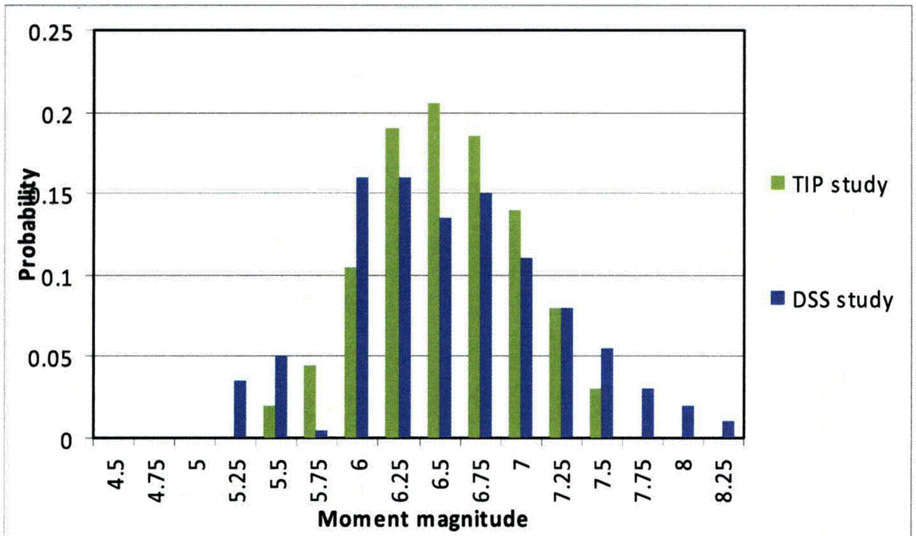

Figure 12: Reproduction of TIP and DSS distributions from Figure 1.

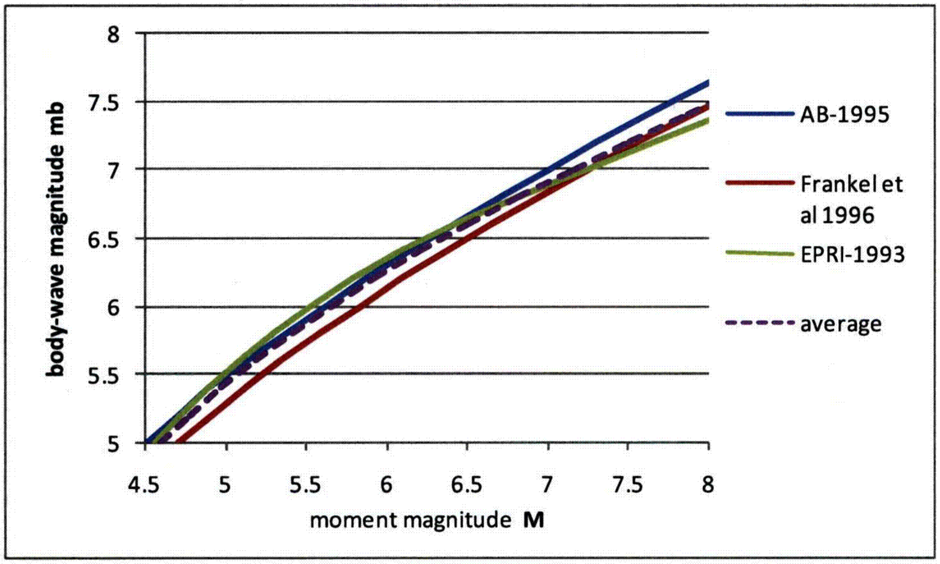

Figure 13: Conversion equations between M and m_b.

Values used to represent the **M** distribution in Figure 12 are shown in Table 2, along with equivalent m_b distributions and "chosen m_b values" which were selected at even 0.1 magnitude increments to be consistent with numerical integrations in seismic hazard calculations. Three magnitude values were selected using the mean and mean $\pm 1.4\times\sigma$ values of the original **M** distribution, and these 3 values were weighted 0.28, 0.44, 0.28. These values and weights accurately replicated the mean and σ values of the original distributions. These 3-point distributions were developed for the TIP study, the DSS study, and a composite distribution of the two.

Table 2. Magnitude distributions for TIP study, DSS study, and composite distribution.

Distribution		Lower (wt=0.28)	Central (wt=0.44)	Upper (wt=0.28)	mean	σ
TIP	**M** value	6.27	6.55	6.83	6.55*	0.21*
	equiv. m_b value	6.45	6.64	6.80	6.63	0.13
	chosen m_b value	6.4	6.6	6.8	6.6	0.15
DSS	**M** value	6.01	6.58	7.15	6.58*	0.43*
	equiv. m_b value	6.26	6.67	7.00	6.64	0.28
	chosen m_b value	6.2	6.6	7.0	6.6	0.30
Composite	**M** value	6.13	6.56	6.99	6.56*	0.32*
	equiv. m_b value	6.35	6.64	6.91	6.63	0.21
	chosen m_b value	6.3	6.6	6.9	6.60	0.22

*--values consistent with distribution from Figure 12.

The TIP and DSS studies are consistent in terms of mean $\mathbf{M}_{max}$ value, with both studies indicating a mean $\mathbf{M}_{max}$ of about 6.6. The TIP study has a smaller σ of 0.21 compared to 0.43 for the DSS study, and the composite distribution indicates a σ of 0.32. The σ values for the distributions in terms of m_b are somewhat lower because the slope of the **M-to-**m_b conversion is less than 1 (Figure 13).

SENSITIVITY TO ALTERNATIVE INTERPRETATIONS

To examine the effects of the extended catalog and the alternative m_{max} distributions, a test site was chosen at location 84.2°W, 35.5°N (see Figure 14). This site lies near the center of historical seismicity in the region and is a representative test case in the sense that any increase in hazard caused by the alternative m_{max} distribution will affect this site directly, compared to a site at the edges of the ETSZ or farther away where the ETSZ will have relatively less contribution to total seismic hazard. Note that the geometry of the ETSZ depends on the study and the specific interpretation.

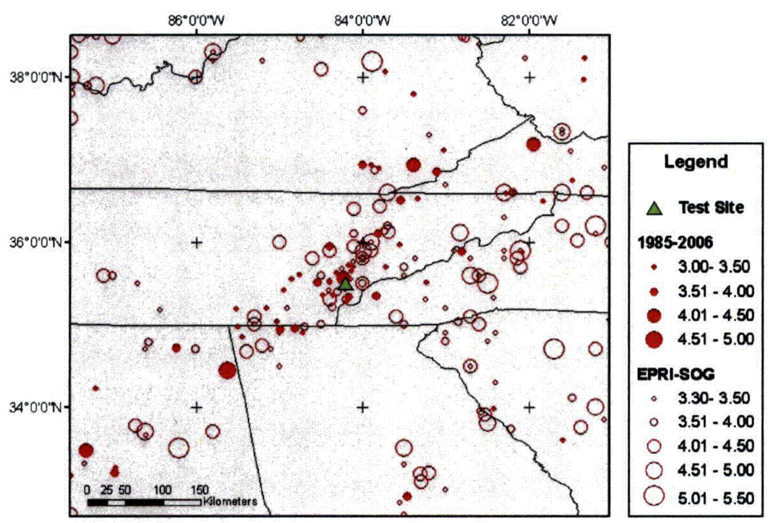

Figure 14. Map showing seismicity in ETSZ region from EPRI-SOG catalog, from extended catalog (1985—2006), and showing location of test site.

In order to properly represent the seismic hazard at the test site, several additional sources were included in the hazard calculations. These were the New Madrid faults, which were represented using the model developed for the Clinton ESP application (Exelon, 2003), and the Charleston seismic zone, which was represented using the model developed for the Vogtle ESP application (Ref. 10). These sources had the following characteristic magnitude ranges:

	Characteristic magnitudes
New Madrid faults	7.0—7.9
Charleston seismic zone	6.7—7.5

Three New Madrid faults are included in the model: the Blytheville fault, the East Prairie fault, and the Reelfoot fault. Earthquake occurrences were represented with a cluster model, accounting for the likelihood that a large earthquake on one fault will trigger large earthquakes on the other 2 faults (as happened in 1811-1812), and the parameters for the cluster model were taken from Ref. 3.

The test site shown in Figure 14 will accentuate any effect of an alternative m_{max} distribution for the ETSZ because only seismic sources representing the ETSZ, the New Madrid faults, and the Charleston seismic zone will be modeled. In a typical seismic hazard, adjacent seismic sources also contribute to seismic hazard, thus diluting the influence of any one source, but these adjacent seismic sources are not modeled here, for the sake of simplicity. As noted above, the test site is located near the center of the ETSZ and is within the seismic sources used to characterize the ETSZ by the EPRI-SOG teams.

Seismic hazard was calculated with the EPRI (2004) ground motion equations, using the Abrahamson and Bommer (2006) updated standard deviations representing aleatory uncertainty for those equations. These equations and aleatory uncertainties are available for spectral acceleration at 7 spectra frequencies: 100 Hz, 25 Hz, 10 Hz, 5 Hz, 2.5 Hz, 1 Hz, and 0.5 Hz. Hazard calculations were made, both without and with the Cumulative Absolute Velocity (CAV) filter documented by Hardy et al (2006) for both the original EPRI-SOG parameters and the alternative parameters. All calculations were made for hard-rock site conditions.

Seismic hazard was first calculated with the original EPRI-SOG seismicity parameters and m_{max} distributions for the ETSZ and with the updated New Madrid faults and Charleston seismic zone. This calculation used the source representation for the ETSZ indicated in Table 1. Specifically, the Bechtel team had 3 alternative representations for the ETSZ, with the P_a values shown in Table 1. Dames & Moore had 2 alternative representations. Law Engineering had one interpretation with P_a of 0.62, with a background active (with the complementation probability of 0.38) when the ETSZ was not active. The Rondout team had 3 sources, with P_a=1, representing parts of the ETSZ. Woodward-Clyde had 2 alternative representations, with a background zone active when neither of the ETSZ representations was active. Weston had one ETSZ and a background zone.

Plots of mean seismic hazard by source for each team for the non-CAV hazard calculation are included in Appendix A for 10 Hz and 1 Hz, those being typical measures of high- and low-frequency seismic hazard. Generally the ETSZ and background zones dominate the hazard for high frequencies, but the New Madrid faults show an important contribution at 1 Hz. The Charleston seismic zone generally does not contribute significantly to hazard.

A second calculation of seismic hazard was made with alternative parameters (updated seismicity parameters and the alternative m_{max} distribution summarized in Table 2). For this (and subsequent) calculations, the "composite distribution" of Table 2 was used. This alternative m_{max} distribution was applied to all ETSZ sources listed in Table 1, but not to background zones since these represent the interpretation (and probability) that a separate ETSZ does not exist.

Table 3 compares the 10^{-4} and 10^{-5} UHRS amplitudes and the GMRS amplitudes for the two calculations. The GMRS is calculated per Reg. Guide 1.208 using the following equations:

$$A_R = SA(10^{-5}) / SA(10^{-4}) \quad (1)$$

$$GMRS = \max[SA(10^{-4}) \times \max(1.0,\ 0.6\ A_R^{0.8}),\ 0.45 \times SA(10^{-5})] \quad (2)$$

where $SA(10^{-4})$ is the spectral acceleration for the 10^{-4} UHRS, and similarly for $SA(10^{-5})$. Table 4 shows a similar comparison that is identical in all respects except that this comparison is made between the original, CAV-filtered hazard and the alternative assumptions using the CAV-filtered hazard.

Table 3: Comparison between GMRS at test site for original EPRI-SOG parameters and alternative parameters, non-CAV hazard (note: % differences were calculated with more decimal places than are shown in the tables).

Freq. (Hz)	Orig 1E-4 (g)	Orig 1E-5 (g)	GMRS (g)	Alt. 1E-4 (g)	Alt. 1E-5 (g)	GMRS (g)	% DIFF
100	0.264	0.875	0.413	0.280	0.915	0.433	4.9%
25	0.725	2.45	1.15	0.765	2.56	1.21	4.8%
10	0.480	1.48	0.709	0.508	1.548	0.743	4.9%
5	0.306	0.896	0.434	0.322	0.942	0.456	5.2%
2.5	0.173	0.454	0.225	0.180	0.475	0.235	4.6%
1	0.0894	0.217	0.109	0.0911	0.220	0.111	1.4%
0.5	0.0615	0.165	0.0814	0.0620	0.165	0.0814	0.0%

Table 4: Comparison between GMRS at test site for EPRI-SOG parameters and alternative parameters, CAV-filtered hazard (note: % differences were calculated with more decimal places than are shown in the tables).

Freq. (Hz)	Orig 1E-4 (g)	Orig 1E-5 (g)	GMRS (g)	Alt. 1E-4 (g)	Alt. 1E-5 (g)	GMRS (g)	% DIFF
100	0.135	0.885	0.398	0.157	0.929	0.418	5.0%
25	0.351	2.43	1.09	0.410	2.56	1.15	5.4%
10	0.257	1.43	0.644	0.295	1.51	0.681	5.8%
5	0.191	0.842	0.379	0.210	0.893	0.402	6.1%
2.5	0.114	0.422	0.195	0.122	0.445	0.206	5.8%
1	0.0545	0.202	0.0933	0.0572	0.205	0.0954	2.2%
0.5	0.0302	0.149	0.0672	0.0314	0.149	0.0671	-0.2%

Tables 3 and 4 show that, for a site located near the center of seismicity in the ETSZ, when surrounding sources are not included in the analysis, and when all ETSZ of the EPRI-SOG teams are modified to adopt the alternative m_{max} distribution, the potential change in GMRS is about 6% or less, across all spectral frequencies. Figure 15A plots the PGA hazard curves for the original parameters and for the alternative parameters. Figure 15B expands Figure 15A for PGA amplitudes between 0.1g and 1g, and for annual frequencies between 10^{-4} and 10^{-5}. The small triangle in Figure 15B illustrates the effect of the 5% change in the GMRS from Table 4 (from 0.418g to 0.398g). Decreasing the GMRS by 5% will, for these amplitudes, imply a 6% increase in annual frequency of exceedence, because the log-log slope of the hazard curve is almost -1 (due to the effect of the CAV filter).

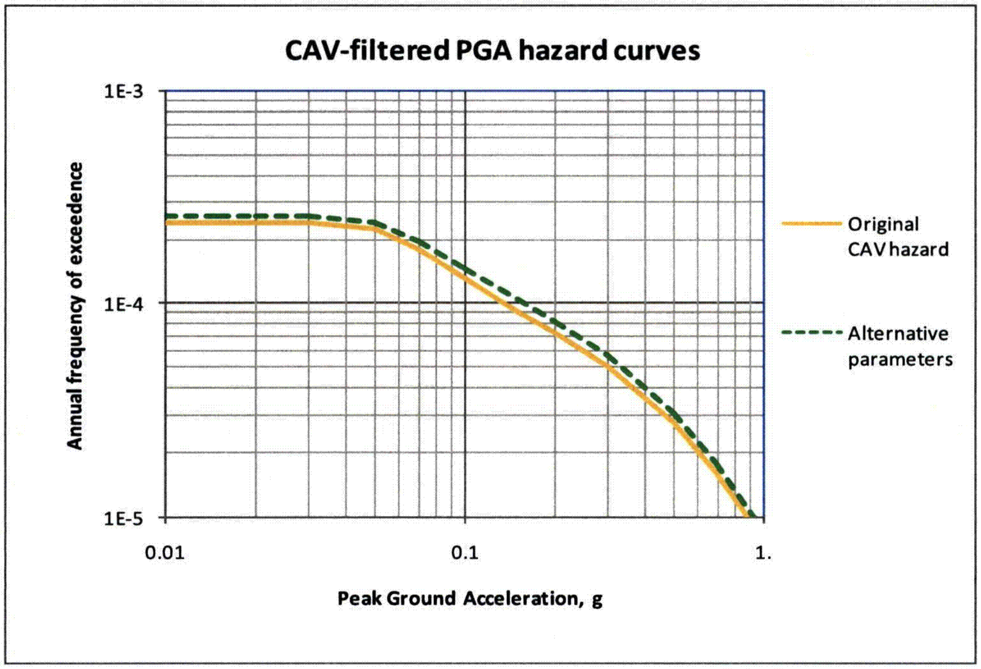

Figure 15A: PGA hazard curves using CAV filter for original analysis and for alternative parameters.

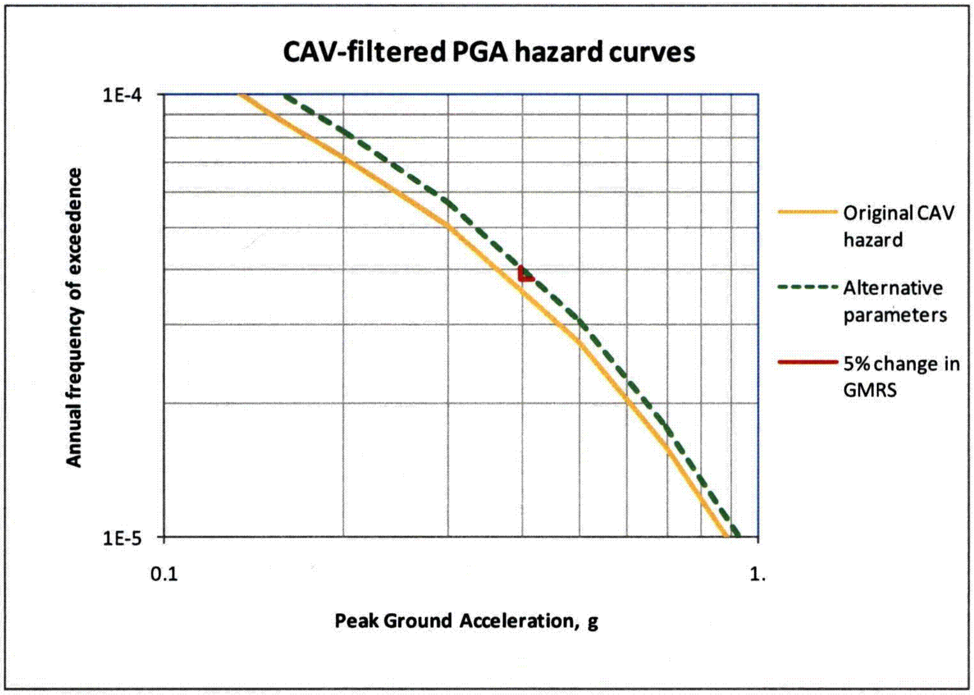

Figure 15B: PGA hazard curves from Figure 15A expanded to show only one order of magnitude on amplitude and frequency axes. The red triangle shows the change in amplitude and annual frequency when using the GMRS calculated from the original analysis compared to the alternative parameters.

INTEGRATION OF ALTERNATIVE INTERPRETATIONS

As mentioned above, it would not be appropriate to discard the m_{max} distributions for the ETSZ sources from the EPRI-SOG study entirely and substitute the alternative m_{max} distribution. The alternative m_{max} distribution was not developed as a result of earthquake occurrences in the region or a widely adopted theory, but rather represents alternative interpretations of two studies.

One reasonable way to include the alternative m_{max} distribution would be to say that it represents 2 additional studies (representing 2 additional teams) that should be added to the composite hazard calculation. This can be achieved by calculating the hazard for the 6 EPRI-SOG teams, giving this hazard 75% weight (6 teams out of 8), and calculating the hazard the for EPRI-SOG teams with the alternative m_{max} distribution and giving this hazard 25% weight (representing 2 additional teams out of 8). Both calculations would use the updated seismicity parameters through 2006 to represent the extended earthquake catalog. This is designated here the "integrated calculation."

Table 5 compares the 10^{-4} and 10^{-5} UHRS amplitudes and the GMRS amplitudes for the original EPRI-SOG assumptions and for the integrated calculation using the non-CAV hazard. Table 6 shows a similar comparison between the original CAV-filtered hazard and the integrated, CAV-filtered hazard.

Table 5: Comparison between GMRS and UHRS at test site for EPRI-SOG parameters and integrated m_{max} values, non-CAV hazard (note: % differences were calculated with more decimal places than are shown in the tables).

Freq. (Hz)	Orig 1E-4 (g)	Orig 1E-5 (g)	GMRS (g)	Alt. 1E-4 (g)	Alt. 1E-5 (g)	GMRS (g)	% DIFF
100	0.264	0.875	0.413	0.266	0.881	0.416	0.7%
25	0.725	2.45	1.15	0.730	2.46	1.16	0.7%
10	0.480	1.48	0.709	0.483	1.49	0.713	0.6%
5	0.306	0.896	0.434	0.307	0.899	0.435	0.4%
2.5	0.173	0.454	0.225	0.174	0.453	0.225	0.0%
1	0.0894	0.217	0.109	0.0894	0.216	0.109	-0.4%
0.5	0.0615	0.165	0.0814	0.0614	0.165	0.0811	-0.4%

Table 6: Comparison between GMRS at test site for EPRI-SOG parameters and integrated m_{max} values, CAV-filtered hazard (note: % differences were calculated with more decimal places than are shown in the tables).

Freq. (Hz)	Orig 1E-4 (g)	Orig 1E-5 (g)	GMRS (g)	Alt. 1E-4 (g)	Alt. 1E-5 (g)	GMRS (g)	% DIFF
100	0.135	0.885	0.398	0.136	0.893	0.402	0.9%
25	0.351	2.43	1.09	0.355	2.45	1.10	1.0%
10	0.257	1.43	0.644	0.259	1.44	0.648	0.7%
5	0.191	0.842	0.379	0.192	0.845	0.380	0.4%
2.5	0.114	0.422	0.195	0.114	0.421	0.195	-0.1%
1	0.0545	0.202	0.0933	0.0544	0.201	0.0929	-0.5%
0.5	0.0302	0.149	0.0672	0.0301	0.148	0.0668	-0.6%

Tables 5 and 6 show that when the alternative m_{max} distribution is integrated into a total seismic hazard analysis with a weighting that represents the additional studies, the effect ranges from a 0.6% decrease to a 1.0% increase in GMRS. The decrease in GMRS results from extending the seismicity catalog from 1985 to 2006, during which time the mean rate of earthquake activity has decreased in the ETSZ. The effect of m_{max} is smallest for long period measures of ground motion, for which the New Madrid faults have an important contribution to hazard (see the plots in Appendix A). Figure 16 plots the PGA hazard curves for the original and integrated analyses using the CAV filter. The curves are so close that they cannot be distinguished when plotted on the common scale of two orders of magnitude for annual frequency and for ground motion amplitude.

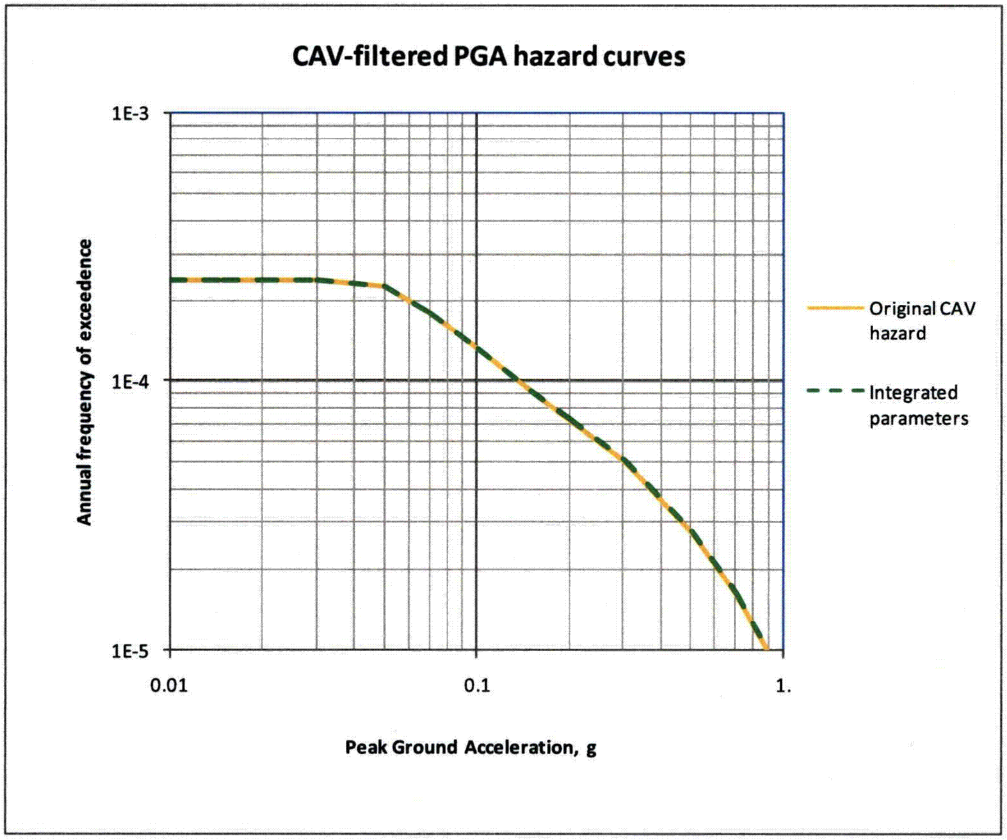

Figure 16: PGA hazard curves using CAV filter for original analysis and for integrated parameters.

It should be noted that GMRS amplitudes calculated for plant license applications are generally reported to 3 significant figures, which corresponds to a precision of $\pm$1% (for example, a GMRS amplitude of 1.00499 would be reported as 1.00, and an amplitude of 1.005 would be reported as 1.01, a precision of 1%). Thus the effect of the integrated calculation summarized in Tables 5 and 6 results in changes to GMRS amplitudes that are on the same order as the precision with which GMRS calculations are generally reported.

CONCLUSIONS

Differences in maximum magnitude distributions for the ETSZ between the EPRI-SOG study and more recent studies (the TIP and DSS studies) indicate that alternative interpretations of m_{max} have a higher mean value than was assessed in the EPRI-SOG study. Adopting this alternative distribution for ETSZ sources would increase seismic hazard estimates for a site located within the ETSZ. A compensating effect would be that more recent seismicity since the EPRI-SOG study indicates lower mean rates of activity in the ETSZ. Overall, combining the alternative m_{max} distributions into an integrated analysis that accounts for changes in mean rates of earthquake activity leads to estimates of changes in GMRS amplitude for a site within the ETSZ between -0.6% and +1.0%. These changes are on the same order of precision with which

GMRS amplitudes are generally reported in nuclear plant license applications. The conclusion is that the potential change in GMRS resulting from integrating the alternative m_{max} distribution into the analysis is not significant, compared to GMRS amplitudes calculated using the EPRI-SOG (1989) m_{max} distributions and activity rates.

These conclusions support the basis for no adjustments to the ETSZ as currently documented in the ESP and COL applications submitted to date.

REFERENCES

1. LLNL (2002). *Guidance for Performing Probabilistic Seismic Hazard Analysis for a Nuclear Plant Site: Example Application to the Southeastern United States*, USNRC Rept. NUREG/CR-6607, Oct.
2. Geomatrix Consultants (2004). *Dam Safety Seismic Hazard Assessment*, report prepared for Tennessee Valley Authority, 2 vol, September.
3. Tennessee Valley Authority (2007). *Bellefonte Units 3 & 4 COLA (Final Safety Analysis Report) Rev. 0 Chapter 02, Site Characteristics*, US Nuc. Reg. Comm. document accession no. ML073110902, Oct. 30.
4. Gardner, J.K., and L. Knopoff (1974). Is the sequence of earthquakes in southern California, with aftershocks removed, Poissonian? *Bull. Seism. Soc. Am., 64, 1363-1367.*
5. Risk Engineering, Inc. (1989). *EQHAZARD Primer*, EPRI Rept. NP-6452-D, Special Report, June.
6. Atkinson, G.M., and D.M. Boore (1995). "Ground motion relations for eastern North America", *Bull. Seism. Soc. Am,* 85, 1, 17-30.
7. Frankel, A., C. Mueller, T. Barnhard, D. Perkins, E.V. Leyendecker, N. Dickman, S. Hanson, and M. Hooper (1996). *National seismic hazard maps: documentation*, US Geol. Survey Open-file Rept. 96-532.
8. EPRI (1993). *Guidelines for determining design basis ground motions, Vol. 5: Quantification of seismic source effects*, EPRI Rept. TR-102293, Nov.
9. Exelon (2003). *09/25/03-Submittal of Exelon Generation Company (EGC) application for an early site permit (ESP) for property co-located with existing Clinton Power Station (CPS) facility in Illinois,* US Nuc. Reg. Comm. document accession no. ML032721596, Sept. 25.
10. Southern Nuclear Co (2008). *Vogtle Early Site Permit Application, Revision 4, Part 2 – Site Safety Analysis Report, Chapter 2, "Site Characteristics," Section 2.5.2,* US Nuc. Reg. Comm. document accession no. ML081020220, March 28.
11. EPRI (2004). *CEUS ground motion project final report*, Elec. Power Res. Inst, Palo Alto, Rept. 1008910, Dec.
12. Abrahamson, N.A., and J. Bommer (2006). *Program on technology innovation: truncation of the lognormal distribution and value of the standard deviation for ground motion models in the Central and Eastern United States*, Elec. Power Res. Inst, Palo Alto, Rept. 1014381, Aug.
13. Hardy, G, K. Merz, N. Abrahamson, and J. Watson-Lamprey (2006). *Program on Technology Innovation: Use of Cumulative Absolute Velocity (CAV) in Determining Effects of Small Magnitude Earthquakes on Seismic Hazard,* Elec. Power Res. Inst, Palo Alto, Rept. 1014099.
14. EPRI (1989). *Probabilistic Seismic Hazard Evaluations at Nuclear Plant Sites in the Central and Eastern United State: Resolution of the Charleston Earthquake Issue*, Elec. Power Res. Inst., Palo Alto, EPRI Rept. NP-6395-D, April.

APPENDIX A

Hazard curves by source for each EPRI-SOG Team for non-CAV calculation, updated rates and alternative M_{max}.

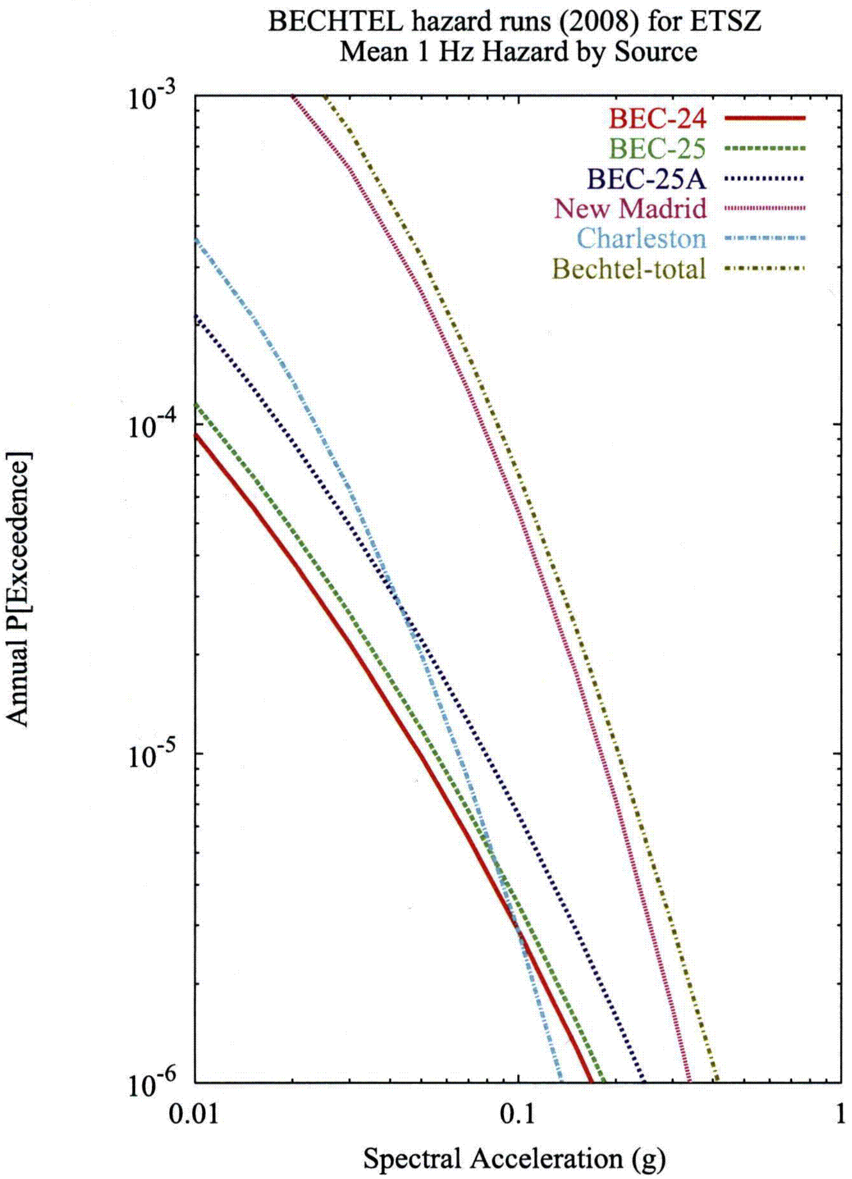

Figure A1: Bechtel 1 Hz hazard

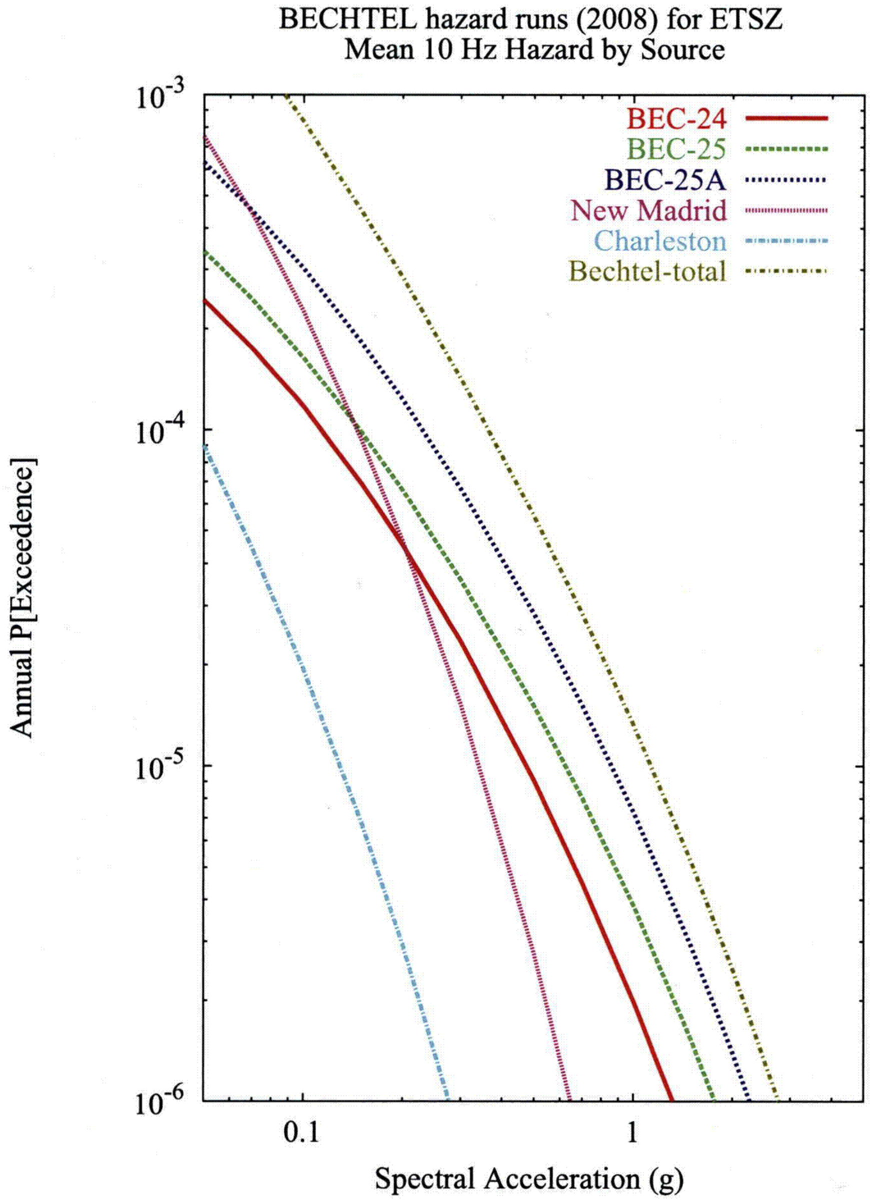

Figure A2: Bechtel 10 Hz hazard

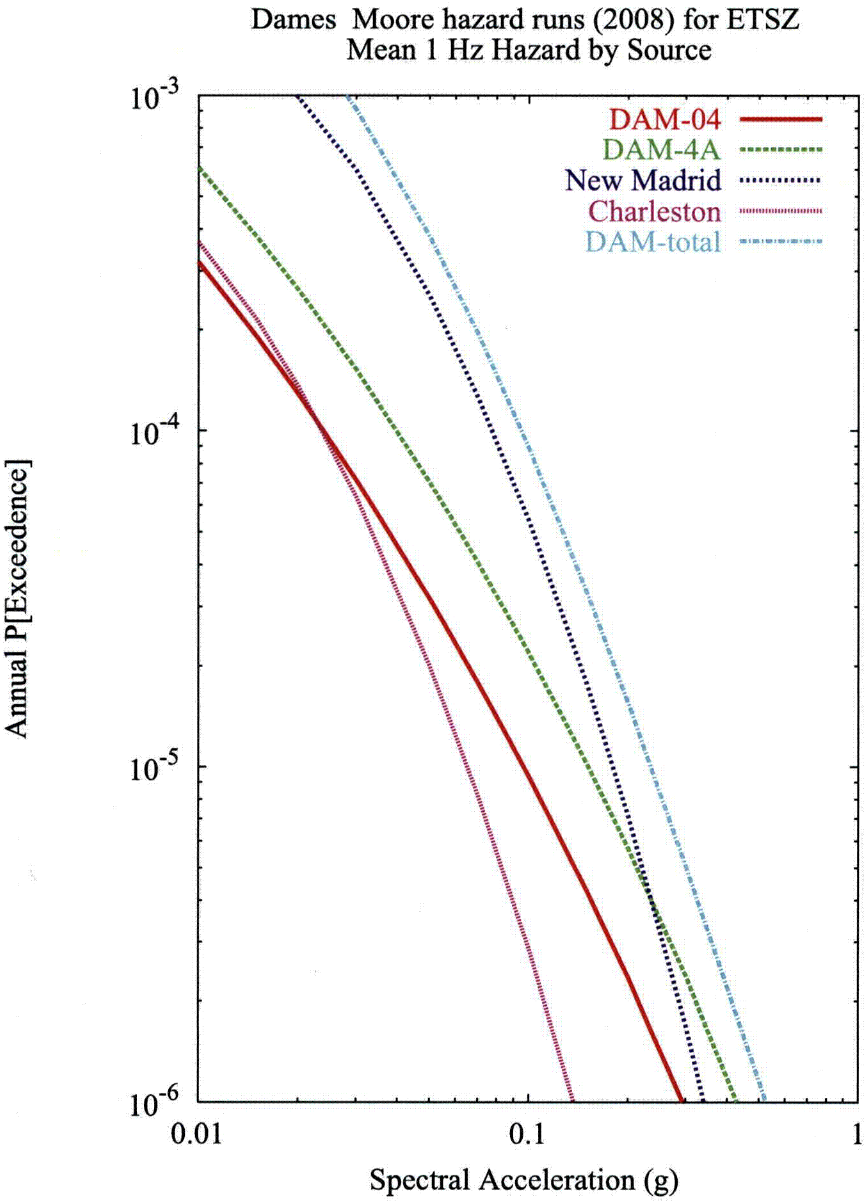

Figure A3: Dames & Moore 1 Hz hazard

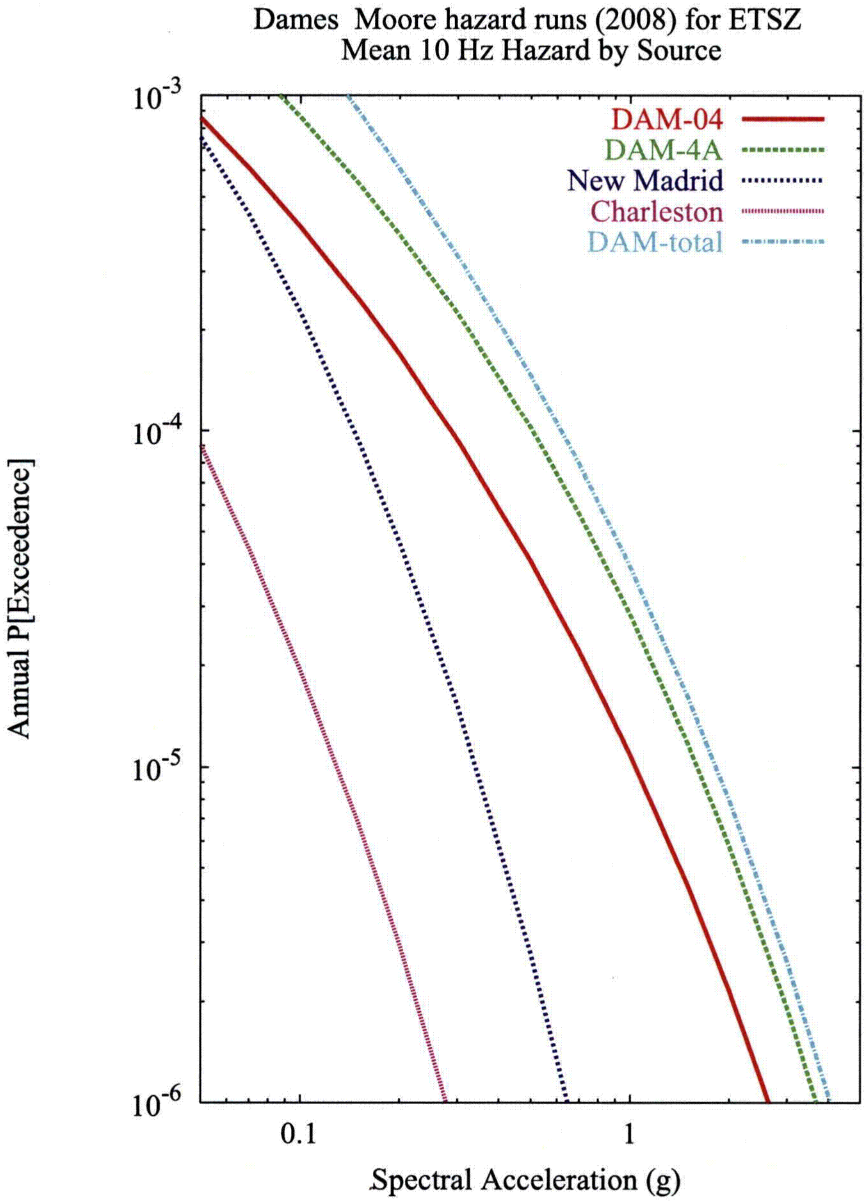

Figure A4: Dames & Moore 10 Hz hazard

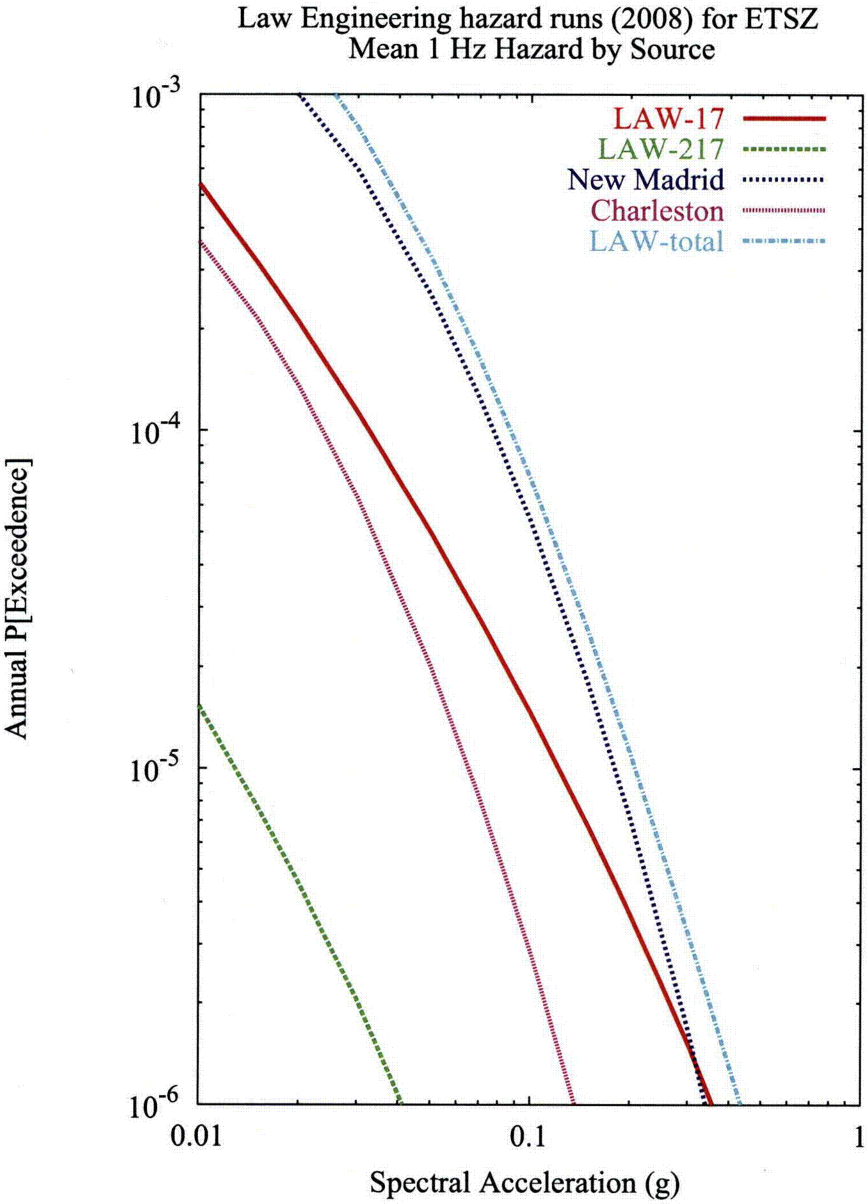

Figure A5: Law 1 Hz hazard

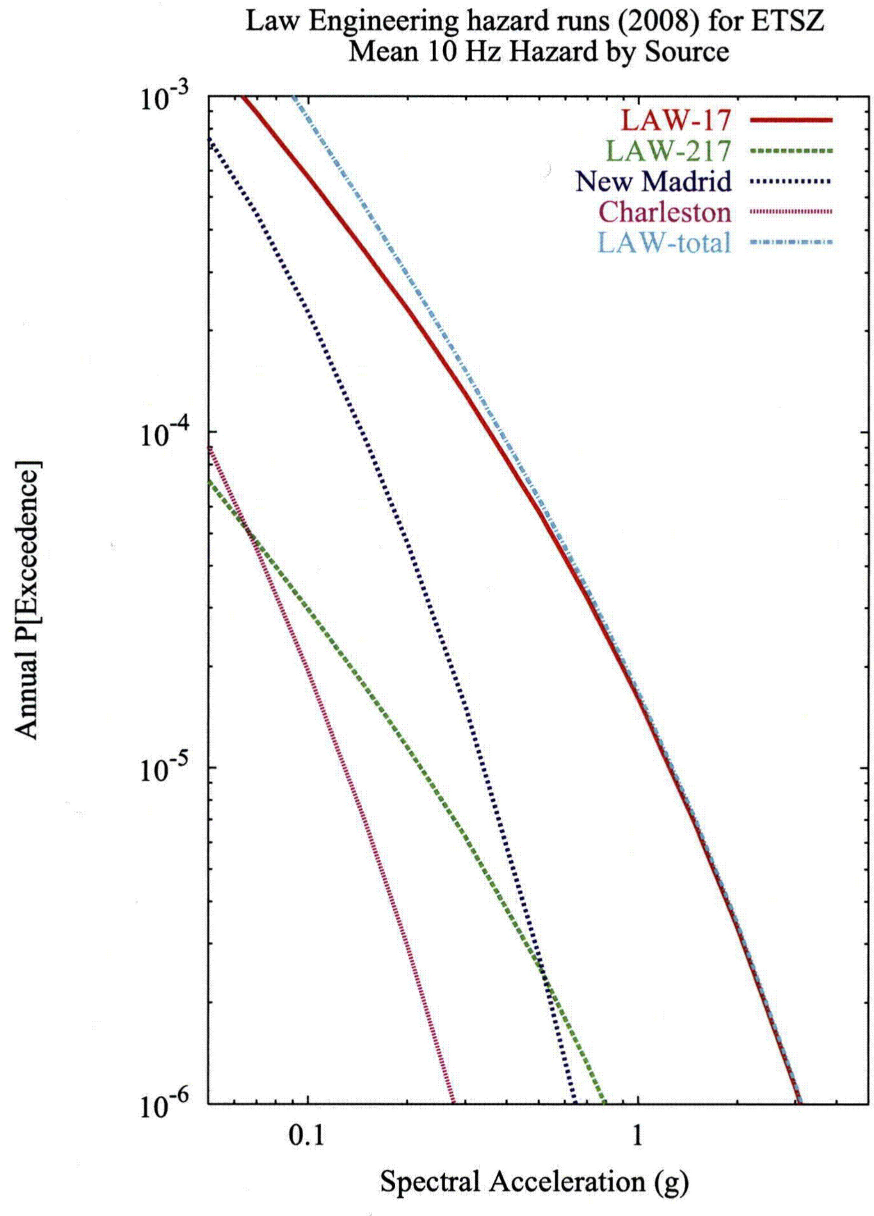

Figure A6: Law 10 Hz hazard

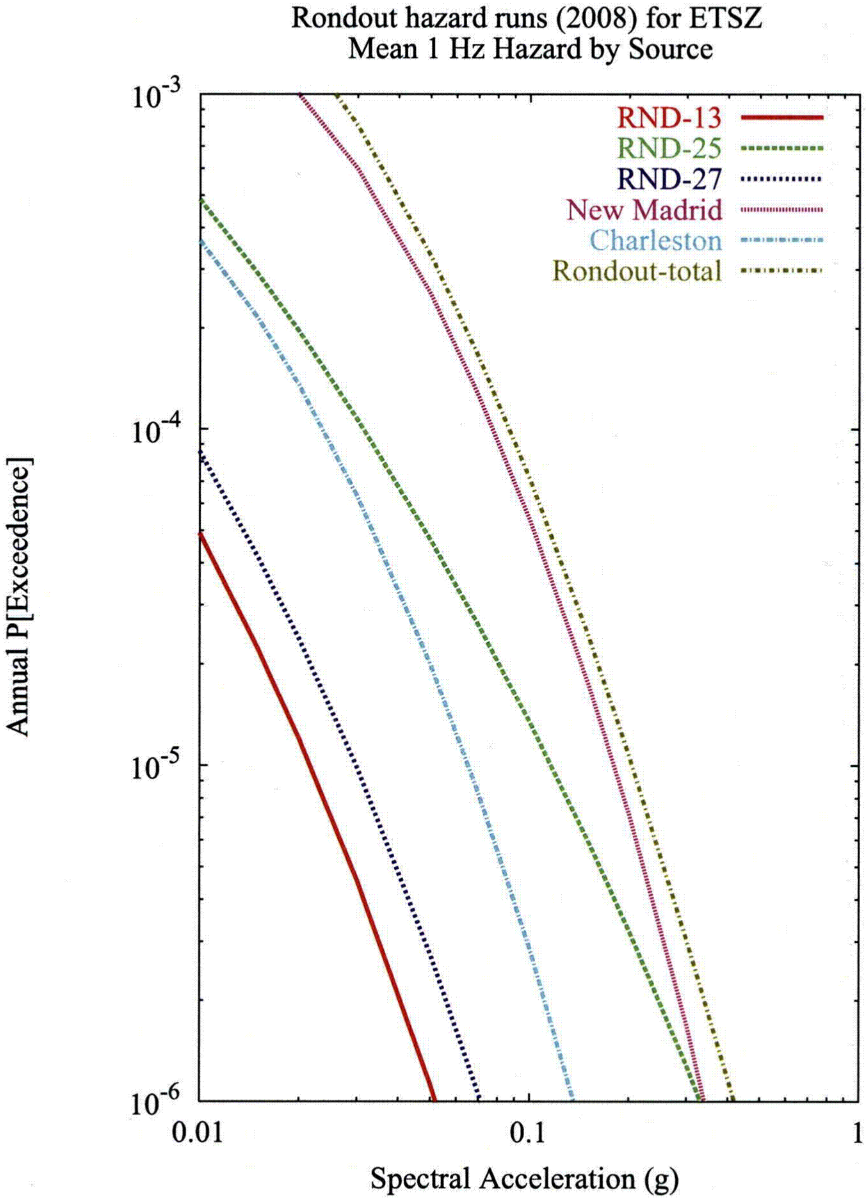

Figure A7: Rondout 1 Hz hazard

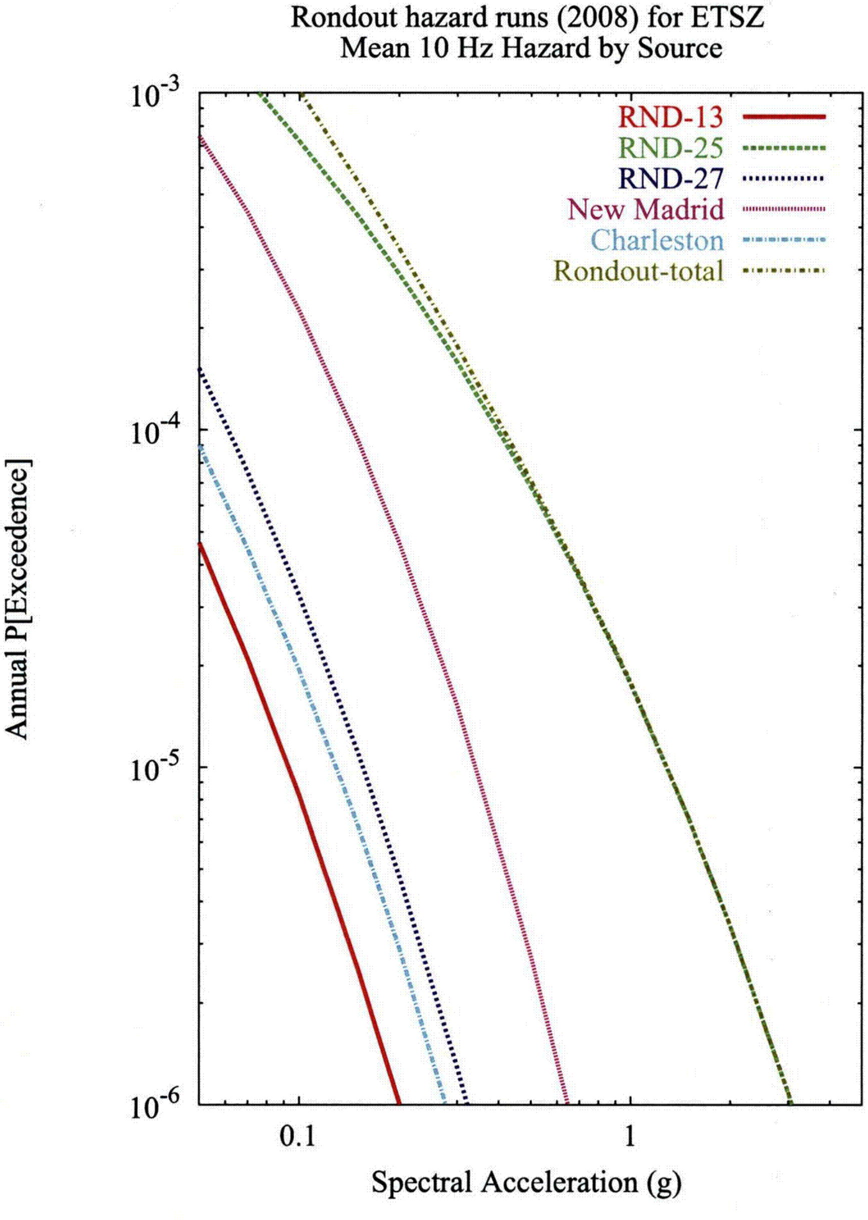

Figure A8: Rondout 10 Hz hazard

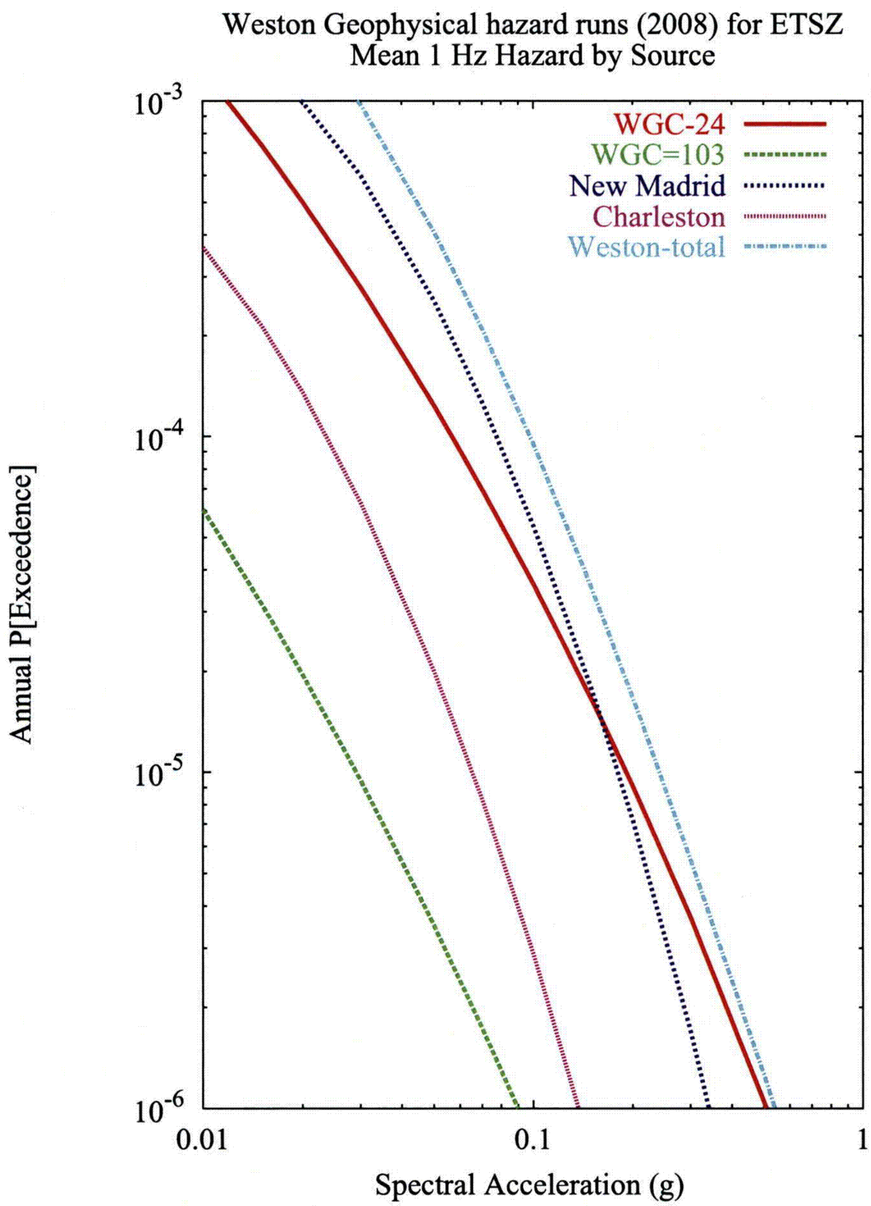

Figure A9: Weston 1 Hz hazard

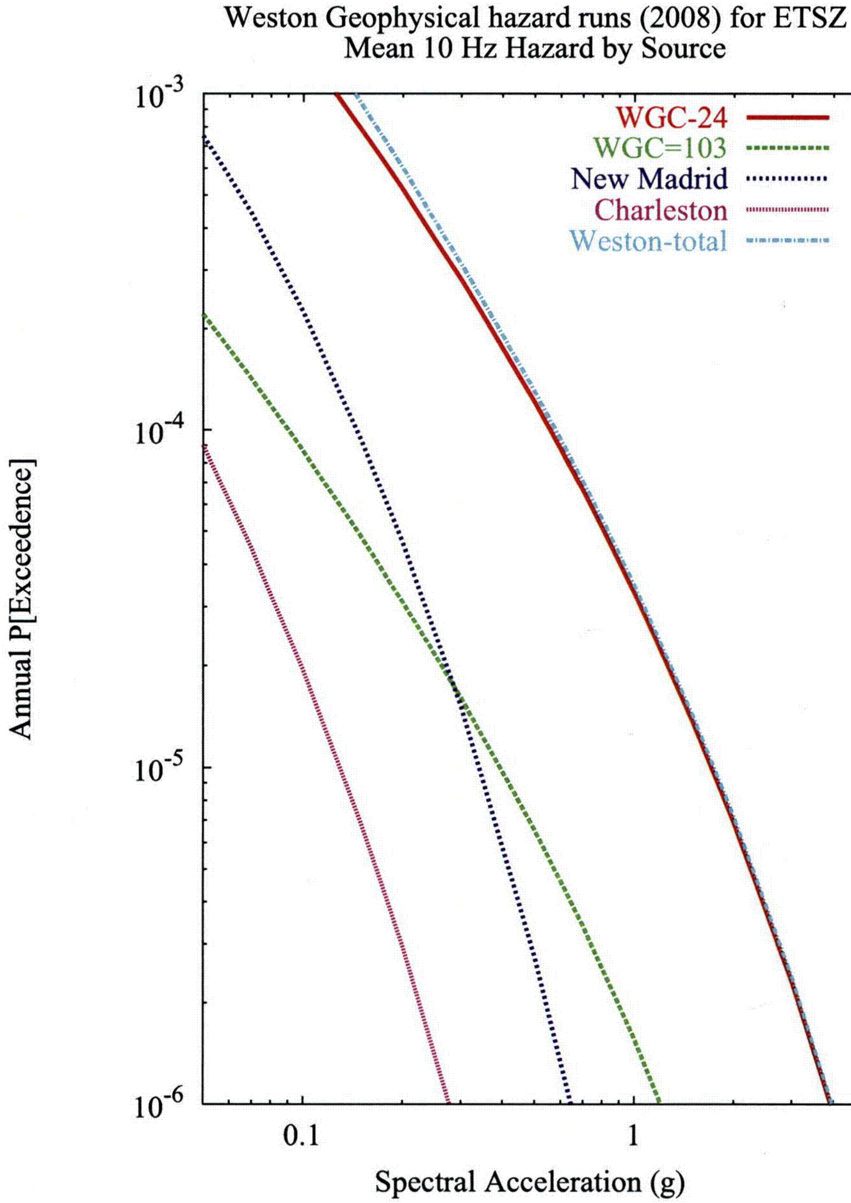

Figure A10: Weston 10 Hz hazard

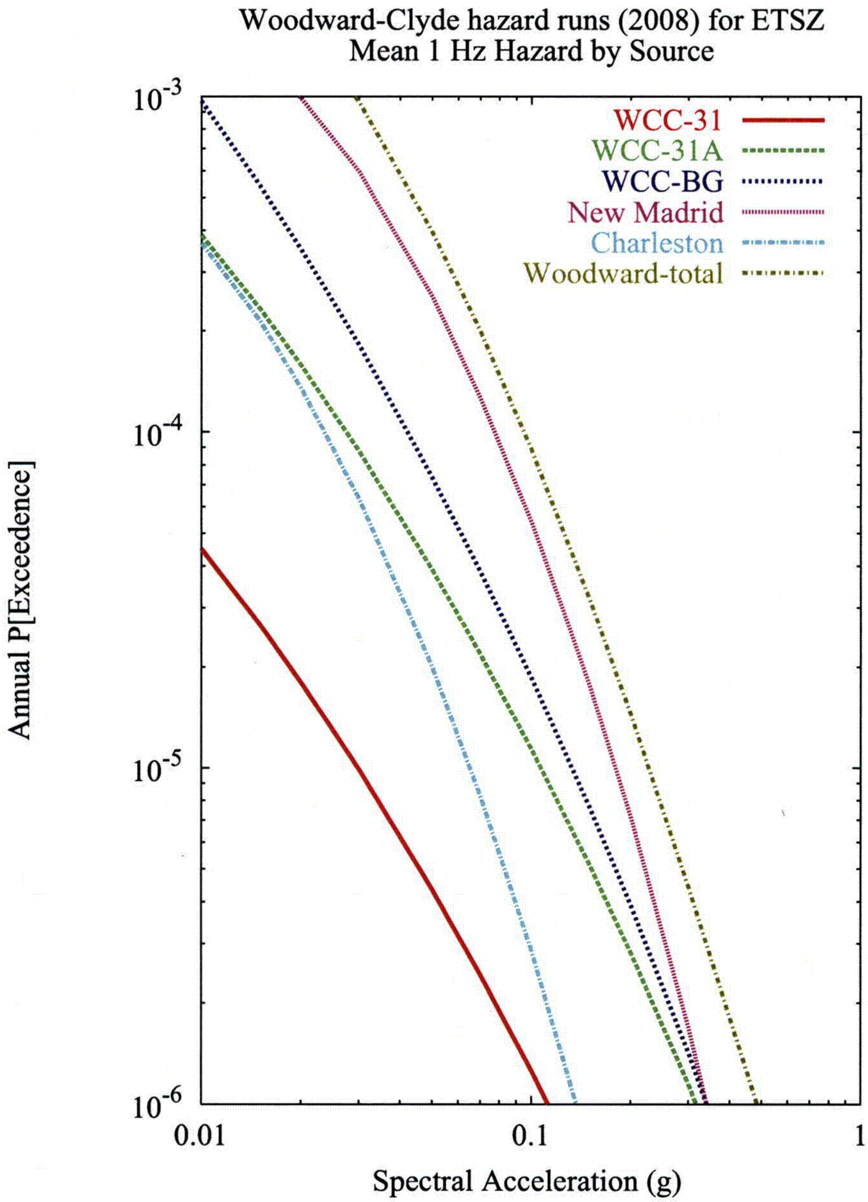

Figure A11: Woodward-Clyde 1 Hz hazard

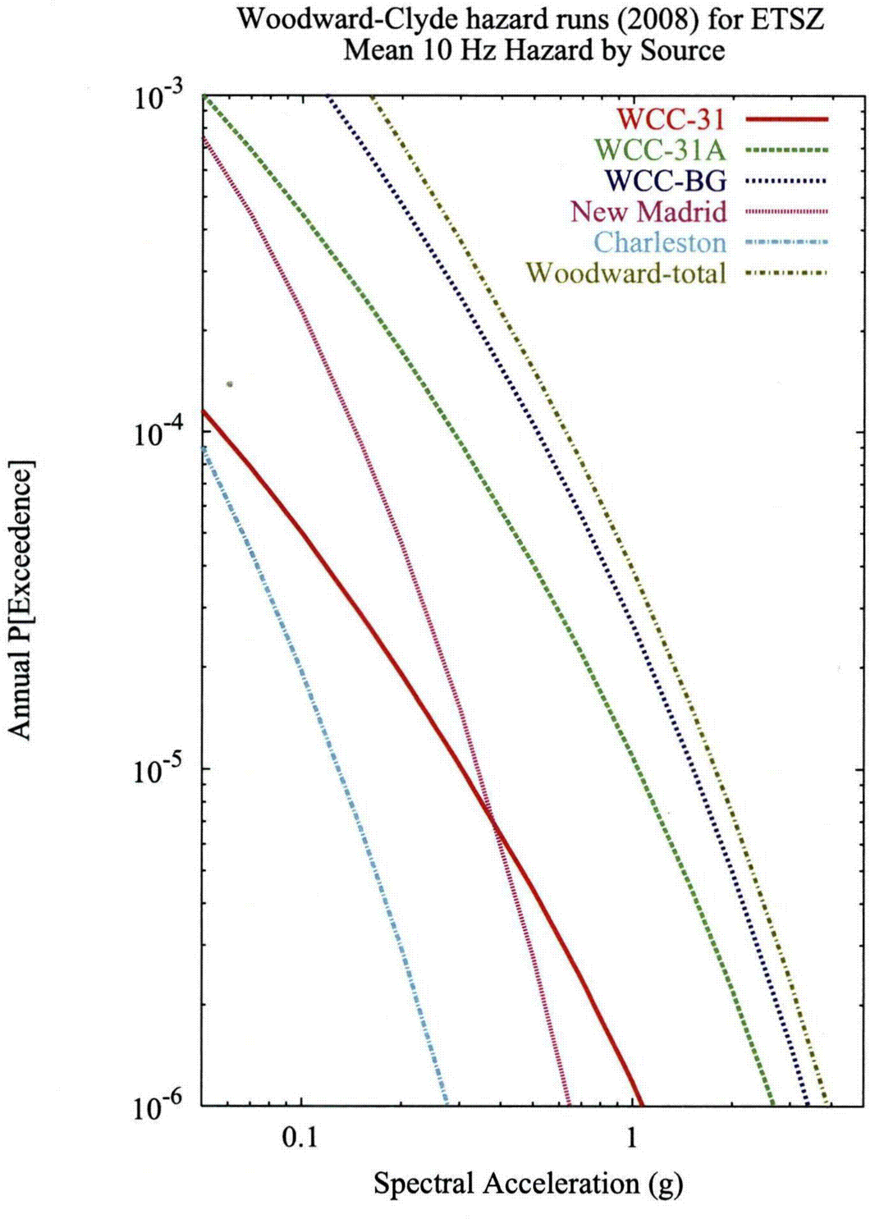

Figure A12: Woodward-Clyde 10 Hz hazard

APPENDIX B

Hazard curves by source for each EPRI-SOG Team for CAV calculation, updated rates and alternative M_{max}.

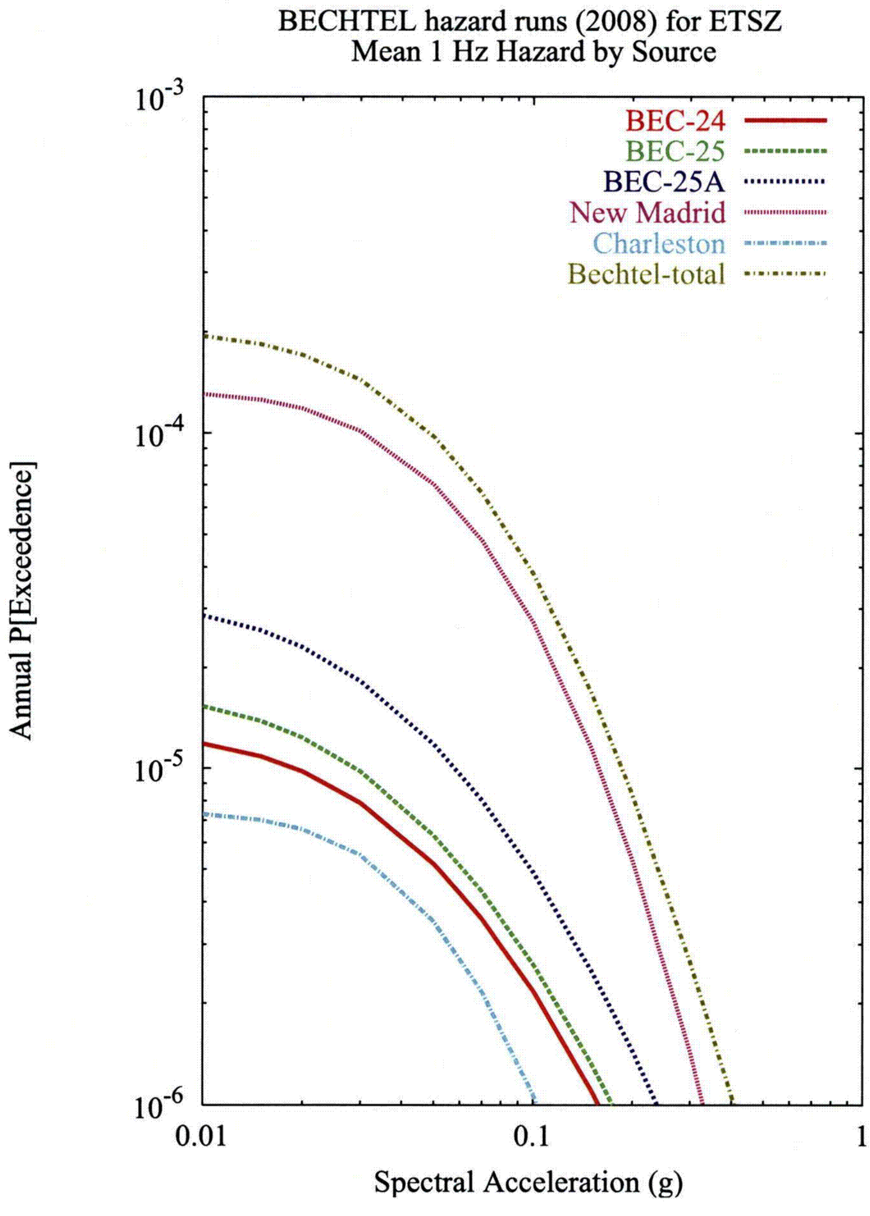

Figure B1: Bechtel 1 Hz hazard

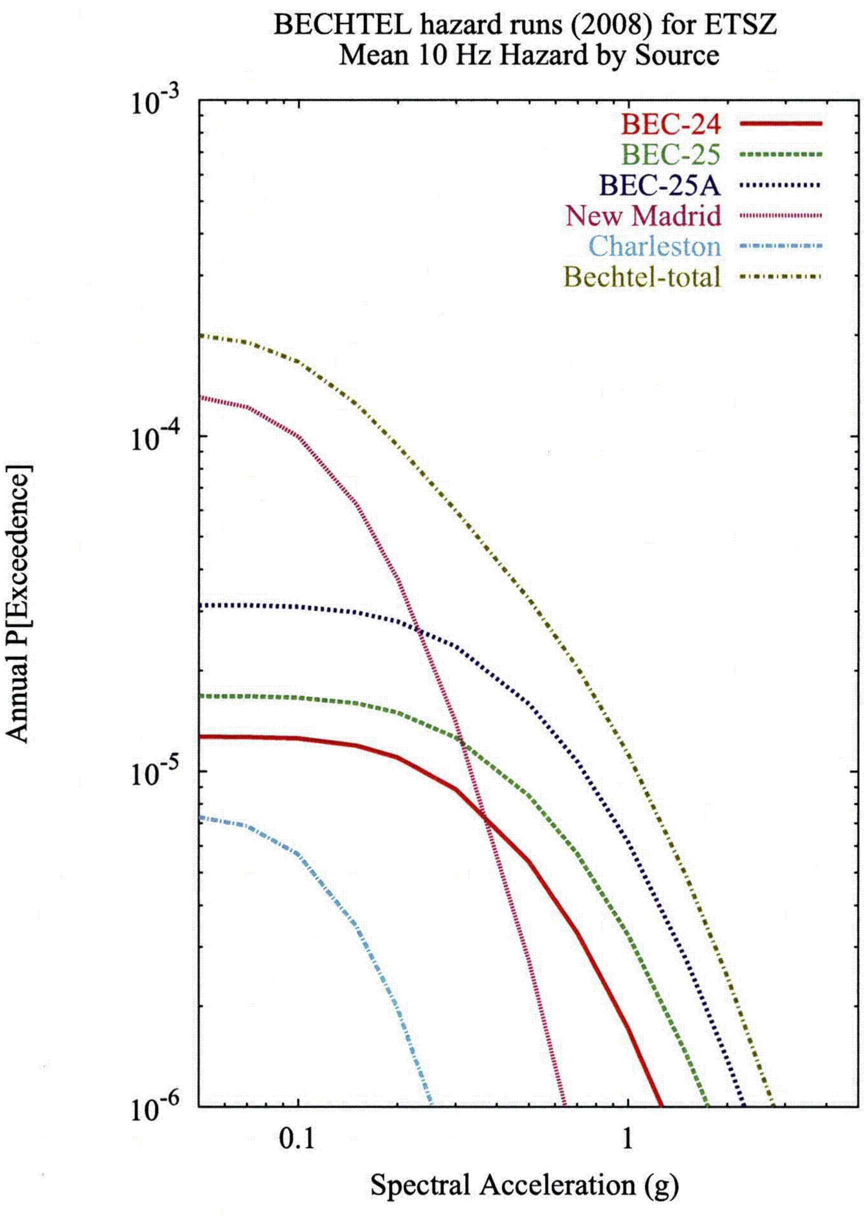

Figure B2: Bechtel 10 Hz hazard

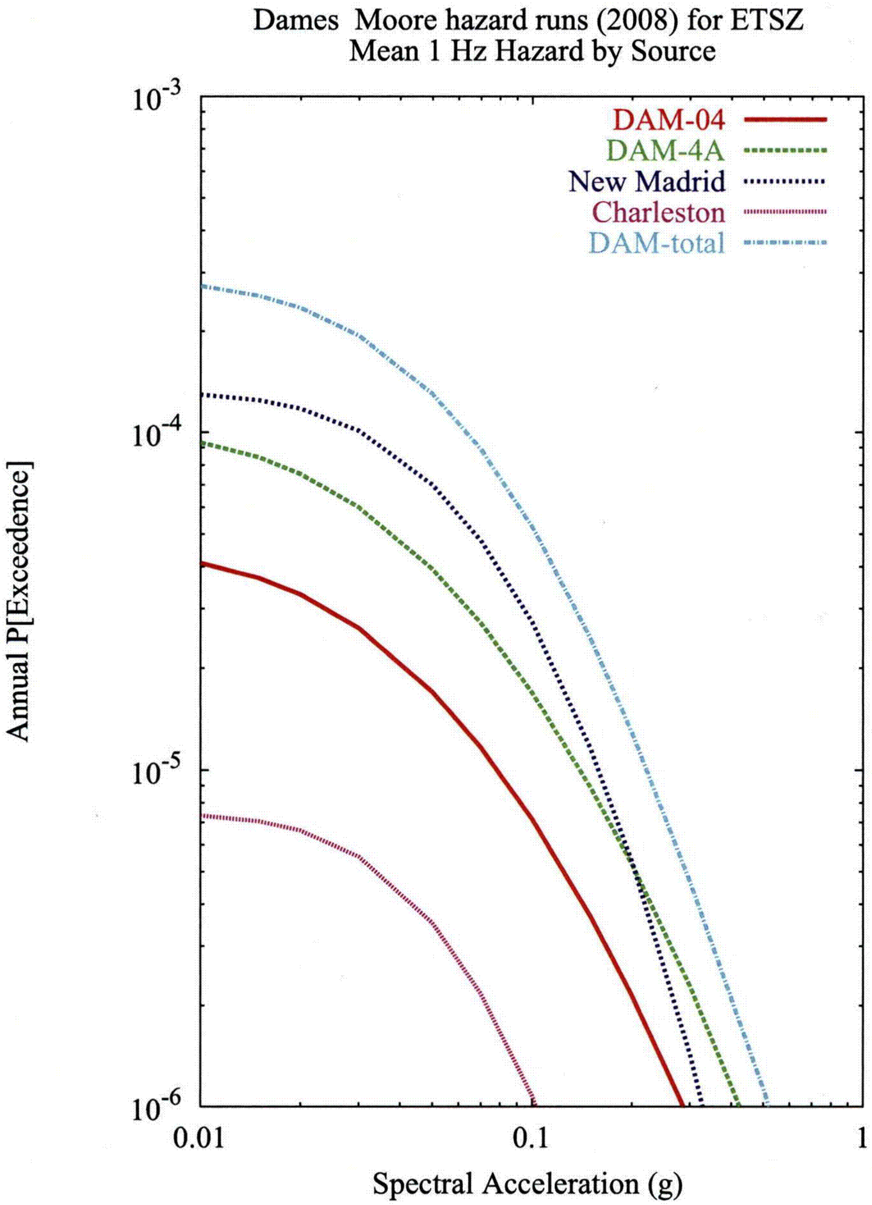

Figure B3: Dames & Moore 1 Hz hazard

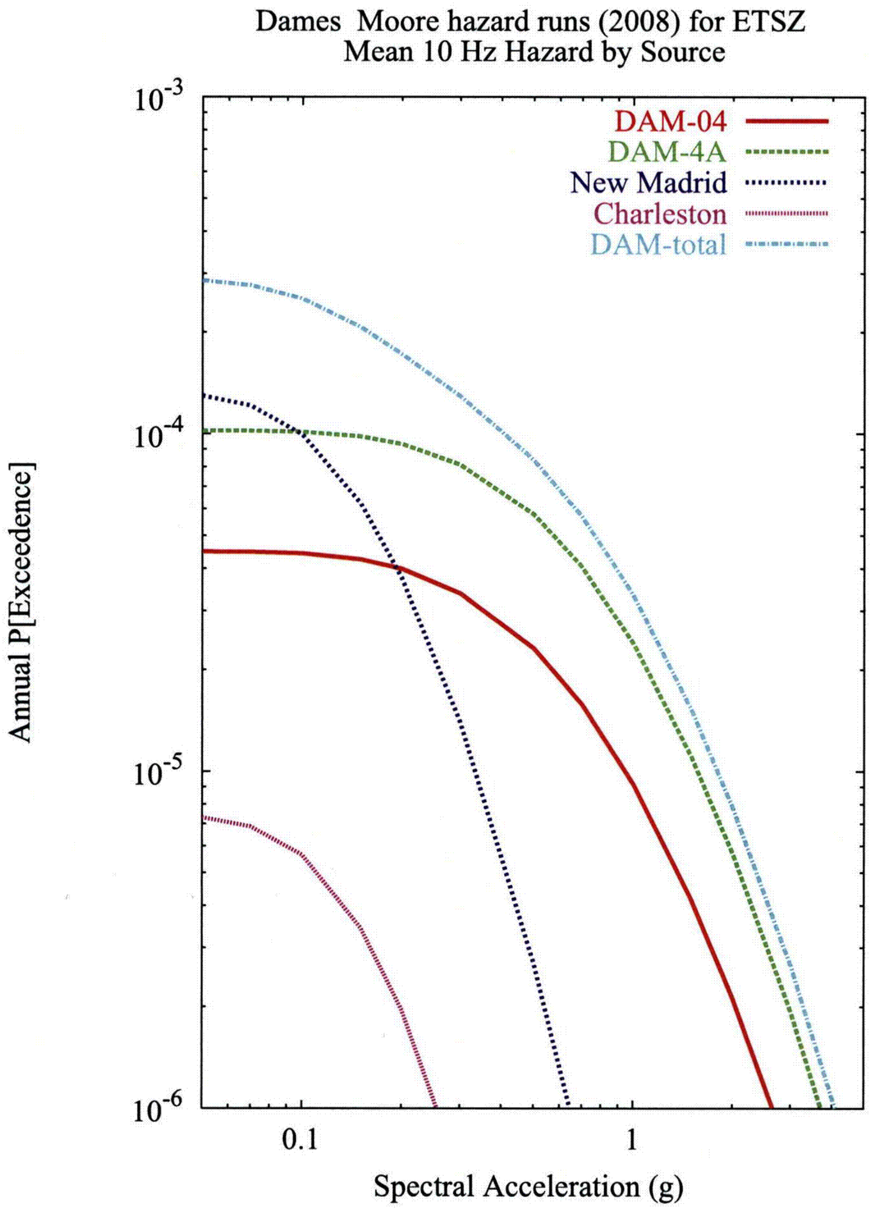

Figure B4: Dames & Moore 10 Hz hazard

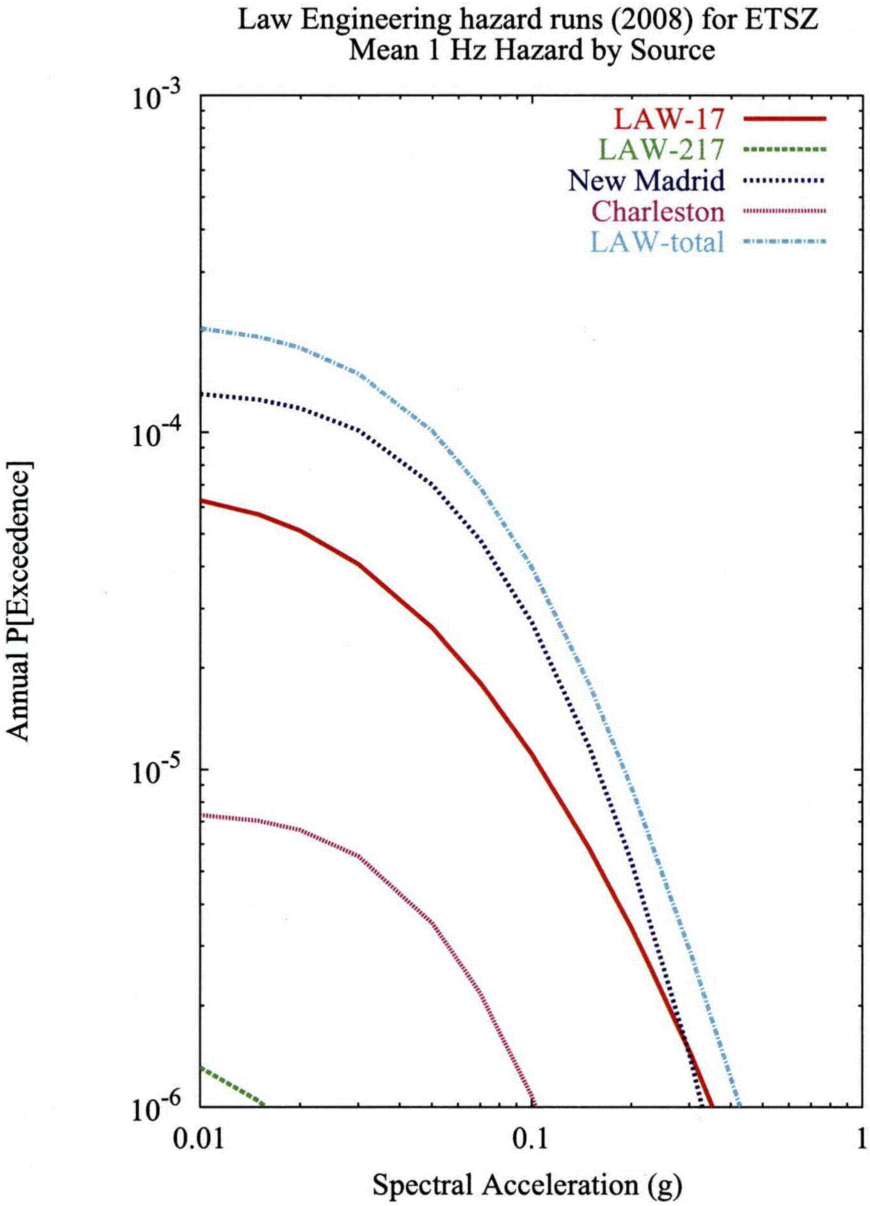

Figure B5: Law 1 Hz hazard

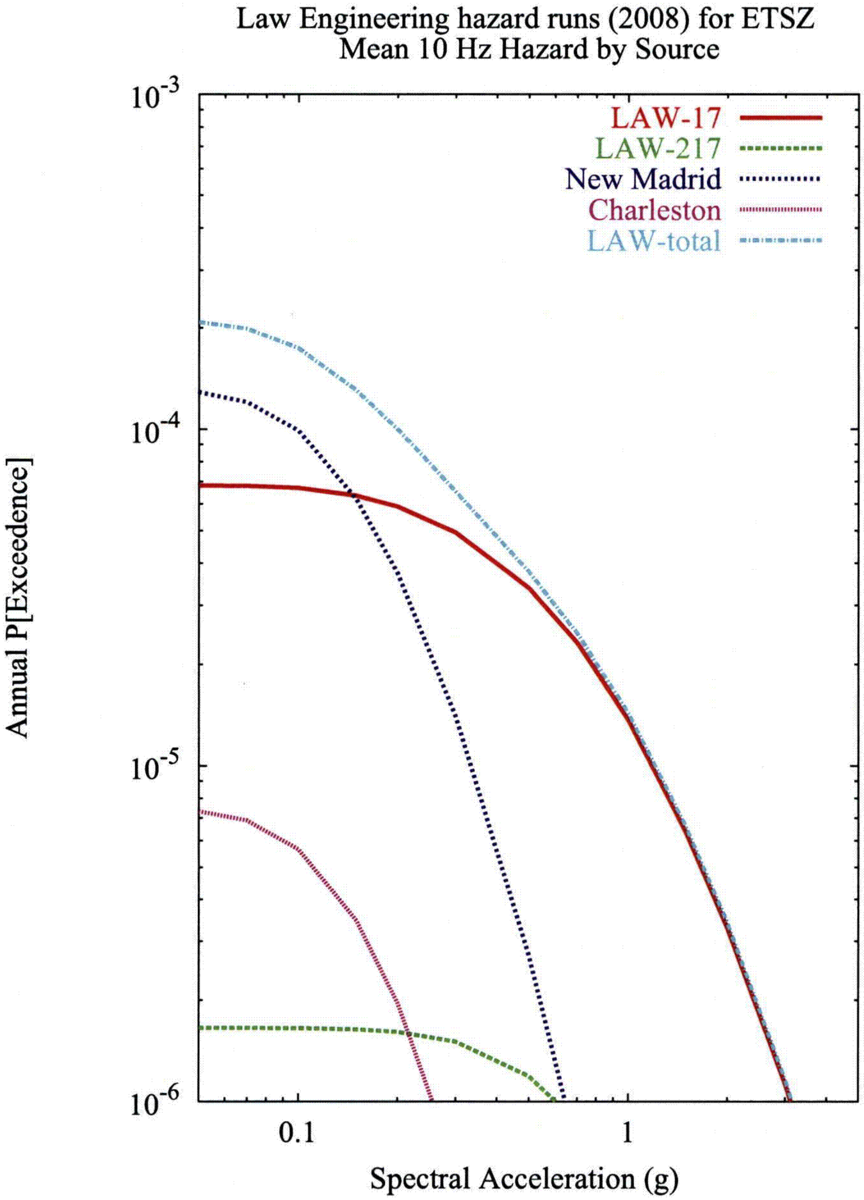

Figure B6: Law 10 Hz hazard

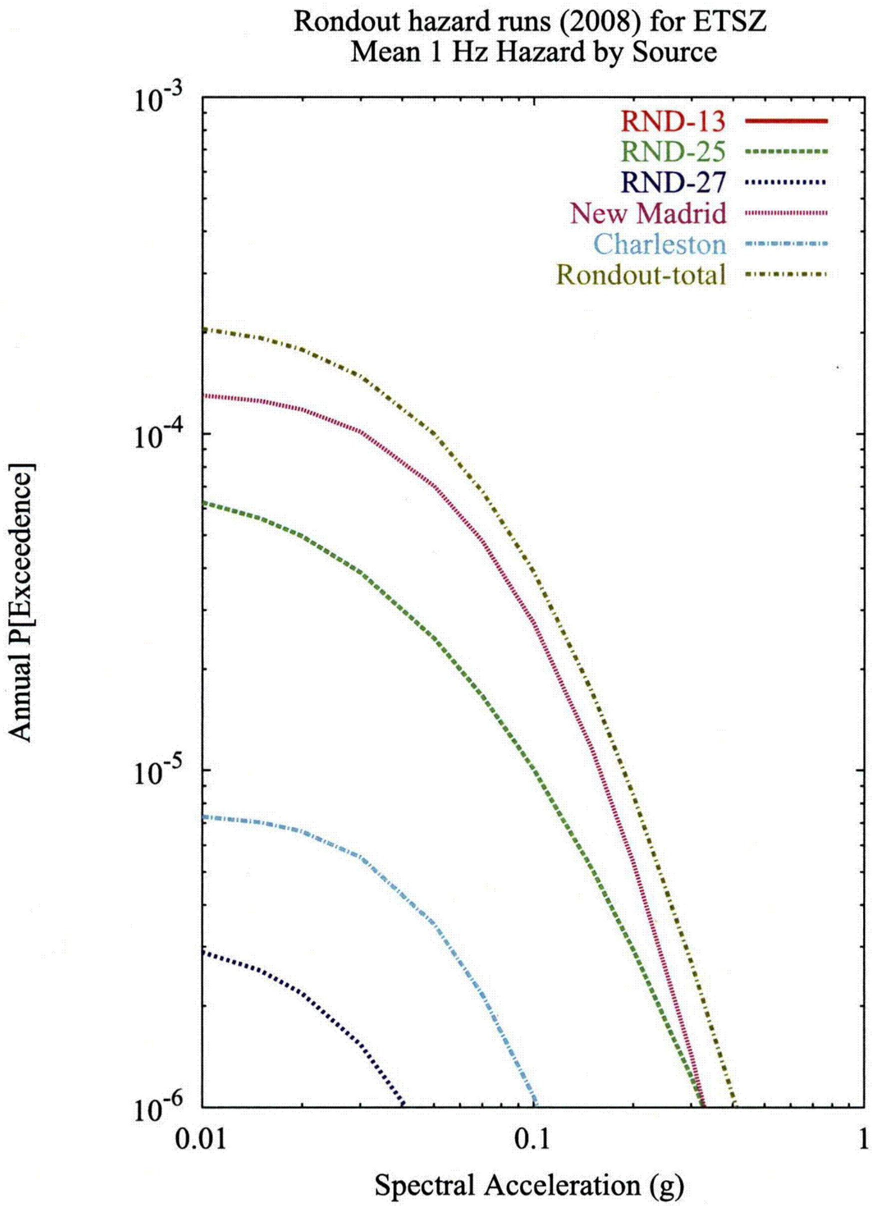

Figure B7: Rondout 1 Hz hazard

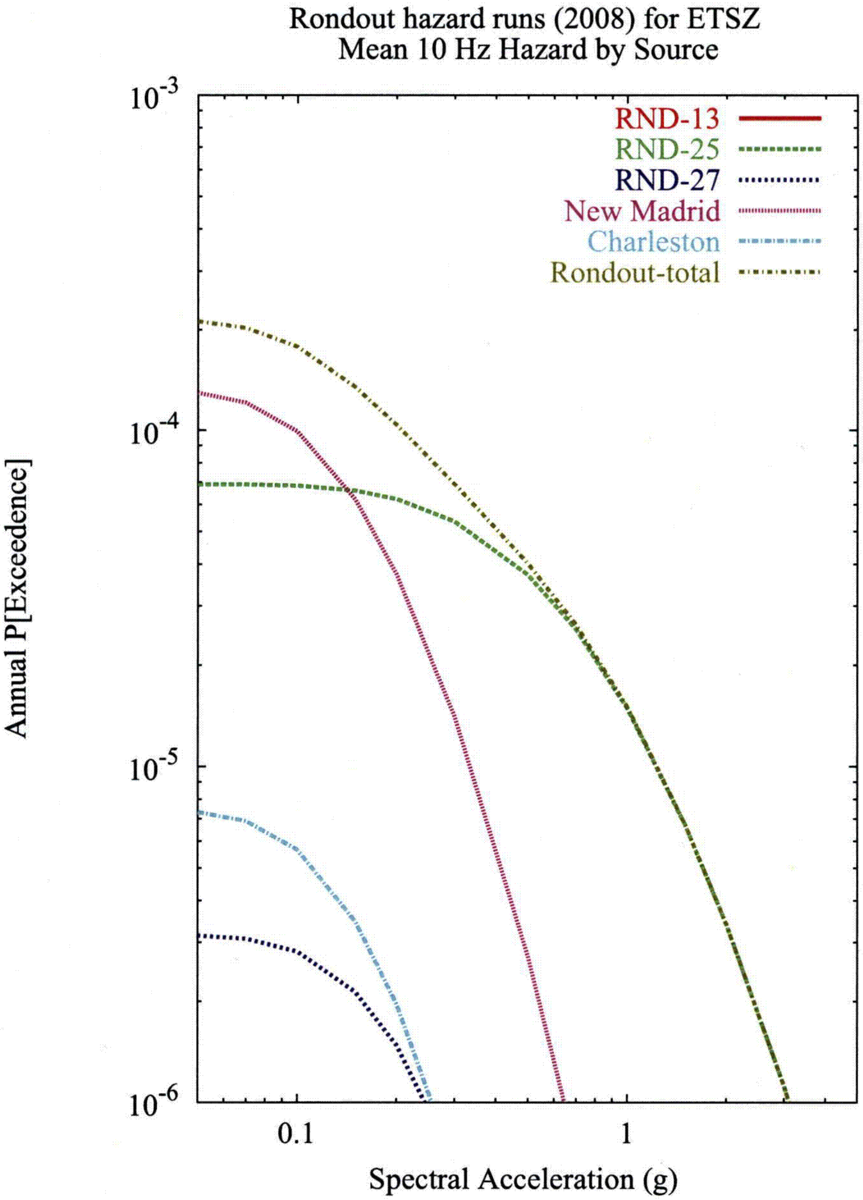

Figure B8: Rondout 10 Hz hazard

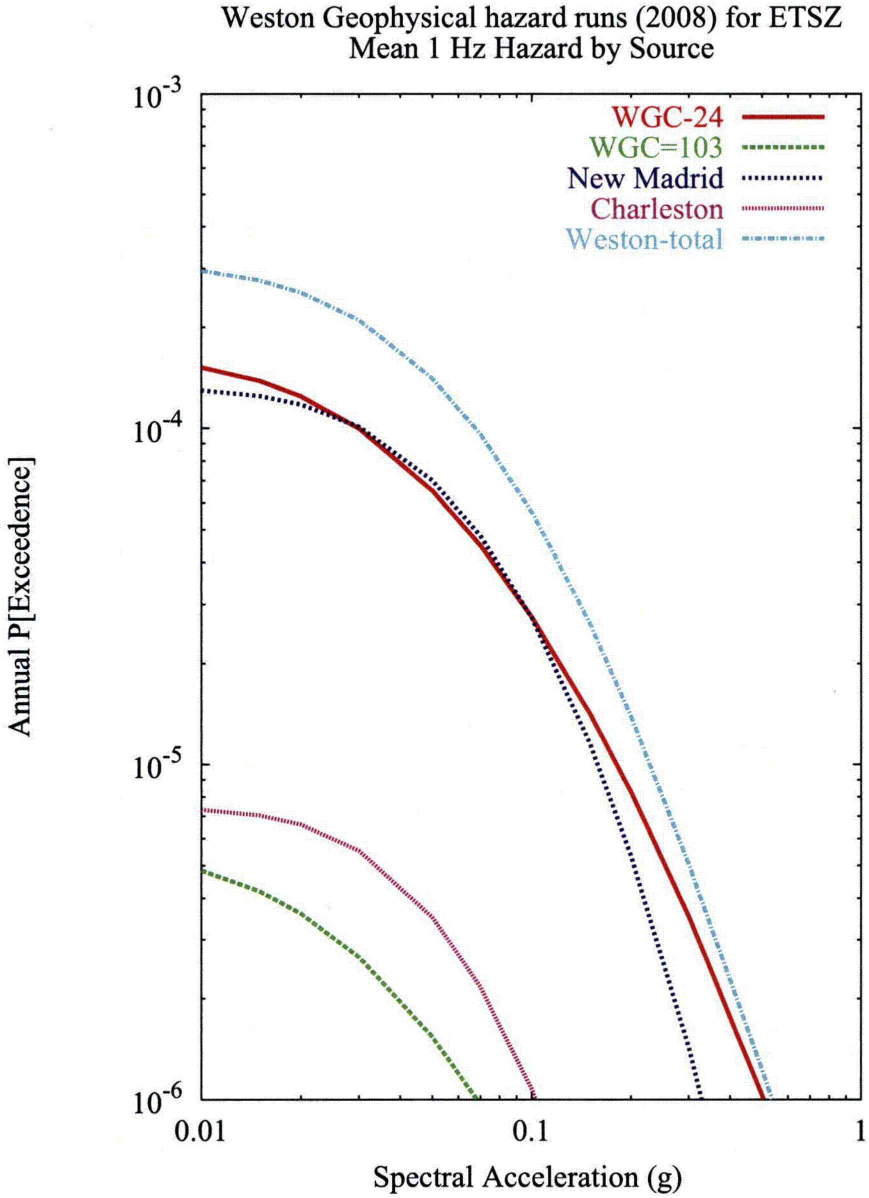

Figure B9: Weston 1 Hz hazard

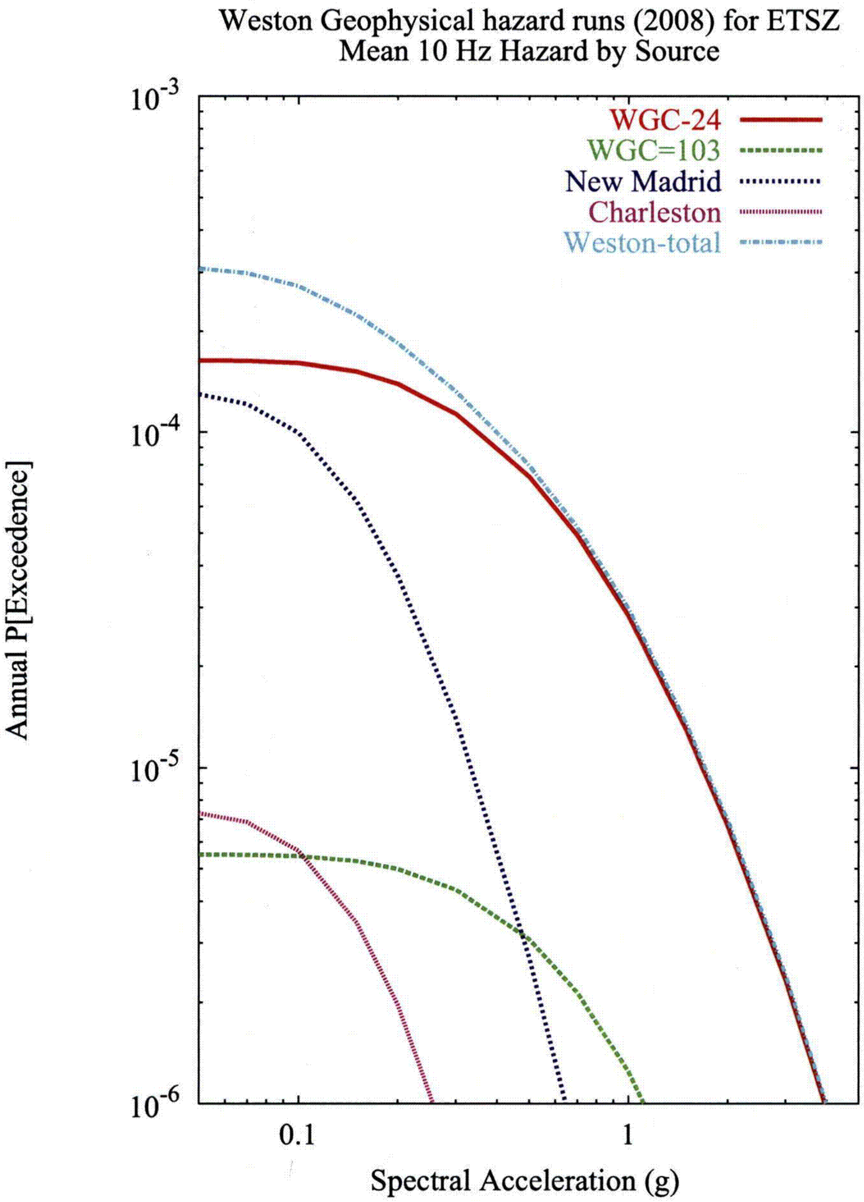

Figure B10: Weston 10 Hz hazard

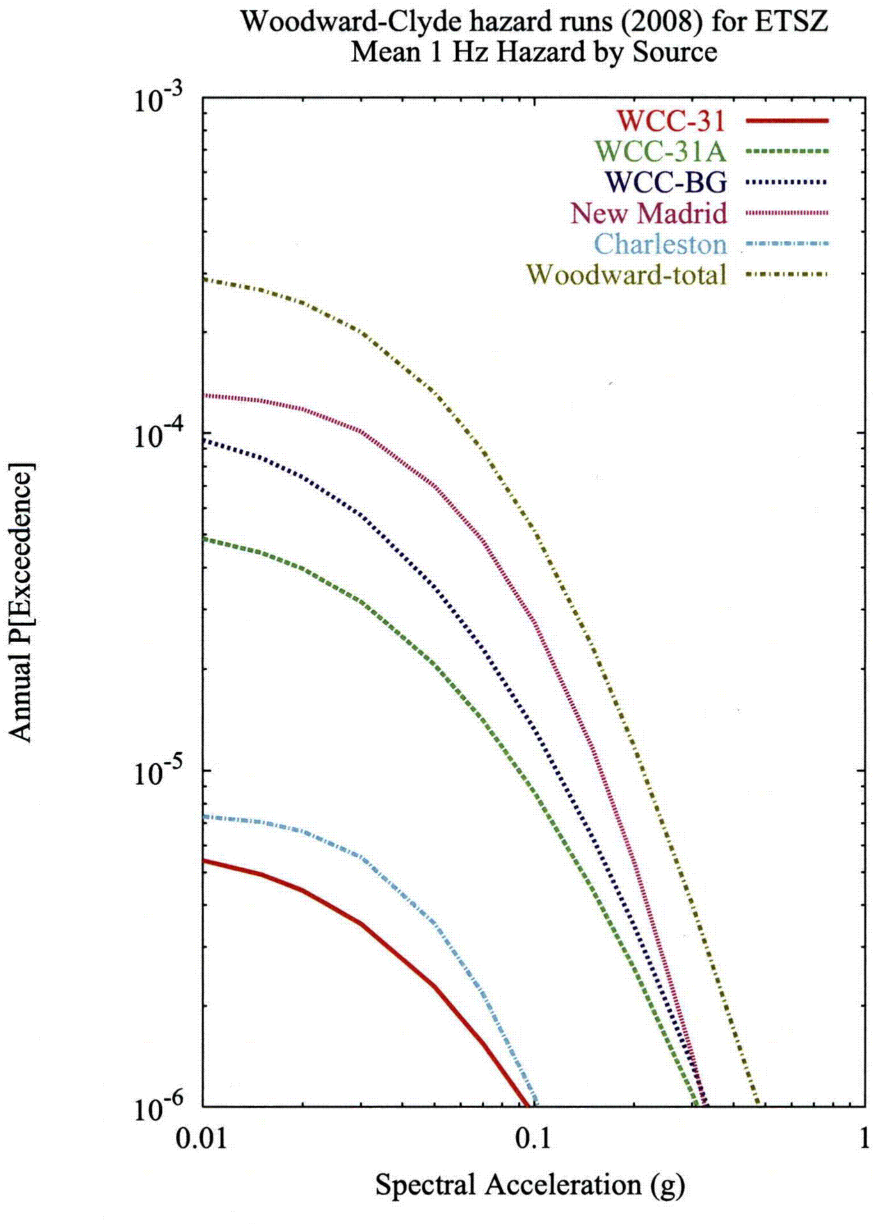

Figure B11: Woodward-Clyde 1 Hz hazard

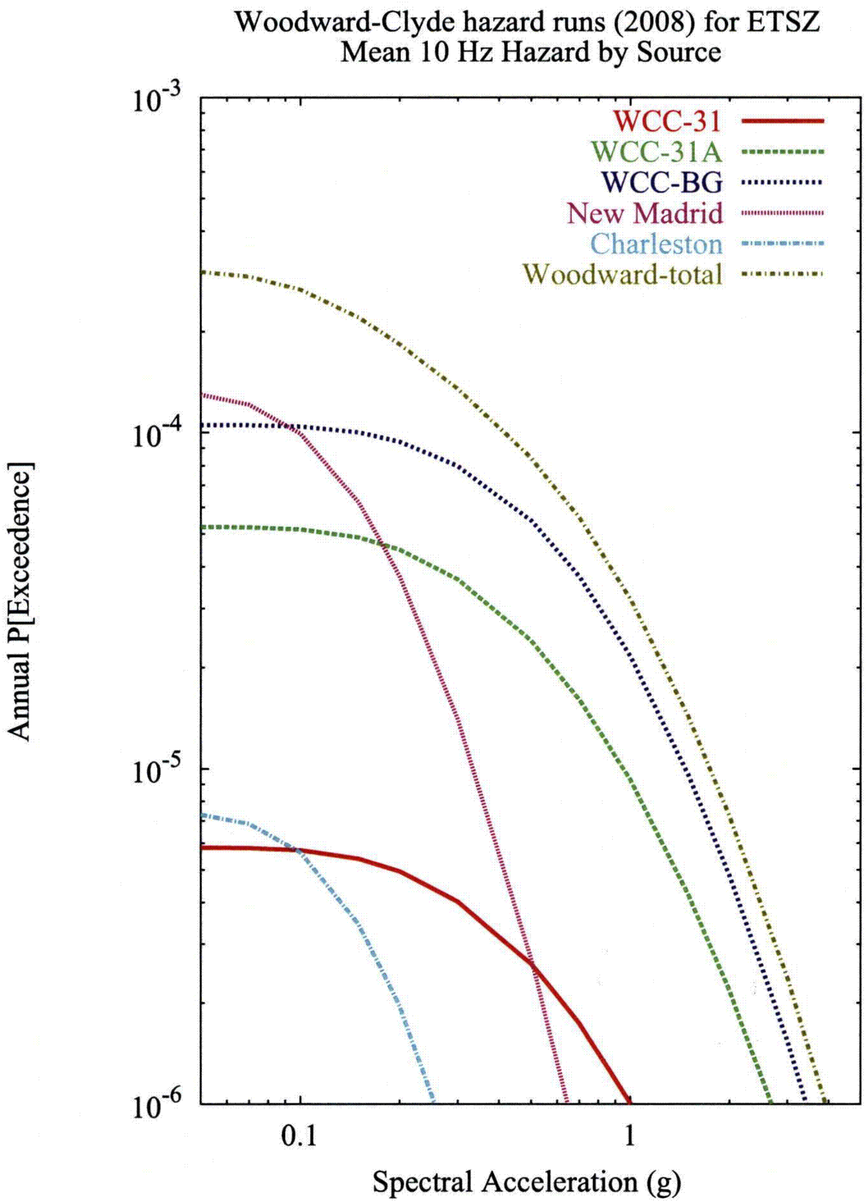

Figure B12: Woodward-Clyde 10 Hz hazard

White Paper on

Influence of Dames & Moore Interpretations for Seismic Hazard Studies in the Southeastern US

Prepared for

Electric Power Research Institute

By

Risk Engineering, Inc.

Boulder, Colorado

May 12, 2008

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INTRODUCTION

The Electric Power Research Institute—Seismicity Owners Group (EPRI-SOG) study (Ref. 1) conducted in the 1980s developed seismic sources and calculated seismic hazard for nuclear plant sites located in the central and eastern US (CEUS). Six earth science teams provided inputs by delineating seismic sources and recommending seismic parameters for those sources. A large amount of effort went into defining these sources on the basis of geology, geophysics, tectonics, and historical earthquake occurrences, and bases for the source interpretations are well documented in separate EPRI reports written by each of the earth science teams.

This study examines the effect on seismic hazard of alternative assumptions regarding the probabilities of activity (P_a) for several seismic sources drawn by the Dames & Moore team for the EPRI-SOG study. The Dames & Moore team made the interpretation that certain parts of the eastern US have some probability of never producing earthquakes with m_b >5.0 in the current tectonic environment. This is consistent with the position that certain parts of the earth's crust are tectonically stable. No data have been observed (e.g. earthquake occurrences with m_b>5.0 in the sources drawn by Dames & Moore) that would invalidate the recommendations of the Dames & Moore team regarding P_a. (It is noted that the NCEER catalog of historical earthquakes in the CEUS assigned m_b=5.0 to a 1913 earthquake that occurred in South Carolina within Dames & Moore source DAM-41. The EPRI-SOG study assigned m_b=4.9 to this earthquake. Both estimates were based on intensity reports.) No new theories have been published that invalidate the recommendations of the Dames & Moore team regarding its seismic sources. This examination is conducted purely as a sensitivity study, to determine the effect of alternative values of P_a for two of the Dames & Moore sources. This effect is measured as the change in uniform hazard response spectra (UHRS) and ground motion response spectra (GMRS) resulting from alternative values of P_a. These results are presented as a "what-if" study and do not endorse the changes to P_a values.

The seismic hazard at two sites is examined here: the Shearon Harris nuclear plant site, and the William States Lee nuclear plant site. These sites have had seismic hazard analyses conducted (Ref. 2 and 3) as part of COL applications, so sensitivity studies are straightforward.

ALTERNATIVE DAMES & MOORE INTERPRETATIONS

Figure 1 shows Dames & Moore seismic sources in the southeastern US (taken from Ref. 1). Seismic sources DAM-41 and DAM-53 are examined for sensitivity, because the P_a is less than unity for these sources. The original Dames & Moore interpretation for these sources is as follows (these descriptions are taken from Ref. 4):

DAM-41 is the default source for the following sources:

DAM-42 (Newark G. Basis, P_a=0.40),
DAM-43 (Ramapo fault, P_a=0.20), and
DAM-46 (Dan R. Basin, P_a=0.28).

The activities of the above 3 sources are mutually exclusive, meaning that only one of them is the explanation of earthquakes with m_b>5.0 in the CEUS. The total P_a of these 3 sources is 0.88, and the remaining P_a of 0.12 is assigned to DAM-41 (the default source).

DAM-53 is the Southern Appalachian Mobile Belt, a default source for the following sources:

DAM-47 (Connecticut Basin, P_a=0.28),
DAM-48 (Buried Triassic Basis, P_a=0.28),
DAM-49 (Jonesboro Basis, P_a=0.28),
DAM-50 (Buried Triassic Basis, P_a=0.28),
DAM-51 (Florence Basis, P_a=0.28),
DAM-65 (Dunbarton Triassic Basis, P_a=0.28).

The activities of these 6 sources are perfectly dependent, meaning that all of them are either active (with P_a=0.28) or inactive (with probability 0.72). When they are inactive, either source DAM-52 (Charleston Mesozoic Rift) is active (with P_a=0.46), or DAM-53 is active (with the remaining P_a of 0.26).

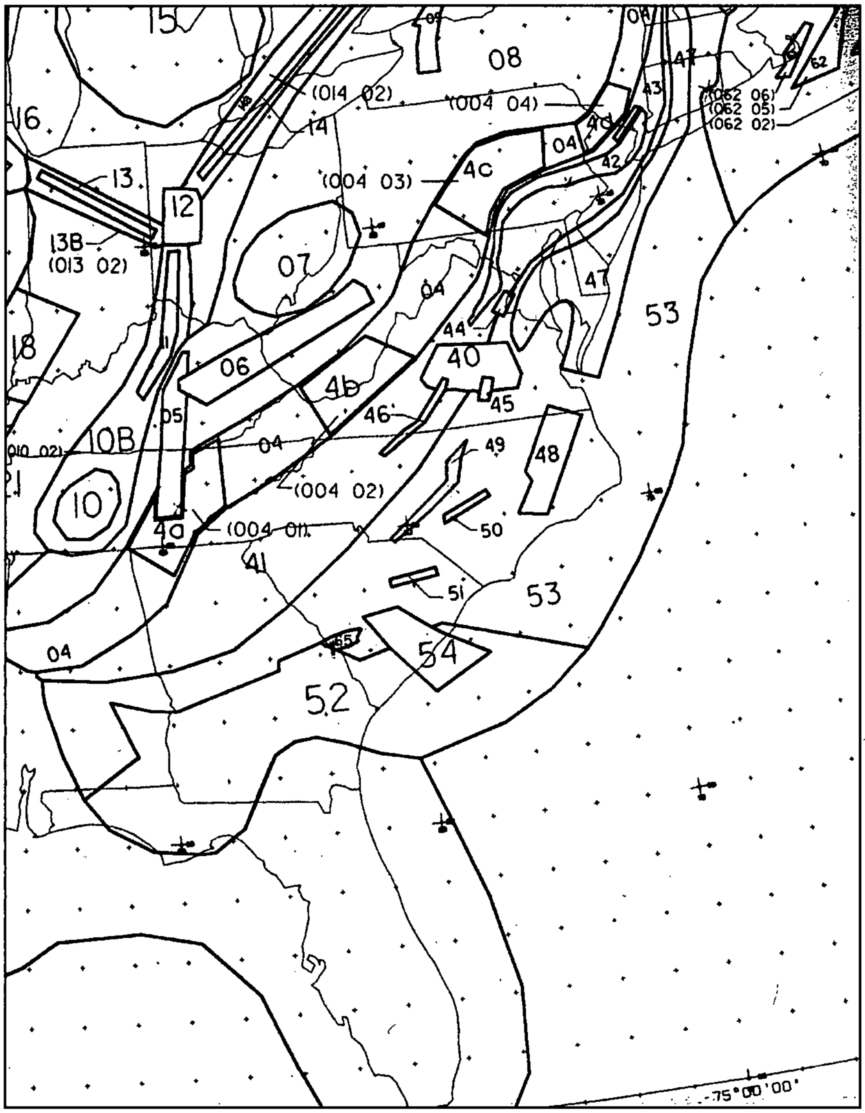

Figure 1. Dames & Moore seismic sources in the southeastern US (from Ref. 1).

The sensitivity study conducted here revises the probabilities of activity for Dames & Moore sources DAM-41 and DAM-53 from the above P_a values to a P_a value of 1.0, meaning that these 2 sources will always be active and capable of producing earthquakes with $m_b \geq 5.0$. In effect the activity of source DAM-41 is being increased for this sensitivity study by a factor of $1/0.12 = 8.33$, and the activity of source DAM-53 is being increased by a factor of $1/0.26=3.85$. Note that at the locations of the alternative sources listed above, the modified P_a values would imply double-counting of seismic hazard, since two sources would be active simultaneously at the same location, both representing seismic activity.

RESULTS OF SENSITIVITY STUDY

Table 1 shows the effect of changing the P_a values for sources DAM-41 and DAM-53 as described above for the Shearon Harris site. The difference in mean UHRS and GMRS amplitudes is shown for the original P_a values and for the modified P_a values. The maximum change in GMRS amplitude is about a 2% increase.

Table 1. Sensitivity of Hazard at Shearon Harris Site to Changes in P_a.

Spectral Frequency	Ground Motion	Amplitudes based on Original P_a	Amplitudes based on Alternative P_a	% Diff
100 Hz	10^{-4} UHRS	0.09	0.091	1.1%
	10^{-5} UHRS	0.283	0.288	1.8%
	GMRS	0.135	0.137	1.5%
25 Hz	10^{-4} UHRS	0.22	0.222	0.9%
	10^{-5} UHRS	0.921	0.94	2.1%
	GMRS	0.415	0.423	1.9%
10 Hz	10^{-4} UHRS	0.202	0.205	1.5%
	10^{-5} UHRS	0.665	0.676	1.7%
	GMRS	0.315	0.32	1.6%
5Hz	10^{-4} UHRS	0.147	0.148	0.7%
	10^{-5} UHRS	0.483	0.488	1.0%
	GMRS	0.228	0.231	1.3%
2.5 Hz	10^{-4} UHRS	0.106	0.106	0.0%
	10^{-5} UHRS	0.329	0.331	0.6%
	GMRS	0.157	0.158	0.6%
1 Hz	10^{-4} UHRS	0.047	0.048	2.1%
	10^{-5} UHRS	0.165	0.166	0.6%
	GMRS	0.077	0.078	1.3%
0.5 Hz	10^{-4} UHRS	0.024	0.024	0.0%
	10^{-5} UHRS	0.112	0.113	0.9%
	GMRS	0.05	0.051	2.0%

Table 2 shows the effect of changing the P_a value for sources DAM-41 and DAM-53 for the Lee site. The maximum change in GMRS amplitude is about an 11% increase.

Table 2. Sensitivity of Hazard at Lee Site to Changes in P_a.

Spectral Frequency	Ground Motion	Amplitudes based on Original P_a	Amplitudes based on Alternative P_a	% diff
100 Hz	10^{-4} UHRS	0.104	0.112	7.5%
	10^{-5} UHRS	0.471	0.524	11.2%
	GMRS	0.212	0.236	11.2%
25 Hz	10^{-4} UHRS	0.249	0.274	10.1%
	10^{-5} UHRS	1.292	1.436	11.1%
	GMRS	0.581	0.646	11.1%
10 Hz	10^{-4} UHRS	0.197	0.212	7.4%
	10^{-5} UHRS	0.820	0.902	10.0%
	GMRS	0.370	0.406	9.7%
5 Hz	10^{-4} UHRS	0.152	0.161	5.9%
	10^{-5} UHRS	0.527	0.568	7.7%
	GMRS	0.247	0.265	7.3%
2.5 Hz	10^{-4} UHRS	0.0946	0.1	5.7%
	10^{-5} UHRS	0.3070	0.322	4.9%
	GMRS	0.146	0.153	5.1%
1 Hz	10^{-4} UHRS	0.0423	0.0445	5.3%
	10^{-5} UHRS	0.1601	0.165	3.1%
	GMRS	0.0736	0.0762	3.5%
0.5 Hz	10^{-4} UHRS	0.0218	0.0229	5.0%
	10^{-5} UHRS	0.1228	0.125	1.8%
	GMRS	0.0553	0.0563	1.8%

Figure 2 plots the PGA hazard curves for the original P_a's and for the modified P_a's for the Lee site. The CAV filter (Ref. 5) was applied in the seismic hazard calculations, so the seismic hazard curves roll over to a constant annual frequency of exceedence at low amplitudes. Figure 2 shows (with red lines) the change in hazard if the GMRS (from the original P_a values) of 0.212g is used instead of the GMRS (from the modified P_a values) of 0.236g. For this ~11% difference in GMRS, the hazard increases about 16%. The reason that the change in hazard is similar to the change in GMRS is that the hazard curve has a log-log slope close to -1.

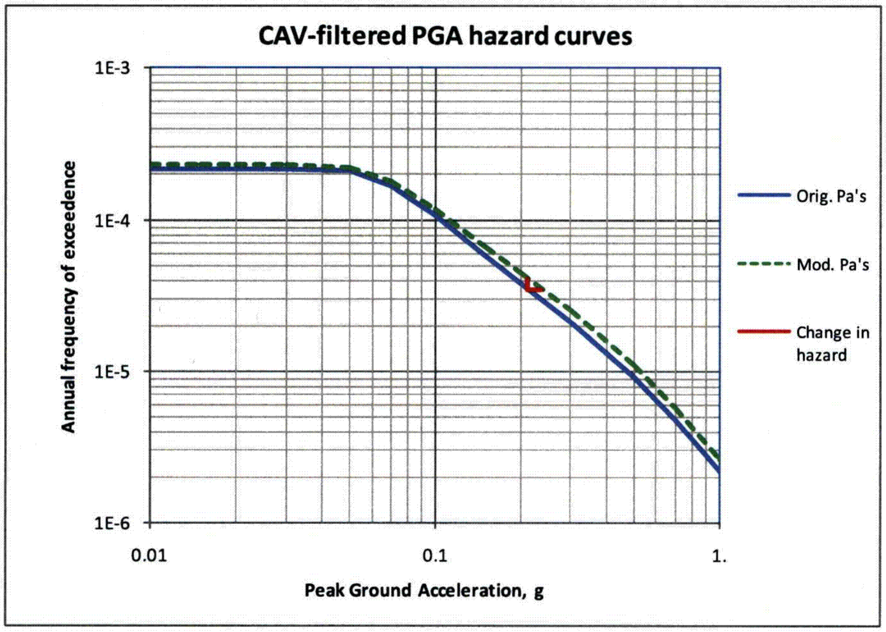

Figure 2: PGA hazard curves for original P_a's and modified P_a's, showing (with red lines) the change in hazard if the GMRS is changed from 0.236g to 0.212g.

CONCLUSIONS

The changes in seismic hazard and GMRS that would occur if alternative probabilities of activity P_a were applied to certain Dames & Moore sources are small. At the Shearon Harris site, the Dames & Moore host source is DAM-53, and the P_a for this source is increased by 385% (P_a is multiplied by a factor of 3.85) for the sensitivity study. The resulting change in overall hazard implies an increase in UHRS values and GMRS of about 2% or less, across all spectral frequencies.

At the Lee site, the Dames & Moore host source is DAM-41, and the P_a for this source is increased by 833% (P_a is multiplied by a factor of 8.33) for the sensitivity study. The resulting change in overall hazard implies an increase in GMRS of about 11% at high frequencies, and 7% or less at frequencies of 5 Hz and lower. The 11% change in high-frequency GMRS implies that, if the original GMRS were used for design (using the Dames & Moore-recommended P_a values), the hazard would be increased by about 16%. Increases at lower spectral frequencies would be smaller.

Changes in mean seismic core damage frequency scale closely with changes in mean hazard at the GMRS (the scaling is exactly proportional if the shape of the mean hazard curve does not change). Thus a change of 16% in mean hazard at the GMRS corresponds to a change of about

16% in mean seismic core damage frequency. This is within the level of change considered to be insignificant.

It should be emphasized again that the modified P_a values for Dames & Moore sources are not supported by any new data that have been observed or by any new theories of earthquake occurrences in the CEUS. The interpretation by Dames & Moore was that certain large seismic sources in the CEUS have some probability that they will never produce an earthquake with $m_b>5.0$. If earthquakes with $m_b>5.0$ cannot occur, this is consistent with the observation that certain parts of the earth's crust are stable within the current tectonic environment, that crustal stresses are relatively uniform, and that active faults do not exist with sufficient dimensions to relieve accumulated crustal stress with moderate or large earthquakes. This is one interpretation out of six EPRI-SOG teams for the CEUS, and is an example of the broad range of diverse, informed scientific opinion that is sought in a large seismic hazard project. Until data are collected that render such opinions invalid, or until the EPRI-SOG study is updated by another study of similar breadth and scope, the Dames & Moore interpretation should continue to be considered one valid interpretation among six.

For these reasons, and because the potential change in Dames & Moore P_a values results in estimated changes to mean hazard and to mean seismic core damage frequency that are insignificant, this study validates the ESP and COL applications submitted to date that use the original P_a values for the Dames & Moore team.

REFERENCES

1. EPRI (1989). *Probabilistic Seismic Hazard Evaluations at Nuclear Plant Sites in the Central and Eastern US: Resolution of the Charleston Earthquake Issue*. EPRI Rept. NP-6395-D, April.
2. Progress Energy (2008) *Shearon Harris Nuclear Power Plant Units 2 and 3 Combined License Application*, US Nuclear Regulatory Commission document accession no. ML080600545, February 18.
3. Duke Energy (2007). *Duke Energy WSL III Units 1 & 2 COLA (Final Safety Analysis Report), Rev. 0 – Chapter 02 Site Characteristics,* US Nuclear Regulatory Commission document accession no. ML073510888, December 12.
4. Risk Engineering, Inc. (1989). *EQHAZARD Primer*, EPRI Rept. NP-6452-D, Special Report, June.
5. Hardy, G, K. Merz, N. Abrahamson, and J. Watson-Lamprey (2006). *Program on Technology Innovation: Use of Cumulative Absolute Velocity (CAV) in Determining Effects of Small Magnitude Earthquakes on Seismic Hazard*, Elec. Power Res. Inst, Palo Alto, EPRI Rept. 1014099.