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Guidance for Performing Probabilistic Seismic Hazard Analysis for a Nuclear Plant Site: Example Application to the Southeastern United States

Lawrence Livermore National Laboratory

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ABSTRACT

From 1981 to 1989, Lawrence Livermore National Laboratory (LLNL) developed a Probabilistic Seismic Hazard Analysis (PSHA) method for the eastern United States (NUREG/CR-5250), followed in 1993 by improvements in the handling of the uncertainties (NUREG-1488). Differences between these results and those of a utilities-sponsored study (Electric Power Research Institute, 1989) led to the formation of the Senior Seismic Hazard Analysis Committee (SSHAC) to identify the sources of differences and give guidance on how to perform a state-of-the-art PSHA (NUREG/CR-6372, 1997).

The present study is a trial implementation of the SSHAC guidance. As part of the project, additional guidance was developed and proposed for performing a PSHA. The trial implementation project tested the issue of development of the seismic zonation and seismicity models for two sites: Watts Bar and Vogtle. It was found that the uncertainty generated by disagreements among experts could be considerably reduced through interaction and discussion of the data, and by concentrating on the elements common to all experts' interpretations. The present study includes analyses of the differences between its results and the NUREG-1488 results (Appendix G).

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EXECUTIVE SUMMARY

During a previous project under the sponsorship of the Nuclear Regulatory Commission, the Department of Energy (DOE), and with contribution by the Electric Power Research Institute (EPRI), a panel of scientists was convened to perform a study of probabilistic seismic hazard assessment (PSHA) methodologies. The panel, named the Senior Seismic Hazard Analysis Committee (SSHAC), developed a set of guidelines which were published as NUREG/CR-6372 and referred to as the SSHAC report.

The SSHAC was tasked with developing an improved methodology that would be useable for regulatory applications for about the next decade for both regional and site-specific analyses. In evaluating existing methodologies and general principles, they found that most of the problems in past PSHA applications were caused by flawed expert elicitation and procedural guidance for PSHA and rigorous treatment of uncertainties. Where necessary, the SSHAC also provided guidance for the subjects of seismic source characterization and ground motion estimation.

Their overall conclusion is that there are important pitfalls in using experts effectively, and that the key task is technical integration. Depending on technical complexities and regulatory significance, the study is led by either a Technical Integrator (TI) or a Technical Facilitator/ Integrator (TFI) who is responsible for the results of the PSHA. The TI is commonly used for less complex tasks, such as a site-specific study for a bridge or other project. The TFI is employed for more complex regional studies or for investigations related to a critical facility, such as a nuclear power plant. The TFI would commonly consist of two or three individuals with the requisite range of experience in earth sciences and expert elicitation. The TFI evaluates a range of hypotheses and models presented by the experts, and arrives at a representation of the knowledge of the group and of the scientific community at large. The expert elicitation depends heavily on group interaction and structured workshops where available facts are presented. The aim of the TFI process is to develop as much of a consensus as possible; however, where that goal is not reached and where there may be "outlier" opinions, it is up to the TFI to formulate the most consistent result, including behavioral aggregation involving qualitative judgment.

With respect to uncertainties in seismic hazard assessment, the SSHAC adopted a rigorous treatment based on a distinction between epistemic and aleatory uncertainties. Epistemic uncertainties are based on a lack of scientific understanding that may be reduced in the future. Aleatory or "random" uncertainties cannot be reduced for all practical purposes. These terms were chosen to avoid multiple meanings associated with words such as "uncertainty" for epistemic. Further characteristics of the SSHAC methodology involve careful documentation of the PSHA process and of the data and models used. Also required is adequate peer review in both the TI and TFI processes, including technical and process peer review. In the course of their work, the SSHAC held several workshops that served to refine the guidelines and prove their efficiency.

Two of the most significant aspects of the new guidelines provided by SSHAC are the TFI concept and a departure from relying on inflexible aggregation schemes, such as a priori equal weights. The guidelines were reviewed by a committee of the National Academy of Sciences (NAS) and given generally positive comments. The review committee, in particular, agreed with and further emphasized the principle of not relying on mechanical aggregation schemes.

The efforts of the SSHAC concentrated on defining the overall procedure for eliciting expert interpretations and integrating them. The procedure was tested partially on the problem of developing ground motion attenuation models. The seismic source characterization is a more difficult problem which was not tackled by the SSHAC, and thus became the starting point for a new project described in this report and called the Trial Implementation Project (TIP). The scope of TIP was to test the recommendation of the SSHAC on the characterization of the seismic sources, and to finalize the development of ground motion attenuation models for eastern North America started by SSHAC. The study had the goal of testing and implementing the SSHAC guidelines for the specific case of the southeastern United States and of two nuclear plant sites in that region, namely Vogtle and Watts Bar. Workshops and expert elicitations were held in accordance with SSHAC principles, with emphasis on seismic source characterization. This project has shown that the TFI procedures can lead to an unusual degree of agreement among experts through thorough discussion of the available data, and through interaction between the experts. Together with the focusing effect of the TFI, this leads to narrower margins of variation without any coercion. For the southeastern U.S. this led to an integrated map of source zones that incorporated the opinions of all the experts involved, even though they began with fairly different source zone maps. This is in stark contrast to the previous situation, where each expert produced a series of map interpretations, leading to a large number of source zone maps, most of which were totally different from each other.

The process used for the southeastern U.S. source map eliminated several variations in source zones, because different experts were able to agree on a compromise solution that was consistent with their interpretation and would not significantly change the final hazard. In some cases, such as near the Watts Bar plant, where a change in zone boundaries can change the site hazard substantially, differing opinions were incorporated by using three versions of a source zone boundary. Each zone boundary variant was assigned a probability relating to the level to which each expert believes it is supported by the observed data and general physical concepts, thus incorporating the range of expert opinions. We found that by concentrating on extracting from the experts' interpretations what was common to all or to the majority, we were able to identify a set of common seismic source zones that all experts could use to formulate their own interpretations in the form of different zonation maps. However, we were careful to identify enough common zones to be able to represent all the diversity in the experts' interpretations. The main purpose of this process was to minimize the unnecessary, or artificial, diversity by making sure that those interpretations which appeared different, were indeed different. Those which were not were folded into a common interpretation, with some uncertainty. These minimum set zones which we refer to as the common building blocks allow us to have a limited number of seismic sources to express all the possible alternatives of all the experts. Then we consider each seismic source separately and obtain its seismicity rate, upper magnitude cutoff characterization (a probability distribution function) by eliciting all of the experts, to model both the aleatory and epistemic uncertainty.

In addition to keeping all of the experts' zonation maps separate (but still using the minimum set zones) we tested the effect of developing a set of composite seismic zonation maps developed by the TFI. We found that to perform that task we needed to include in the set of alternatives all of the experts' alternatives to preserve the dependencies between the seismic sources. This, however, was a relatively easy task, done by putting together the various combinations of seismic sources in the minimum set to build all the needed maps. Our test cases show that the use of composite ground motion models, composite seismic zonation maps, and composite seismicity rates constitutes an estimate of the seismic hazard, the main reasons being that (1) it uses the same building block seismic sources as those defined by the experts and (2) the elicitation process emphasized the effect of the dominant sources on the hazard and consequently experts' diversity is minimized for these seismic sources. The only difficulty that has remained in this and other projects using the SSHAC guidelines is the treatment of uncertainties. Many of the experts still have problems following a rigorous distinction between various epistemic and aleatory uncertainties.

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Pulling all this material together and writing this report has tested the patience, and the strong desire to complete this study, of the two main authors N. Abrahamson and J. Savy, and has shown invaluable support from R. Yamamoto.

ABBREVIATIONS

DOE	Department of Energy
EPRI	Electric Power Research Institute
ETSZ	Eastern Tennessee Seismic Zone
EVA	Expert Evaluator
NPR	New Production Reactor
NRC	Nuclear Regulatory Commission
PSHA	Probabilistic Seismic Hazard Analysis
SRS	Savannah River Site
SSHAC	Senior Seismic Hazard Analysis Committee
TFI	Technical Facilitator Integrator
TI	Technical Integrator
TIP	Trial Implementation Project

1. INTRODUCTION

1.1 Background

Probabilistic Seismic Hazard Analysis (PSHA) is a methodology that estimates the likelihood that various levels of earthquake-caused ground motion will be exceeded at a given location in a given future time period. Due to large uncertainties in all the geosciences data and in their modeling, multiple model interpretations are often possible. This leads to disagreement among experts, which in the past has led to disagreement on the selection of ground motion for design at a given site.

In 1994, in order to review the present state-of-the-art and improve on all the overall stability of the PSHA process, the U.S. Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), and the Electric Power Research Institute (EPRI) co-sponsored a project to provide methodological guidance on how to perform a PSHA.

The project has been carried out by a seven-member Senior Seismic Hazard Analysis Committee (SSHAC) supported by a large number of other experts.

The SSHAC reviewed past studies, including the Lawrence Livermore National Laboratory and the EPRI landmark PSHA studies of the 1980's and examined ways to improve on the present state-of-the-art.

The Committee's most important conclusion was that differences in PSHA results are due to procedural rather than technical differences. Thus, in addition to providing a detailed documentation on state-of-the-art elements of PSHA, the SSHAC report (NRC 1997), provides a series of procedural recommendations. As part of the SSHAC effort, the recommendations of the SSHAC were partially tested in the development of a ground motion attenuation model for North America. That test had been selected because of the relative simplicity of formulation of the ground motion attenuation models. The issues to be discussed and the input to be generated is limited to the characterization of a few, well defined single parameters. In contrast to the case of the development of ground motion attenuation models, the development of seismic zonation maps involves the evaluation of multi dimensional data sets. The description of future seismicity through the use of seismic zonation maps and occurrence models are multiparameters models with very complex formulation and correlation structure.

Although the SSHAC did not test its recommendations on the development of zonation and seismicity models it was understood that the recommendations provided were general enough to apply to any problems in which it is important to characterize the epistemic uncertainty through the use of multiple experts inputs including for the case of seismic source zonation modeling.

1.2 Purpose of the Study, Scope

The purpose of this project, under Job Code W6496, titled "Trial Implementation of SSHAC Guidelines", is to test and implement the guidelines developed by the Senior Seismic Hazard Analysis Committee (SSHAC) developed under FIN L2503 (NRC 1997). Like the SSHAC project, the TIP (Trial Implementation Project) has the purpose of improving our ability to quantify and reduce uncertainties in seismic hazard estimation. The objectives of this study are to exercise the process improvement recommended in the SSHAC report specifically for seismic source characterization and to implement the methodology in a manner designed to achieve optimum stability in the PSHA results.

The scope of this project also includes an update of the ground motion models developed in the test by SSHAC. The test had been limited by the number of pairs of magnitudes and distances sampled by the experts. This project revisits the work done by SSHAC and extends it to a much bigger set of pairs of magnitudes and distances.

As a more substantial effort than the development of ground motion models, the seismic source characterization effort includes investigating the motion of composite seismic zonation maps, and minimum set zones. This part of the scope includes a demonstration of the development of a set of seismic zonation maps which are meant to sample the interpretation of the seismicity experts selected for the project. At each step in this implementation of the SSHAC guidelines, new procedural steps are identified consistent with the guidelines, but specific to the task of seismic source characterization.

1.3 Organization of the Report

After summarizing the general requirements and the guiding principles of SSHAC in Section 2, Section 3 provides some practical guidance on performing a PSHA. The guidance is based on the actual implementation of the SSHAC guidelines documented in Section 4.

Section 4 contains a detailed account of the procedure implemented. It includes the selection of the experts, the process of elicitation of the experts interpretations, the formulation of the alternative maps, the reduction of the set of zones to the minimum set by the Technical Facilitator Integrator (TFI). Section 4.3 gives a detailed account of the process applied to the ground motion attenuation models, and Section 4.4 gives some hazard results for two sites.

1.4 Use of This Document

This document is not intended to provide a compulsory method of performing PSHA. It gives guidance on ways to approach the issue of uncertainty in the characterization of seismic sources and in the development of ground motion models. The guidance will help the analyst in providing a checklist of tested methods for ensuring that all criteria which define a quality PSHA, as set by the SSHAC (NRC 1997) are met.

2. GENERAL REQUIREMENTS OF A PSHA

2.1 Fundamental SSHAC Guiding Principle

PSHA inputs involve multiple issues, e.g., ground motion models, ground motion uncertainty, seismic source identification, seismicity parameters, etc. The complexity, importance and diversity of judgments within the appropriate scientific community regarding any one of these issues vary between study location (east vs. west U.S.), range of the study (site-specific vs. regional), and other factors.

SSHAC (NRC 1997) clearly sets the driving principle for the basis of the inputs in a PSHA as follows:

> "A basic principle defined by the Committee is that the underlying basis for the inputs related to any of these issues must be the composite distribution of views represented in the appropriate scientific community. Expert judgment is used to represent the informed scientific community's state of knowledge. Of course, it is impractical —and unnecessary—to engage an entire scientific community in any meaningful interactive process. Decision makers must always rely on a smaller, but representative, set of experts. Thus, we view an expert panel as a sample of the overall expert community and the individual Technical Integrator (defined later) as the expert "pollster" of that community, the one responsible for capturing efficiently and quantitatively the community's degree of consensus or diversity.
>
> "Regardless of the scale of the PSHA study, the goal remains the same: to represent the center, the body, and the range of technical interpretations that the larger informed technical community would have if they were to conduct the study."

2.2 Procedural Recommendations

Following the fundamental principle, restated above, SSHAC's investigation of the issues led to a set of nine recommendations which are felt to summarize the procedural guidance to achieve the goals of the fundamental principle. These recommendations are reproduced below and constitute the basis for the performance of a state-of-the-art PSHA. (Taken from NRC 1997):

1) SSHAC identifies and describes several different roles for experts based on its conclusion that confusion about the various roles is a common source of difficulty in executing the aspect of PSHA involving the use of experts. The roles for which SSHAC provides the most extensive guidance include the expert as proponent of a specific technical position, as an evaluator of the various positions in the technical community, and a technical integrator (see the next paragraph).

2) SSHAC identifies four different types of consensus, and then concludes that one key source of difficulty is failure to recognize that 1) there is not likely to be "consensus" (as the word is commonly understood) among the various experts and 2) no single interpretation concerning a complex earth sciences issue is the "correct" one. Rather, SSHAC believes that the following should be sought in a properly executed PSHA project for a given difficult technical issue: (1) a representation of the legitimate range of technically supportable interpretations among the entire informed technical community, and (2) the relative importance or credibility that should be given to the differing hypotheses across that range. As SSHAC has framed the methodology, this information is what the PSHA practitioner is charged to seek out, and seeking it out and evaluating it is what SSHAC defines as technical integration.

3) SSHAC identifies a hierarchy of complexity for technical issues, consisting of four levels (representing increasing levels of participation by technical experts in the development of the desired results), and then concentrates much of its guidance on the most complex level (level 4) in which a

panel of experts is formally constituted and the panel's interpretations of the technical information relevant to the issues are formally elicited. To deal with such complex issues, SSHAC defines an entity that it calls the Technical Facilitator/Integrator (TFI), which is differentiated from a similar entity for dealing with issues at the other three less-complex levels, which SSHAC calls the Technical Integrator (TI). Much of SSHAC's procedural guidance involves how the TI and TFI function should be structured and implemented. (Both the TI and TFI are envisioned as roles that may be filled by one person or, in the TFI case, perhaps by a small team).

4) The role of technical integration is common to the TI and TFI roles. What is special about the TFI roles, in SSHAC's formulation, is the facilitation aspect, when an issue is judged to be complex enough that the views of a panel of several experts must be elicited. SSHAC's guidance swells on that aspect extensively, in part because SSHAC believes that this is where some of the most difficult procedural pitfalls are encountered. In fact, the main report identifies a number of problems that have arisen in past PSHAs and discussed how the TFI function explicitly overcomes each of them.

5) For most technical issues that arise in a typical PSHA, the issue's complexity does not warrant a panel of experts and hence the establishment of a TFI role. Technical integration for these issues can be accomplished—indeed, is usually best accomplished— by a TI. In fact, SSHAC has structured its recommended methodology so that even the most complex issues can be dealt with using the less expensive TI mode, although with some sacrifice in the confidence obtained in the results on both the technical and the procedural sides.

6) One special element of the TFI process is SSHAC's guidance on sequentially using the panel of experts in different roles. Heavy emphasis is placed on assuring constructive give-and-take interactions among the panelists thought the process. Each expert is first asked, based on his/her own knowledge (yet cognizant of the views of other as explored through the information-exchange process), to act as an evaluator, that is, to evaluate the range of technically legitimate viewpoints concerning the issue at hand. Then, each expert is asked to play the role of technical integrator, providing advice to the TFI on the appropriate representation of the composite position of the community as a whole.

   Contrasting the classical role of experts on a panel acting as individuals and providing inputs to a separate aggregation process, the TFI approach views the panel as a team, with the TFI as the team leader, working together to arrive at (I) a composite representation of the knowledge of the group, and then (ii) a composite representation of the knowledge of the technical community at large. (Neither of these representations necessarily reflects panel consensus—they may or may not and their validity does not depend on whether a panel consensus is reached.)

   The SSHAC guidance to the TFI emphasizes that a variety of techniques are available for achieving this composite representation. SSHAC recommends a blending of behavioral or judgmental methods with mathematical methods, and in the body of the report several techniques along these lines are described in detail. key objective for the TFI is to develop an aggregate result that can be endorsed by the expert panel both technically and in terms of the process used.

7) The TFI's integrator role should be viewed not as that of a "super-expert" who has the final say on the weighting of the relative merits of either specific technical interpretations or the various experts' interpretations of them; rather, the TFI role should be seen as charged with characterizing both the commonality and the

diversity in a set of panel estimates, each representing a weighted combination of different expert positions. SSHAC thus sees the TFI as performing an integration assisted by a group of experts who provide integration advice.

8) Thus, the TFI as facilitator structures interaction among the experts to create conditions under which the TFI's job as integrator will be simplified (e.g., either a consensus representation is formed or it is appropriate to weight equally the experts' evaluations of the knowledge of the technical community at large). In the rare case in which such simple integration is not appropriate, additional guidance is provided. In the main report, guidance is presented on two possible approaches involving (i) explicit quantitative but unequal weights (when it becomes obvious that using equal weighting misrepresents the community-as-a-whole); and (ii) "weighing" rather than "weighting", in cases when the experts themselves, acting as evaluators and integrators, find fixed numerical weights to be artificial, and when it is appropriate to represent the community's overall distribution in a less rigid way.

9) The SSHAC guidance gives special emphasis to the importance of an independent peer review. We distinguish between a participatory peer review and a late-stage peer review, and we also distinguish between a peer review of the process aspects and of the technical aspects for the more complex issues. We strongly recommend a participatory peer review, especially or the process aspects for the more complex issues. This paper details the pitfalls of an inadequate peer review.

2.3 Implementation for Ground Motion Attenuation and Seismic Source Characterization

SSHAC had already demonstrated the applicability of its general principle and procedures to the case of development of ground motion attenuation models. In this area, the study reported here does not add substantially to the overall methodology described in the SSHAC report (NRC 1997). Rather, our effort was concentrated on re-sampling the ground motion experts to provide a higher resolution in the definition of the inputs to defining the composite ground motion attenuation models, and incorporate the latest scientific developments in the area of ground motion estimation.

The implementation for the seismic source characterization is more complex because different experts will typically offer alternative models of seismic sources, and of recurrence of earthquakes which seem to have no commonalities. This makes impossible the task of providing composite distribution of views about well identified parameters.

Therefore, the basic driving concept in developing the inputs for seismic source characterization consisted of:

- Identifying the commonalities between the alternative models of seismic sources formulated by all the experts.
- Developing a core seismic sources model that all the experts agree upon, (although each expert might assign different degree of credibility on the models).
- Characterizing each seismic zone by simple parameters which can be the object of discussion by all the experts and lead to a composite distribution of views.
- Developing the remaining set of seismic sources to represent the views of all experts for those alternatives not included in the core seismic sources.

The main challenge in this exercise is sorting out between different experts what constitutes real scientific disagreement and what is merely misunderstanding or nuances of interpretation of the same idea. For example it is not uncommon to have two experts formulate two different seismic zone shape and/or size for a particular area. In this case, the role of the TFI is just to determine whether the two different models come in two different interpretations of the data, through the use of different, say equally valid, physical models. If this is the case, it is not possible to reduce the two different models to a single, simpler one. However, if it is found, after full interaction of the experts, TFI, and possibly other experts, that the scientific bases for formulating, the model are common, it is then possible to narrow the differences and formulate a simpler single model, with uncertainty to express the various nuances of interpretation.

This study demonstrates that it is possible to express the entire distribution of views of all the experts in seismic source characterization with a limited number of individual seismic sources. This we call the minimum zone set. Each seismic source and its uncertainty is the results of interaction between all the experts in the project and each of the identifiable parameters characterizing a source are defined by these distributions of views of the experts. It is at the level of these distributions of views (which for single parameters translate into probability distribution functions) that we talk about a consensus of the experts.

3. GUIDANCE FOR A PRACTICAL APPROACH

3.1 General Road Map

The level of effort that will be allocated for a project will determine the level of detail and size of each portion of the project tasks. However, following the set of principles established by the SSHAC and summarized in Section 2, it is important to recognize that the overall process of a PSHA which relies on the use of experts inputs needs to contain all of the following twelve steps:

1. Selection of participants
   - Technical Facilitator Integrator (TFI) either single or team
   - Experts, (Technical Experts and Expert Evaluators EVA) either individuals or teams
2. Knowledge dissemination for the seismic source definitions, and ground motion modeling
   - general data
   - proponent interpretations
   - issues relevant to the particular project
   - training of the participants (hazards, uncertainty)
3. EVAs evaluate individually and formulate draft interpretation of sources, or of ground motion estimates or model selections prior to extensive interaction.
4. EVA's individual interpretations are discussed, explained, clarified in group interactive session organized and facilitated by the TFI.
   - clarification of EVA's interpretation
   - Formulation by the TFI of the Minimum Zone Set
   - Formulation of acceptable ground motion attenuation models
5. EVA finalize their individual set of alternative interpretations
6. Detailed documentation is generated by the EVA for the geometrical description of the source zones for the derivation of ground motion estimates.
7. Knowledge dissemination for the sources seismicity characterization
   - review data bases
   - analysis tools
   - analysis support
   - review technical issues relevant to the particular project
8. EVAs evaluate individually and formulate draft interpretations of seismicity characteristics.
9. EVAs individual interpretations are discussed explained and clarified in group interactive sessions and facilitated by the TFI.
10. EVAs finalize their individual interpretations.
11. Detailed documentation is generated by EVA for the models of seismicity characterization.
12. Peer Review of the implementation of the actual PSHA process.

This general road map applies for both the seismic source characterization and ground motion attenuation modeling.

The twelve elements can be implemented in a variety of ways. The case study in Chapter 4 describes one of the ways which can be viewed as intermediary between a simple minimum type of analysis and a full fledged analysis.

The selection of the TFI and of the experts is the first step and a very delicate one. To avoid bias or other problems likely to shed negative lights on a study, it is recommended, as much as possible to adopt a well structured, well documented process at least of the type described in the case study Section 4.1.

The knowledge dissemination, formulation of draft interpretations and finalization constitute the "experts" elicitation process. It can be achieved by a combination of interactive workshops, extensive one-on-one interaction between the TFI and the EVAs, generation of white papers to discuss specific issues, written questionnaires, one-on-one (elicitation) interviews, and (TFI) facilitated group interaction sessions.

Figure 3-1 shows a typical example of the general structure of a PSHA.

Not shown on Figure 3-1 are numerous possible improvements. Implementation of the improvements is dependent on the overall level of analysis, for a specific project. They include, but are not limited to the possibility of providing interaction between the ground motion attenuation experts and the seismic source characterization experts. This is always desirable as it helps both sets of experts understand the practical issues. It helps them identify the important elements of their modeling, so they can concentrate on those rather than effects less important to the hazard. For example, an expert might consider different types of attenuation models if the most important seismic sources are faults close to the site for which the hazard is to be estimated, as opposed to the case where the dominant hazard would be contributed by a distant source. The type of faulting, hanging wall, foot wall etc., are also considerations that would influence a ground motion expert in the selection of appropriate models of attenuation.

White papers are very useful tools to help the experts interact by pushing them to develop position sometimes in opposition to their own beliefs and scientific persuasions. They discover some ways of interpreting data, that are new to them, and help them formulate ranges of possible interpretations that they would not see otherwise.

Sensitivity analyses are important to show the experts, in a generic fashion, the effects of various hypotheses on the estimation of the seismic hazard. It is crucial that these sensitivity studies be generic so that the owner of the results cannot be accused of influencing the experts by presenting "undesirable" results.

There is a need however to present the final results to all the experts and ask for their comments. In the case of disagreement among experts, there is no absolute need to make additional changes, but all forms of disagreement need to be documented as well as all forms of consensus developed by the experts.

3.2 Data Requirements

All of the available data that could have an influence in forming the bases for models of where, when and what types of earthquakes occur as well as the ground motion they might generate at the site of the nuclear power plant, must be collected reviewed and evaluated. A detailed description of the type of data, their use and how to evaluate them is given in NUREG/CR-6372.

At each step of the way in the study, the need for additional data might become an issue. In particular, site specific geotechnical data are essential for performing educated soil amplification studies. What and how much data is enough cannot be determined in the absolute. It depends on many factors, including, technical need and economics.

At the minimum, before embarking in a costly field investigation campaign, a simple cost benefit analysis should be performed. In most cases, additional field investigations, such as "geologic" trenches, help in confirming a hypothesis (or informing) regarding the existence of a fault or some of its characteristics. As mentioned above, soil sampling and laboratory testing can be essential in developing input for models of the soil amplification at a site.

3.3 Elicitation and Integration Process

One of the goals of the TIP was to determine whether it is possible to develop a composite model of the seismic source zonations by integrating the models formulated by a set of individual experts (or separate teams of experts), into a single set of alternative zonation maps. This would be obviously possible by stacking all the experts' maps but very impractical. Instead it is possible, a the cost of loosing some aspects of the correlation between the source zones, to develop a simplified integrated set of maps that we call the composite seismic source zonation model. All other things being equal, the composite model should lead to the same mean hazard but possibly only slightly different estimates of the uncertainty.

The TFI will develop the composite SSC. In doing so, the features of the models of all the EVA which are important to the hazard at the site, and important to the quantification of the uncertainty on the hazard, will be included in the composite model.

Thus, deciding whether one wants to perform an analysis including all the experts interpretation kept separate or by using a composite model will depend on the amount of resources and time available. The development of a composite model should follow all the same principles of Section 3.1, and for which guidance is given in the following subsections, but for which each step can be simplified.

For example, a simplified approach could be based on small team of analysts including a TFI. In this case, the SSHAC (NUREG/CR-6372, p. 22) makes a distinction between Technical Integrator (TI) and the Technical Facilitator Integrator (TFI). The case where there is a need for full extensive interaction with a well identified group of experts who are an integral part of the project, and "a component distribution of the informed technical community" is sought, is referred to the role of the TFI. The role of the TI is also to develop "a composite distribution of the informed technical community" but without the expensive trappings attached to the TFI approach. In this guidance document, we do not differentiate between the TI or TFI, they are seen as the same entity, implementing different levels of the same process. C'est tout! Experts will be consulted, formally, but not necessarily within the context of workshops. The TFI gathers all the information, proceeds with interaction with the experts, following all the basic steps, on step 1 through 12 described above, but without formally eliciting the experts. The experts interpretations are inferred by the TFI and discussed with the experts. The peer review can be a simple review of the process by an independent reviewer who understands the SSHAC process and seismic hazard analysis.

3.3.1 Selection of TFI

The primary role of the TFI is to facilitate the interaction between the technical experts and help them evaluate the data and the proposed models of data interpretation. The TFI does not evaluate the data but rather evaluates the extent to which each of the EVA's interpretations are supported by the data and have threads of commonality so that an integrated version, the composite model, can be developed which represent a distribution of the informed technical community. In consequences, the attributes sought for in a TFI (or TFI Team) are as follows:

- Knowledgeable in the PSHA process as defined in this guidance document and in NUREG/CR-6372.
- Be Technically independent, (not being the proponent of any specific model),
- Knowledgeable in the generic aspects of the related scientific areas to understand the technical issues and be able to facilitate the experts discussion.
- Have general knowledge of the statistical, geological and geophysical analysis tools used in PSHA and by the experts.
- Have demonstrated the ability to socially interact positively with a group of engineers and scientists with different views.

- Be able and willing to devote all the needed level of effort to carry out the implementation of the project within the bounds of time required by the sponsor.

The above attributes, augmented by considerations specific to a particular project will be used to identify a pool of candidates for the TI/TFI team from which to select one in a manner similar to the process described in Section 3.3.2 for the selection of the experts. However, in practice the choice is limited between a few candidates or teams in general already associated with the sponsoring organization. Nevertheless, the same general attributes have to be used for the final selection. A lack of the right pedigree on the part of the TI/TFI Team could jeopardize the overall credibility and value of the final results, especially in controversial licensing cases, such as those of Nuclear Power Plants siting or other critical facilities siting.

3.3.2 Selection of Experts

Experts can be asked to pay several different roles in the course of a PSHA. The Senior Seismic Hazard Analysis Committee (NRC 1997) defines the expert roles of proponent, evaluator, and integrator, roles that were understood and employed by the experts. A proponent advocates a particular technical hypotheses or interpretation, an evaluator considers the support for alternative hypotheses and interpretations in the available data and evaluates the uncertainties associated with the assessments, and an integrator combines the evaluators' alternative interpretations into a composite distribution that includes uncertainties. The experts are informed of their roles as evaluator experts and of the need to forsake the role of proponent in making their interpretations and evaluating uncertainties. Proponents of specific hypotheses or interpretations are engaged as resources and present their hypotheses or interpretations in workshops. Alternative proponent views are presented to the experts and open scientific debates of alternative views are facilitated among them at the workshops. Some expert evaluators also can be engaged temporarily as proponents to describe a particular hypothesis or interpretation in a workshop.

Expert interactions are deemed vital in the SSHAC process and must be properly facilitated. Experience form numerous seismic hazard studies has shown that experts interact frequently in their professional activities, and that workshops serve to provide information and interaction that facilitate their consideration of hypotheses and data and, ultimately, their evaluations and interpretations. Expert interactions are encouraged and must be facilitated through multiple workshops and, for seismic source characterization, a field trip if possible.

Finally, the SSHAC (1997) process emphasizes the need to consider at the outset the strategy for integration or aggregation of the experts' evaluations, so that the analyses are structured in a way that is conducive to aggregation. This project at the outset defined a strategy to combine the evaluations of the experts using equal weights. The key procedural components of the project (ranging from the selection of experts to the dissemination of date sets) were designed to allow the equal-weights strategy to be implemented in a defensible manner.

The selection process must therefore be tailored to fulfill these requirements. The final selected individuals/teams should as best as possible represent a uniform sampling of the community of experts. No particular school of thoughts or specific interests should be more represented than others.

All the experts/teams selected should be among the best available technically and be among the most knowledgeable of the issues of interest, including knowledge of the data, the current interpretations of the data, the methods and tools of analysis and above all show the willingness to devote the necessary time and effort to the elicitation process. In this regard, experience shows that volunteer individuals do not perform as well as individuals on paid assignments to the project. Costly delays can develop as a result of lack of availability or commitment of an expert.

The case study gives a typical example of how to select individual experts. (See Section 4.1.)

3.3.3 Conduct of the Workshops

There is no general rule for setting up, organizing and conducting the workshops since their purpose and goals can be very different. In general, there will be the need for a workshop or working meeting each time an issue or series of issues need to be discussed interactively with all the "appropriate" experts associated with a particular project. The word "appropriate" is used here to signify that the type of issue, the area of study, will be the main considerations to determine who should be part of these workshops. Depending on the level of funding and the level of effort allocated to a project the participants to these workshops can be either the members of the analysis team, including a TFI, or can also include outside technical experts for the purpose of discussing single particular issues. To maximize the usefulness of the workshops several conditions must be met which will also help in generating a positive atmosphere and facilitate the interaction between participants.

- There must be a clear agenda for the workshop, with purpose and goals clearly explained to all the participants sufficiently in advance of the meetings.
- The role of each of the experts must be clearly explained and understood prior to the meetings.
- All the technical material necessary in support of presentation and technical discussions must be made available to the experts sufficiently in advance of the meeting that they can review the material and come prepared to the meetings.
- A detailed summary of the meetings, with account of resolutions, identification of issues must be part of the overall documentation.

Essentially there are three types of workshops:

1. Workshops on data dissemination.

   All the data available relevant to the issues of interest are brought together for evaluation and to ensure that all the experts are uniformly cognizant of the entire body of information available. The general conduct of such a workshop is very much free flow. After the project analyst or project manager provides general introductory information the project and the agenda, purpose and goals, with presentation and discussion of the overall methodology of the project all the information available is reviewed.

   Since the presentation of the data and all information is principally intended to provide a uniform basis of knowledge and to ensure that no important piece of information is being overlooked, the participants are not required to make any specific preparation, other than that associated with their own presentation if requested.

2. Workshop on formulation of models. The data and all relevant information have been collected and reviewed, the group of expert evaluators (EVA), are required to formulate their own independent models. In the case of the seismic source characterization they are asked to formulate seismic source maps which reflect their interpretation of the data as to where they believe earthquakes are likely to occur in the future. In the case of the ground motion attenuation they are requested to develop estimates of ground motion parameter values for a selected set of magnitudes and distances and possibly for a variety of source mechanisms and regions.

   The expert evaluators will come to the workshop with their initial formulations ready.

   The purpose of the workshop will be to review each individual expert's formulation, evaluate, and for the TFI and the experts to interactively construct the composite model, or distribution of views of the EVAs.

For this task, it is important to conduct the workshop in such a way as to ensure that each expert formulation is first clearly presented and fully understood by all before any real challenging, critique and/or endorsements are expressed in order to avoid any biasing or misunderstanding by the experts. One way of achieving this is to: (1) have each expert present his/her own interpretation of the data formulation and only allow questions related to understanding the details of what is proposed; (2) open the floor for detailed discussions including friendly challenges, critique, comparisons etc., where the TFI has the double duty of opening, steering without introducing his/her own personal opinions and biases, and also very importantly facilitating the discussion to keep it within the margins of civility, courtesy and professionalism.

3. Feedback Workshops.

   The purpose of these workshops is to review the result of the integration process and evaluate it in the light of the existing data and information. It is an important step in verifying that the experts' inputs have been used as intended, clear up misunderstandings and gross errors. It is also a necessary step to allow the experts to update their formulations if they deem it necessary once they have been able to compare them with the rest of the group of experts who also have provided input. Therefore, a feedback workshop will generally consist of at least three parts. The first part intended to review and evaluate the result of the integration by the TFI and a second part to update individual expert's inputs and finally a third part for the TFI to finalize the integration.

3.3.4 Conduct of the Interviews

The elicitation process is not limited to the act of responding to a request for information. It is the combination of all those tasks which enable the expert evaluators to formulate their opinion, express it and finally document it. The elicitation process comprises workshops, writing individual papers or formulation of models in interpretation of data, by the experts, open interaction with other experts and the TFI. It can also include answering questions to a series of questionnaires. Another way of securing and documenting the inputs from the experts is through one-on-one interviews.

The purpose of these one-on-on interviews is to ensure that the input provided comes entirely from the individual expert, to make sure that the original true diversity is preserved, and that it will appear at the time of the integration in the form of uncertainty.

The interviewing team must be composed of at least one person specialized in the elicitation of experts with an emphasis on expressing ranges of views on specific issues and must be able to help the expert express his/her uncertainty in a way that can lead to a quantification. In addition to this normative elicitor, another person, the technical elicitor must be fully cognizant of the technical issues pertaining to the elicitation. It is possible in some cases to use experienced individuals who can cumulate both functions.

It is recommended however to have one separate individual entirely devoted to the documentation of the interview, so that all notes remarks and important results can be passed on to the expert later for review. All data sets and information developed in the project must be available at the interview, and the conduct of the interview must follow a logical flow, predictable by the interviewees, with an interview preparation at the beginning to repeat the purpose goals, roles and modus operandi.

3.3.5 Final Integration

The concept of integration envisioned by SSHAC (NRC 1997) is the process of developing a composite model, as a range of views or a distribution of alternatives which represent the full range of views of the expert evaluators. The final composite model is the result of a careful weighting, in the view of the data and all the information, and level of support for each of all the alternative models, done interactively by the TFI in "complete symbiosis" with the group of experts. For the simple case of the characterization of a single numerical parameter, this translates into the development of a probability distribution function, where the input from each expert is fully represented. The integration process ends up being a consensus process in which the consensus is on the procedure that led to the composite model. Implicitly it is a consensus on the property of the distribution functions (or ranges of views), but it is not a consensus on any particular value of the model parameter since the experts may still retain different individual views.

3.4 Peer Review

The purpose of the Peer Review is to provide assurance that the study incorporates the diversity of views prevailing within the technical community, that uncertainties have been properly considered and incorporated into the analysis and the documentation of the study is clear and complete.

SSHAC (NRC 1997) identifies two types of peer reviews:

- Technical peer review
- Process peer review

and two modes of performing the review:

- Participatory
- Late-stage

It is important that both the technical and process peer reviews be performed to provide credibility to a PSHA study. On the other hand, participatory or late-stage is a matter of practicality and depends on the circumstances. A late-stage review can have the disadvantage of creating "surprises", participatory will provide a continuous feedback to the analyst, but it also can be an important additional burden and introduce biases added by the reviewers.

In any case, an internal peer-review should be seen as integral part of the study itself even before the results of the study are released. In this instance the word "internal" is meant to signify that the peer-review is internal to the project itself, although to satisfy the recommendations of SSHAC (NRC 1997), the actual reviewers must be outside of the project team to ensure independence.

3.5 Documentation

SSHAC (NRC 1997) has extensively described the attributes of the documentation necessary to ensure that:

- Others in the technical community can understand or review the analysis and the results
- A later analysis team with new information or improved model can utilize a PSHA to update it, revise it, or validate that it does not need an update or revision.
- the sponsoring organization can retain an adequate record of the process it supported.

The reader is referred to the SSHAC document for details on the documentation process. We only reproduce here the list of the various elements of the PSHA process for which documentation is required.

- Roles and Responsibilities of the Project Participants and Consultants
- Comparisons with other PSHA Studies
- Internal Quality Control and Review
- PSHA Methodology
- PSHA Results
- External Peer Review
- Documenting Citations

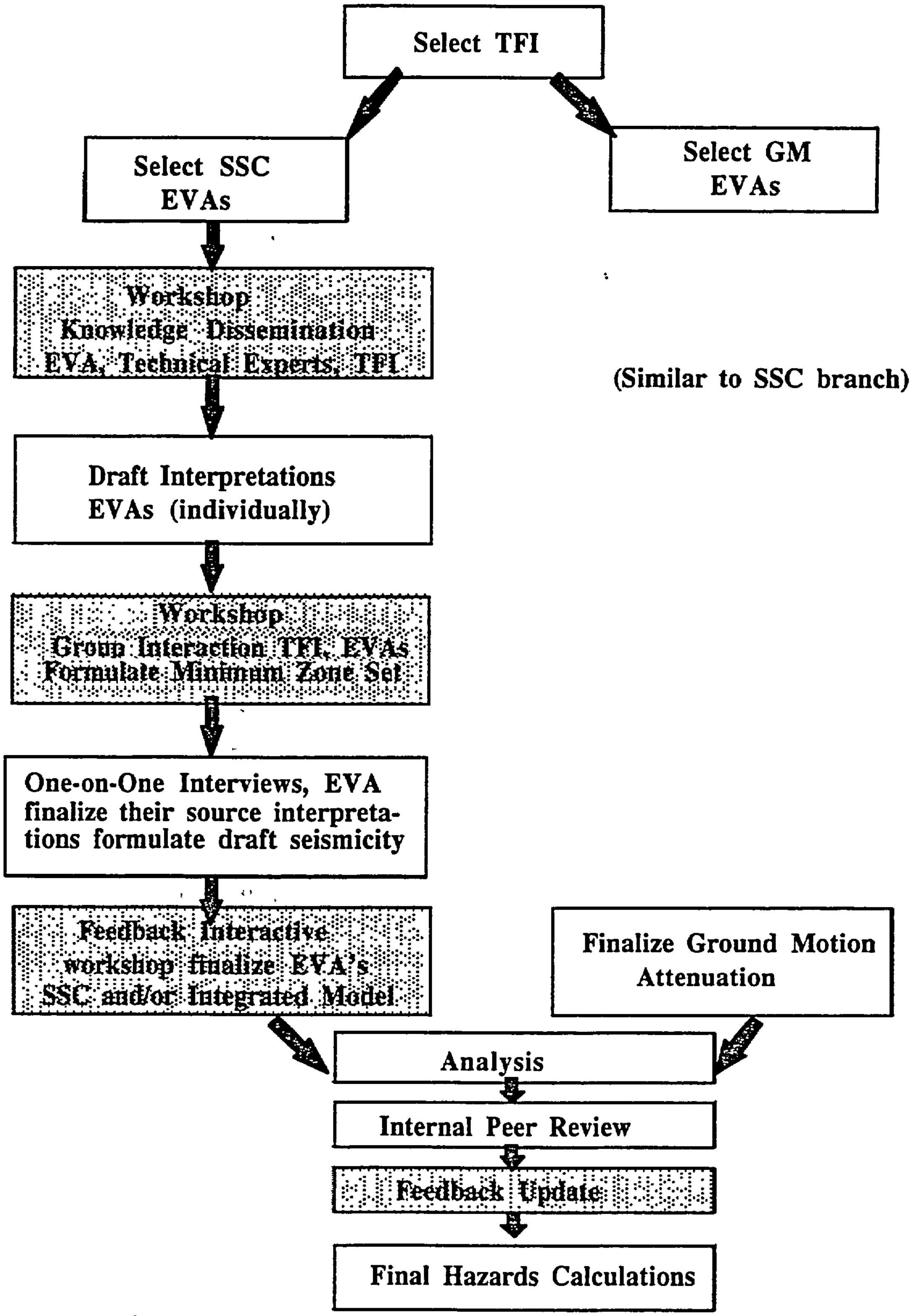


Figure 3-1 Typical PSHA Road Map.

4. CASE STUDY: DETAILED IMPLEMENTATIONS FOR TWO SITES IN SOUTHEASTERN U.S.

4.1 Expert Selection

The selection of the expert evaluators consists of a relative ranking of the experts in the pool performed by an analysis team according to a weighted average of the grades assigned to the experts for a series of criteria which express the requisite attributes needed of an expert evaluator. The value given to a grade is intended to express the degree to which an expert satisfies the criterion. The importance of each of the criteria with respect to the project at hand is specifically evaluated and is reflected in the weight assigned, relative to the other criteria.

The attribution of the weights which define the importance of each criterion, and of the grades that each of the experts in the pool are given for each of the criteria, is performed by the analysis team. It is a subjective process which is based on the knowledge that the team has of each of the experts in the pool. In performing this operation, the members of the team made a concerted effort to gain the maximum possible information on each of the experts in the pool, and exchange all known information between themselves before actually assigning grades. Each member of the team, then, assigned his own grades, the weighted grades were calculated for each expert in the pool and finally averaged over the members of the analysis team. The individuals were then ranked according to this averaged weighted grade, the highest grade leading to the highest rank.

The task of selecting the expert evaluators is probably one of the most important tasks in a PSHA with multiple experts. It has to be conducted very carefully and in full possession of all the necessary information on the experts in the pool. However it is only a small portion of such a project and must be organized in such a way as to maximize the resources of the project. It is not the project itself and is generally supported by limited funds. Thus the analysis team is not always in the position of being able to develop complete information on each of the experts in the pool and is constrained to assign grades sometimes with little information. For the purpose of this project, after a reasonable effort to gain knowledge on a particular expert, it was assumed that if the information was still not sufficient, the grade assigned to this particular expert would be some arbitrary low value, to reflect the lack of general notoriety.

For the purpose of this project, a set of criteria selected by the analysis team and arranged in five classes is given in Table 4.1-1.

The criteria for the purpose of ranking the experts in the pool are sorted into three classes:

1. Knowledge

2. Lack of bias, credibility

3. Interaction abilities

In addition, a fourth class of criteria was used to evaluate the availability of the individuals and finally a fifth class of criteria was used for achieving a balance in the composition of the panel of evaluators:

4. Availability

5. Balance of the panel

Table 4.1-1 gives the criteria used in implementing the procedure described above for the TIP project. Table 4.2-2 gives the weight assigned to each criterion. The list of experts in the pool is given in Table 4.1-3. The first column of the table gives the names of individuals identified and the weights assigned to each of the criteria appears in the line labeled "Normalized weights". Note that for this project, the analysis team selected a total weight of 0.5 for knowledge. Lack of bias and credibility was given 0.3 and Interaction abilities was given 0.2.

The last column of criteria in Table 4.1-2, dealing with availability, was given a weight of zero to perform the pre-selection of the experts. It was to be used in case there would be a choice to make between several selected candidates.

Following that procedure, the final selection of expert evaluators (EVA) is given in Table 4.1-4.

4.2 Seismic Source Characterization

4.2.1 Introduction

4.2.1.1 Background

In 1989, the results of a multi-year study supported by the Nuclear Regulatory Commission and performed by LLNL provided probabilistic estimates of the seismic hazard for 69 sites in the eastern United States (Bernreuter et al. 1989). The study used individual experts to develop the seismic source characterization and the ground motion attenuation models. During the same period the Electric Power Research Institute (EPRI 1989) published the results of a similar industry-sponsored study. The EPRI study was also based on input from experts, but those were grouped in teams.

Both studies used various techniques of elicitation to develop the inputs to their analysis. These included written questionnaires, workshops, elicitation interviews and peer reviews.

From the experience of these two studies and others later on, the SSHAC developed the recommendation published in 1997 (NRC 1997), based on a critical evaluation of the various procedures of elicitation and overall approach to performing PSHA.

The emphasis of these recommendations is on using procedures of elicitation that ensure the highest quality possible of inputs from the experts. This is achieved by insisting on reviewing, evaluating, challenging and critiquing the work of the experts so that no misunderstandings or errors are likely to be introduced in their work.

The newer and more important aspect of the SSHAC recommendations is in advocating the concept of integration and composite models.

It is this aspect of integration, especially integration of the epistemic uncertainty that this Trial Implementation Project is testing. Studies prior to the SSHAC study (NRC 1997), [except for a study for the Department of Energy, for the seismic site characterization of the New Production Reactor (NPR) (Savy 1992), and the development of ground motion for the update of the 1989 NRC study (Savy 1993).] did not use the same concept of integration.

4.2.1.2 Objectives

The objective of the seismic source characterization task was to develop an integrated set of seismic sources, with their seismicity rates, using the elicitation procedure recommended by SSHAC (NRC 1997). Just like the concept of a composite model was used in the development of ground motion attenuation models in the NRC Seismic Update study (Savy 1993), and recommended by SSHAC, we tested the same concept on the development of seismic source maps.

The seismic source models were developed for each of the experts and a set of common elements, common sources, are identified as basic building blocks for all the sources and alternative sources proposed by the experts. These building blocks, which we named the minimum zone set, were then used to create the composite model of seismic sources.

4.2.1.3 Products of the Expert Elicitation

Using the information and data described in section 4.2 below, the seismic source experts each developed a set of initial seismic source models. They provided all the elements necessary to express their uncertainty, in the form of alternate sources, alternative full maps, with an assessment of their level of support for each map or portions of map. Following the objective set for this project, the experts' input was received and analyzed. The final set of maps based on the experts' personal maps was developed using the building blocks of the minimum zone set.

Since all the seismic sources in the final experts' models are common as being parts of the minimum zone set, the recurrence properties of each one were developed by all the experts.

For every single seismic source in the minimum zone set, the probability distribution function of the recurrence parameters was elicited from all the experts. These included the upper magnitude cutoff, estimation of the frequency of events for two different magnitude values and the nature of the recurrence process, i.e., whether the occurrence rate followed a truncated exponential model or a characteristic model. In the case of characteristic model, additional information was necessary, including the range of magnitude of recurrence of the characteristic event, its frequency of occurrence, and separately if necessary, the description of the non-characteristic part.

An important aspect of the elicitation was to quantify the uncertainties. For the single independent parameters, which describe the activity rates of each of the seismic sources in the minimum zone set, the uncertainties were simply included in the final composite probability distribution functions.

For the seismic source maps, the experts were asked to construct a set of alternative maps and assign weight to each of them. These sets of alternative maps each constitute the composite models of seismic source zonation. One composite set for each expert.

4.2.2 Road Map for the Seismic Source Characterization

In following the recommendations of the SSHAC, we developed a project plan in which the flow went from acquisition and confirmation of the experts and TFI knowledge to identification of the range of interpretations, clarification, then formulation of alternative models, feedback, review and document control. This was implemented through a series of workshops, one-on-one interviews, white papers and otherwise any other type of communication systems as shown in Table 4.2.2-1.

The first workshop was intended to ensure that all the experts contributing to the project had a similar level of knowledge of the scientific data available and of the issues associated with the development of probabilistic seismic hazard estimates for the two sites considered.

The objectives of the second workshop were to evaluate the experts interpretations, discuss an integration of their inputs into a minimum set of possible alternative source maps and to discuss methods of estimating the seismicity models, including the uncertainty.

The third workshop had the goal of finalizing the experts' models of seismic source maps and the integrated model.

A detailed summary of each of the workshops is given in the following sections as the first workshop dealt in the review of technical issues, the second workshop dealt in the review of proponent models and review of the data, and the third dealt in finalizing the models of the experts after their interpretations had been developed through interviews and intensive interaction at the previous workshops.

4.2.3 Review of Technical Issues, Workshop 1

The first phase in defining the technical issues was to review previous studies and design the first workshop so that the knowledge dissemination would be in large part directed towards identifying and discussing these issues. In summary, the most important technical issues were:

- Seismic source definition methodology.
- The Charleston Earthquake source zone.
- The Eastern Tennessee Seismic Zone.
- The local seismic source zone for the Vogtle site.

The first workshop took place in Augusta, Georgia on June 17-18, 1996. Participants in the Augusta workshop (see List of Participants in Table 4.2.3-1) included the panel of five expert evaluators, the Technical Facilitator/Integrator (TFI) team, expert proponents and presenters, and Allin Cornell, consultant to the TFI team.

The objectives of the workshop were: (1) To ensure that the evaluators are up to date on the seismotectonics of the southeastern US and of specific earthquakes, and techniques for defining seismic sources and estimating maximum magnitudes in the eastern US; (2) to initiate interaction and feedback among the panel, presenters and TFI team in order to narrow unintentional disagreements among the panel members arising from misunderstandings, to define important unresolved issues, and to ensure maximum transfer of knowledge; and (3) to begin to utilize this knowledge in seismic source characterization by having each evaluator prepare individual first-cut source maps.

The first objective was achieved by presentations of recent research and interpretations by the presenters. In order to avoid covering well-trodden ground, the evaluators were expected to be familiar with the state of knowledge as it existed at the end of 1992, the time of the Savannah River Site (SRS) New Production Reactor (NPR) summary report. To this end, the evaluators were furnished with copies of relevant material, including the NPR report and supporting material before the workshop.

The format of the workshop was designed to maximize interaction and feedback. Participants were encouraged to ask questions during and after presentations to ensure understanding of data and interpretations. Each of the technical sessions was followed by a discussion moderated by the TFI team in which key outstanding technical issues were defined. These key issues were then assigned to evaluators as the topics of "white papers" to be written after the workshop. The objective of these papers is to clarify the arguments for and against key interpretations having direct bearing on seismic source characterization in a way that will stimulate interaction among the evaluators.

4.2.3.1 Technical Background

The technical background session introduced the study region and test sites and summarized existing site-centered source characterization for the region. The main rationale for choosing the Vogtle and Watts Bar nuclear plants as test sites is that the technical issues in defining the sources that make the main contribution to the hazard differ at each site. The hazard at Vogtle is characterized by relatively little near-by seismicity but is potentially influenced by the distant Charleston source zone. The nearby, comparatively active Eastern Tennessee Seismic Zone is the major potential contributor to the hazard at Watts Bar. Nuclear sites were also chosen because of the availability of existing data on potential local sources.

4.2.3.2 Seismic Source Definition Methodology

The first technical session dealt with recent developments in defining source zones based on smoothed seismicity catalogs. These techniques are currently gaining favor as a means of mapping seismicity rates and can be utilized at the same time to help define source zones. The panel concurred that these techniques are potentially valuable and the evaluators expressed their desire to have them available. The TFI agreed to develop this capability. This entailed evaluating the relative utility of the techniques that have been proposed and the sensitivity of the resulting maps to the functional form of the smoothing kernel and to parameterization. The most critical parameters were identified as the smoothing (correlation) length and cut-off distance. Another aspect to be investigated was the use of anisotropic smoothing, based, for example, on moment tensors (Kagan and Jackson) or lineations defined in the seismicity maps. There is still a question as to the validity of using the distribution of low magnitude seismicity to predict the occurrence of large earthquakes.

4.2.3.3 Charleston Earthquakes

The second technical session dealt with recent work on the Charleston earthquake source zone. (Dave Amick had coordinated with Pradeep Talwani, who was able to merge Dave's paleoseismicity presentations with his own. Dave attended the second day of the workshop so was able to participate in the discussion of paleoseismic issues.) The issues dealt with in this session were: (1) whether the Charleston earthquakes should be characterized by a discrete source or by a broader source zone; and

(2) the size of the 1886 and other Charleston-type earthquakes.

Charleston Source Zone

Integrated interpretation of seismicity, geophysical (aeromagnetic, gravity, seismic reflection), morphological, and geodetic data presented by Pradeep Talwani and Ron Marple strengthens the case for a discreet source, the Woodstock fault, within the 1886 Somerville-Middleton Place epicentral area. The existence of this NNE-striking buried fault had originally been inferred from sparse seismicity data and is now tentatively identified as the possible source of a 200 km-long "zone of river anomalies" trending NNE through the epicentral area. If this hypothesis is correct, then it implies that the minimum length of the Woodstock fault is about 200 km. However, the evidence is still inconclusive and, at the other extreme, it remains possible that the 1886 earthquake is characteristic of the zone between the fall line and continental slope break along the entire eastern seaboard. The consensus was, therefore, that this remains a key issue to be addressed by evaluator white papers.

The hazard at the Vogtle plant will be sensitive to the northwestern and western extents of the Charleston source zone. There appears to be no compelling reason to extend the source to the northwest from the 1886 epicentral area by connecting the Somerville-Middleton Place and Bowman zones of microseismicity. Dave Amick has found no paleoliquefaction evidence for strong ground shaking in the Bowman area, and the microseismicity there is much shallower than in the epicentral area.

Ongoing work on paleoliquefaction features in the zone of seismicity in the southeastern US, along the SC Coastal Plain provides strong evidence for recurring earthquakes in the Charleston area. The main outstanding question being addressed by this work is whether clustered paleoliquefaction features near Georgetown and Bluffton, SC, northeast and southwest of Charleston, respectively, were all caused by Charleston earthquakes (perhaps by focusing), or whether they imply three separate sources. Preliminary analysis of existing data allows most but not all of the Georgetown and Bluffton paleoliquefaction events to be associated with Charleston events, but present results remain equivocal. It was agreed that this issue has only a secondary effect in defining source geometries because all three of the possible source zones are at similar distances from the Vogtle site. However, this question has an influence on determining recurrence for Charleston and possible similar earthquakes. A major source of uncertainty in recurrence is the effect of sea level fluctuations on liquefaction susceptibility along the Coastal Plain.

Charleston Earthquake Magnitude

The best estimate of $M_W7.3\pm0.26$ for the 1886 Charleston earthquake resulting from Arch Johnston's latest analysis based on M_W vs. intensity regressions for the eastern US, is somewhat lower than previous estimates (Arch's previous estimate was $M_W7.5$). This estimate is generally consistent with the range of 7.0-7.5 estimated by Jimmy Martin based on near-field liquefaction. Jimmy favors $M_W \approx 7$, but suggests that this near-field estimate is consistent with Arch's estimate based on far-field intensity when the potential attenuating effect of the Coastal Plain sedimentary wedge is considered. Assuming reasonable source parameters, Arch's best estimate for the length of the $M_W7.3$ Charleston source is 50 km, approximately consistent with the maximum dimension of the 1886 meizoseismal area. One important issue that remains unresolved is whether there is evidence for events larger than the 1886 earthquake in the paleoliquefaction data.

4.2.3.4 Eastern Tennessee Seismic Zone

The Watts Bar site is situated close to the northwestern boundary of the 300 km long northeast-trending Eastern Tennessee Seismic Zone (ETSZ). Because it is the most extensive and most active, the ETSZ will make the major contribution to the hazard at Watts Bar. The level of the estimated hazard will depend critically upon the way in which the ETSZ is characterized. Martin Chapman presented evidence suggesting that activity within the

ETSZ may be associated with a conjugate system of west- and northeast-striking faults. The features defined by Martin's analysis of the seismicity range from several tens to over 100 km long. Chris Powell demonstrated the striking correlation of the northwestern boundary of the ETSZ — now sharply defined by hypocenters relocated in the UNC group's 3-D velocity model — with the New York-Alabama magnetic lineament, the regional-scale, long-wavelength gravity anomaly, and the steep northwest-southeast transition from high to low crustal velocities. This leads to the hypothesis that the ETSZ (and perhaps the Appalachian zone as a whole) represents a northeast-striking, left-stepping, right-lateral fault system several hundreds of km long. The overall capability of this hypothesized fault system would depend upon its origin and stage of evolution; for example, if it is forming by reactivation of Iapetan normal faults or is actually a pre-existing right-lateral system.

The question as to whether these new results are sufficient to allow the ETSZ to be characterized as a system of discrete faults rather than, as in the past, an areal source zone based purely on the seismicity was identified as the second key unresolved issue to be addressed by evaluator white papers.

4.2.3.5 Vogtle Local Sources

Dale Stephenson and Alice Stieve presented results of the very extensive studies in the vicinity of SRS since 1987. Dale concluded that there is no evidence for direct association of seismicity in the vicinity of SRS with major tectonic structures, such as basin-bounding faults imaged by deep seismic reflection. The South Carolina-Georgia seismic zone looks similar to the Central Virginia zone in that the seismicity appears to occurring by reactivation of numerous splays off a major detachment at about 10 km depth. Alice presented detailed evidence, including high-resolution reflection, Quaternary geology and drilling results, that the Pen Branch fault is the northwest bounding fault of the Triassic Dumbarton basin that was reactivated in compression during the Cretaceous and early Tertiary. However, the most recent displacement that is presently well defined occurred about 50 Ma ago. It is doubtful that more recent movement could be seen in the geology, and much better near-surface velocity control is needed to correlate reflections with dateable horizons. Recent small earthquakes at SRS apparently were not associated with the Pen Branch fault. A USGS reflection profile shows that the fault continues across the Savannah River.

The question arising from this session is whether the available data require that characterization of local sources for Vogtle should include specific faults, specifically the Pen Branch fault, or whether local sources are adequately accounted for by including the Vogtle area in a broad Coastal Plain-Piedmont zone based on seismicity. Given that the Pen Branch fault passes within 1.5 km of the Vogtle site, it appears to be a classic case of a reactivated Mesozoic boundary fault, and would be assigned a length of ~50 km (the apparent length of the Dumbarton Basin), the consensus was that this is a key issue affecting the hazard at Vogtle that will be addressed by evaluator white papers. These white papers will also specifically address the intersecting fault model put forward by Richard Holt, one of the expert evaluators for the NPR study.

4.2.3.6 Watts Bar Local Sources

There is very little site-specific information in the Watts Bar FSAR. Geomatrix's recent study for the Haysi dam project, located close to the ETSZ further to the northwest, indicate that the ETSZ is the controlling source for sites within the Appalachian Highland.

4.2.3.7 White Papers

In all three different issues were deemed to warrant additional discussion and interaction through the use of white paper writing. In this situation the experts were asked to act as proponents of a certain scientific position and since the issues selected involved dichotomous positions they sometimes had to argue for a position that they do not necessarily defend. This has the advantage of forcing the experts, and all the participants, into discovering the positive aspects of scientific concepts other than their own. The assigned subjects of white papers were as follows:

Discrete Charleston earthquake source.

Pro: Pradeep Talwani

Con: Gill Bollinger

Discrete fault sources within the ETSZ.

Pro: Martin Chapman

Con: Klaus Jacob

Discrete local fault sources for Vogtle

Pro: Kevin Coppersmith

Con: Pradeep Talwani

A copy of each of the above white papers is given in Appendix A.

4.2.3.8 Preliminary Source Maps

As the conclusion to the workshop the five evaluators spent about 30 minutes preparing first-cut source maps, which they then presented. The purpose of this final exercise was to capture the evaluators' initial thoughts and ideas in a very preliminary set of maps, to get an initial feel for how closely they agreed (or otherwise). The range of the sources in these maps reflects the key outstanding issues. Evaluators who had previously been involved in source characterization for the region modified their source maps, in some cases significantly, in light of the recent work presented at the workshop. Most encouraging to the goal of arriving at a small set of maps that spans the existing different interpretations of the data was that all of the evaluators included alternative characterizations (some weighted) for some of their sources.

4.2.4 Proponents Models, Workshop 2

After the first workshop, the expert evaluators studied the positions defended in the white papers resulting from the workshop discussions and developed their own interpretations for possible scenarios of specific seismic source zones. These interpretations would later be taken in workshop 2 as the proponents' models. Then, still prior to workshop 2, the experts developed a first draft of their set of models of seismic source zonations. These preliminary maps provided by the experts are shown in Appendix B. They were not intended to be detailed and final positions of the experts. Some were actually drawn by hand without recourse to sophisticated tools or plotting software.

All the above work was performed in preparation of the second workshop on Source Characterization, which was held in Boulder, Colorado on September 5 and 6, 1996.

Participation in this workshop was limited to the five-member expert evaluator panel, the technical facilitator-integrator (TFI) team, Ernst Zurflueh, TIP project manager for NRC, and Allin Cornell, consultant to the TFI.

The first source characterization workshop (June 17-18, 1996) had focused on knowledge dissemination. At the conclusion of the first workshop the five expert evaluators prepared preliminary source maps for each of the two test sites, the Vogtle and Watts Bar nuclear plants in Georgia and Tennessee, respectively, based upon their previous knowledge and upon the new information presented at the workshop. In the interval between the first and second workshops each evaluator finalized his source map(s) (some of the evaluators had alternative maps), based upon careful consideration of all the available information, and documented his results. As an important part of this process, each evaluator wrote a "white paper" on a significant issue identified during the first workshop (see Workshop I summary). The white papers were circulated among the evaluators during the inter-workshop period to facilitate elucidation of these issues and to promote interaction among the evaluators and between the evaluator panel and the TFI. During the inter-workshop period the TFI carried out hazard sensitivity analyses based upon the alternative source definitions contained in the evaluator's draft source maps. The TFI also performed spatial smoothing of the VPI/EPRI seismicity catalog using a variety of smoothing kernels and their associated parameters (see discussion below).

4.2.4.1 Objectives of the Second Workshop

The objectives of the second workshop were to :

Examine and discuss in detail the individual evaluators' final source maps.

Integrate the evaluators' source maps into the smallest possible set of maps that spans the opinions of the panel.

Elicit the evaluators' weights for each of the sources and/or each complete map in the integrated set of maps.

Determine methods for estimating distributions of recurrence rates and maximum magnitudes for the sources in the integrated set of maps, including assignment of white papers dealing with significant issues in rate and maximum magnitude estimation.

4.2.4.2 Conduct of the Workshop

Before the meeting, the TFI decided that presentation and discussion of the "strawman" integrated maps would not be particularly useful, and may in fact be detrimental to the process of map integration. The time allocated for this purpose was therefore used for extended discussion of the individual evaluator maps.

4.2.4.3 Presentations of Evaluator Maps

Each evaluator made a detailed presentation of his preliminary source map(s) (Appendix C), and provided the rationale underlying his preliminary source characterization and the data and interpretations upon which it is based. The TFI encouraged maximum interaction during these presentations, which provoked in-depth discussion among the participants about the alternative characterizations and their underlying bases. This interaction was effective in maximizing the evaluators' understanding of all of the alternatives. The discussion also helped some evaluators to clarify their thinking about their own maps, for example, in defining dependencies among certain source zones. Most importantly, the discussions proved to be a good preparation for the map integration process. The evaluators' final maps and documentation are contained in Appendix C. At the conclusion of the presentations, the TFI summarized the significant differences among the maps.

4.2.4.4 Source Sensitivity

The purpose of the sensitivity studies carried out by the TFI before the workshop was to give the evaluators an idea of how much influence differences among their source characterizations have on hazard estimates at the test sites. This is of value in the map integration process; for example, demonstrating that relatively minor differences in alternative definitions of a given source have only a small impact on hazard would enable the evaluators to reach an appropriate compromise with which they are all comfortable, thus helping to achieve the objective of a small set of integrated source maps. The sensitivity analyses concentrated on the sources having the greatest potential impact on hazard variability. These were identified as Charleston in the case of the Vogtle site and the eastern Tennessee seismic zone for Watts Bar. The example analyses were carried out using the VPI/EPRI catalog to estimate seismicity rates. The main conclusions from the sensitivity results, presented by Don Bernreuter, were: (1) The Charleston source is significant to the long period ground motion hazard at Vogtle, but the detailed nature of the source characterization is not critical; (2) the short period ground motion hazard at Vogtle is sensitive to the geometry of the "host' source zone and the location of its SW boundary; (3) Because Watts Bar is located very close to the NW boundary of the ETSZ, the hazard there is sensitive to the exact location and characterization of that boundary.

4.2.4.5 Seismicity Smoothing

At the first workshop, the evaluator panel expressed their wish to evaluate the use of smoothed seismicity maps to define source zones and in mapping seismicity rates. Two evaluators, Martin Chapman and Klaus Jacob, include regional smoothed seismicity as one alternative source map. Later in the second workshop, all but one of the evaluators gave a moderate to high weight to determining seismicity rates within the ETSZ by smoothing.

Bill Foxall presented smoothed seismicity maps both for the study region as a whole and for the ETSZ alone, using Gaussian, Epanechnikov, and $1/R^a$ smoothing kernels. (Gaussian and $1/R^a$ kernels are being used to construct hazard maps by USGS and by SCEC and CDMG, respectively.) Trials with Gaussian and Epanechnikov kernels utilized a range of smoothing widths. As is generally observed, only minor differences were found between the results obtained with the Gaussian and Epanechnikov kernels; essentially the same maps result when the Epanechnikov smoothing width is 1.5-2.5 times the Gaussian width. Fairly good definition of the major regional seismicity zones, including the ETSZ, Charleston meizoseismal zone, central Virginia and Giles county, and the NW-trending South Carolina-Georgia zone, is obtained using Gaussian widths in the range of 25-50 km. Further work is needed to determine the optimal smoothing length for seismicity rate mapping. The $1/R^a$ kernel does not appear to smooth the seismicity enough, but picks out small concentrations of seismicity such as Somerville and Bowman. Gaussian smoothing lengths in the range of 15-20 km appear to provide good definition of the ETSZ. In applying smoothing to the ETSZ, the evaluators favor finding the smoothing length that produces a definition of the zone that most closely matches the shape and size determined visually from the seismicity in conjunction with geophysical and geological information. The seismicity rates within the ETSZ obtained using that smoothing length will then be used for hazard calculation. Application of the $1/R^a$ kernel to the ETSZ merits further investigation.

4.2.4.6 Map Integration

Final integration of the evaluator maps was accomplished during a 5-hour session led by the TFI. Following the evaluators' presentations, the TFI had finalized the list of significant differences among the maps, which provided the starting point of the formal integration process.

The following source zones have significantly different alternative definitions:

Charleston

Vogtle local zone

South Carolina-Georgia Piedmont and coastal plain.

ETSZ

Based upon the evaluators' definitions of each of these source zones, the TFI, interactively with the rest of the participants, developed the smallest set of zone geometries that incorporates all of the evaluators' zone definitions. Thus, for example, five alternative zones are required to represent what the evaluators consider to be the range of feasible sources for Charleston. In this particular case, the integrated set contains all of the alternatives originally proposed by the evaluators. This is because all of the evaluators wish to include two or more alternative characterizations of the Charleston source, rather than strongly supporting only one model. The five alternative geometries for the ETSZ similarly reflect consensus on the configurations most of the evaluators want to see represented, rather than disagreement among the panel. In contrast, all but one of the evaluators' geometries for the South Carolina-Georgia seismic zone are similar, so the integrated set contains only three alternatives; in fact, the one evaluator zone that is significantly different from the rest forms a background zone to the other two alternatives.

Integration of the maps progressed smoothly. Most probably, this was possible largely due to the previous detailed discussion of the evaluator maps, which meant that all of the participants had developed a good understanding of the significant issues in integrating the maps before the formal process began. Integration was also made easier by the fact, noted above, that, in most cases, evaluators wanted to see alternative source definitions in the integrated product, rather than strongly favoring single interpretations. This, on the other hand, results in a rather larger set of integrated maps than might have been anticipated. The final geometries of all of the zones are shown in Figures 4.2.6-1 and 4.2.6-2 and Table 4.2.6-2.

4.2.4.7 Source Weighting

The source weighting session also evolved into an interactive process. The need for this approach became obvious when the participants began to consider the rather intricate dependencies among some of the source zones, particularly among the Charleston zones and between Charleston and the SC-GA host zones for Vogtle. These dependencies necessitated further careful thought about the implications of each zone during the weighting process. Therefore, weighting was approached through interactive development of an event tree composed of branches that correspond to the alternative source definitions and that expresses the source dependencies. Having developed the tree, each evaluator, after deliberation, independently assigned weights to the branches. The TFI provided some coaching on the method of assigning the weights. (Kevin Coppersmith had to leave the workshop in the early afternoon, so his weights were elicited in San Francisco at a later date.)

4.2.4.8 Preparation to the Elicitation Process

We had intended to hold a mock elicitation to show the experts the type of procedure and interaction. Instead, Kevin Coppersmith talked about the extensive experience in expert elicitation gained by the Geomatrix team during the Yucca Mountain probabilistic volcanic hazards study. The purpose this talk was to familiarize the evaluators with the individual elicitation process in preparation for the elicitation of their seismicity rate estimates.

4.2.4.9 Rate Methodologies

The two interactive sessions, on map integration and source weighting, were successful in generating the desired product - a small set of source maps together with source weights. In the next phase of the hazard analysis the evaluators will assign their distributions of recurrence rates and maximum magnitudes to each source. At the end of the second day of the workshop there was a general discussion of the requirements for the next phase of the project and the approaches that will be adopted for estimating rate and magnitude distributions. This involves the TFI supplying the evaluator panel with alternative sets of rate and magnitude estimates. Feedback from the panel about data bases, methodology, etc. will largely drive this effort.

4.2.4.10 White Papers

We also discussed more general issues, including estimation of maximum magnitude, in general and for specific sources such as Charleston, extrapolating rates from small magnitudes to large, estimating magnitude from intensity in the eastern US, and catalog completeness and de-clustering. Based upon this discussion, white paper topics were assigned for the next phase of the project. The assignments agreed upon at the workshop were:

extrapolating rates for small magnitudes to large magnitudes:

pro: Klaus

con: Martin

estimating maximum magnitude:

strong position on using fault plane area/length for ETSZ Gil

strong position on using global data Kevin

Pradeep subsequently agreed to tackle the problem of estimating magnitude from paleoliquefaction data, but lacking a volunteer for the "con" position, he actually looked at both sides.

A copy of actual completed assignments is given in Appendix B.

4.2.5 One-on-one Elicitation Interviews

A formal elicitation interview between the elicitation team and each expert was held after the second workshop, in preparation for the finalization of the experts' seismic source models and for the characterization of the seismic source activity rates.

The elicitation team included Bill Foxall and Jean Savy. Each of the interviews started with a general discussion on the purpose, objective and goals of the elicitation interview. The experts were given an opportunity to clarify the description of models proposed at the workshops and in the white papers. We reviewed in detail all the seismic source models and reviewed briefly the procedures for characterizing uncertainty. We re-emphasized the fact that the interview on seismic activity rates was for the purpose of developing preliminary probability distributions of the occurrence models and that the process of integration into a composite model, for each seismic source would be performed during workshop 3.

The parameters to be elicited during these one-on-one interviews were:

the upper magnitude cutoff M_{max}, for each seismic source, all in the M_{bLg} scale.

$F_{(mo)}$, the number of events, per year, equal or greater than a maximum M_{bLg} magnitude M_o = 4.0

$F_{(m1)}$, the number of events, per year, greater or equal to a M_{bLg} magnitude, arbitrarily equal to 1/2 unit less than M_{max}

For each seismic source, the experts were asked to characterize the shape of the probability distribution (uniform, triangular, trapezoidal with left taper, trapezoidal with right taper, or beta).

Then the experts were asked to provide a lower bound (interpreted as a 5% percentile) the upper bound (95% percentile) and the mode, median or most likely value of the parameter value.

All the material available to the elicitation team was brought to the interviews. This included all the seismic source descriptions, all the results of the preliminary rate calculations, made with several different approaches as requested by the experts, including various approaches corrections for completeness of the catalogs, and area smoothing. That information, had also been sent to the experts prior to the interview. The experts were requested to review the material and prepare their interpretation. They were asked to perform analyses if necessary and generally get ready to provide their estimates of the seismic sources seismicity rates parameter probability distribution.

The interviews were given a full day of available time, but most of them were actually completed in half a day. The experts were in general well prepared. In two cases, the experts reserved their estimation for one or a few seismic sources until after they had gone back to their offices and been allowed to perform additional analyses of their own. In these cases, the experts provided their additional input before or at Workshop 3.

4.2.6 Integration and Feedback, Workshop 3

4.2.6.1 Introduction

The third workshop on source characterization for the Test Implementation Project was held at the LLNL offices in Germantown, MD on January 15-17, 1997. Participation in this workshop was limited to the five-member expert evaluator panel, the technical facilitator-integrator (TFI) team, Ernst Zurflueh, TIP project manager for NRC, Allin Cornell, consultant to the TFI, and observers from the Department of Energy (Jeff Kimball) and the NRC/NRR (Cliff Munson) and NRC/NMSS (Bakr Ibrahim) (see list of participants—Table 4.2.6-1).

The first source characterization workshop (June 17-18, 1996) had focused on knowledge dissemination. At the conclusion of the first workshop the five expert evaluators prepared preliminary source maps for each of the two test sites, the Vogtle and Watts Bar nuclear plants in Georgia and Tennessee, respectively. In the interval between the first and second workshops each evaluator finalized his source maps (some of the evaluators had alternative maps), based upon careful consideration of all the available information, and documented his results.

The second source characterization workshop (September 5-6, 1996) focused on development of the smallest set of source zone geometries that incorporates all of the zone definitions contained in the maps of the individual evaluators. The final set of zone geometries is shown in the maps contained in Fig. 4.2.6-1. The zones in this set comprise the basic building blocks which are variously combined by the evaluators to construct the final versions of their source maps, or "scenarios". Therefore, although the source scenarios differ among the evaluators, the evaluators and TFI are able to concentrate on determining magnitude recurrence parameters for a *common* set of zones. Combining the zones into source scenarios was accomplished by constructing logic trees for five source "modules" (see Figure 4.2.6-2) during an interactive TFI-led session. Each scenario is represented by one complete path along a set of connected branches (i.e. source zones). The evaluators built their scenarios by assigning preliminary weights to each of the branches.

As a result of discussion of maximum magnitudes, in general and for specific sources, several "white papers" were assigned to help the evaluators in assigning maximum magnitudes. The justification for extrapolating rates from small magnitudes to large magnitudes was debated by Klaus Jacob and Martin Chapman, and methods of estimating maximum magnitude from fault length and from global data were discussed by Gil Bollinger and Kevin Coppersmith, respectively. Pradeep Talwani evaluated the use of paleoliquefaction data in estimating maximum magnitudes for Charleston and other paleoliquefaction sites along the coastal plain. The white papers were passed to all the evaluators to aid in their preparation for Workshop 3.

In the interval between Workshops 2 and 3, the TFI digitized the set of source zone geometries finalized during Workshop 2, and, following the general directions given by the evaluators during and subsequent to Workshop 2, computed magnitude-frequency distributions for the zones using two alternative approaches (see below). The evaluators were provided with this material as a basis for their recurrence rate estimates. The TFI elicited maximum magnitude and recurrence rate estimates from individual evaluators on December 18, 19, 20, 1996 and January 7, 1997. This provided the preliminary magnitude recurrence parameter estimates that were the starting point for discussion at Workshop 3.

4.2.6.2 Objectives of the Third Workshop

The objectives of the third workshop were to:

Review and confirm all source zone geometries.

Integrate the evaluators' source scenarios for each source module into a composite set (i.e. a composite logic tree for that module).

Integrate the evaluators' preliminary maximum magnitude and seismicity rate estimates and their uncertainties into a set of composite probability distribution functions.

Elicit the evaluators opinions on the overall process employed in the project (feedback).

4.2.6.3 Conduct of Workshop 3

<u>Source Zone Maps and Logic Trees</u>

The workshop started promptly with the development of a set of composite logic trees, which were intended to represent the full range of the evaluators' source scenarios. The underlying assumption in adopting this approach was that, among all the possible scenarios, there is a small set of dominant ones on which the community of experts (here the panel of evaluators) would agree. To complete the composite logic trees, the uncertainty, or rather the full range of interpretations, was to be expressed with a small set of additional scenarios.

It quickly became clear that even though the EVAs may agree on the choice of a dominant (preferred) topology for some parts of the logic trees, their opinions on the correlations and dependencies between the different portions of the trees could be drastically different, meaning that the weights assigned to each branch vary widely. This makes it impossible to develop simple composite logic trees in which all the dependencies are faithfully represented for all the evaluator opinions. It was concluded that the only way that the latter objective could be achieved was by developing all of the logic trees implied by all of the evaluators' interpretations.

Therefore, it was decided to realign the workshop to this new realization by focusing on the formulation of the simplest set of trees for each expert, rather than on composite trees. It was agreed by all participants that the TFI team would still develop composite trees after the workshop and that the results of both approaches would be compared and evaluated, including at the level of the hazard.

Presentation of the Evaluators' Maps and Logic Trees

Each of the logic trees corresponding to the 5 source zonation modules was reviewed together with the source zone maps. The experts had the opportunity to revise, modify and update the branches and weights of their logic trees. The revised trees are shown as Fig. 2.2.6-2a to 2.2.6-2e (see also Table 4.2.6-2 for explanations of seismic sources). The weights assigned by the evaluators to the branches of each tree are shown in the table below the tree.

The approach used in developing preliminary weights for the composite trees was discussed at length, leading to following simple rules:

Take the average weight across the experts for those branches where the spread of weights is small.

When the range of weights is large and there is a strong dominant value, use that value for the composite.

When the distribution of the weights is clearly bi-modal create two separate alternative origin nodes.

Maximum Magnitudes and Rates of Occurrence at M_0 and M_1

Most of the second day of the workshop was spent in reviewing, comparing and revising the maximum magnitude and M_0 (= magnitude 4) and M_1 occurrence rate estimates given by the evaluators in their individual elicitations. The evaluators had estimated the maximum magnitude for each of the zones based upon a variety of data, including the seismicity catalog, recent work by Arch Johnston on the Charleston earthquake, geological considerations, and the EPRI global study. They had based their rate estimates upon cumulative frequency-magnitude plots supplied by the TFI before the elicitations, paleoseismic data for the Charleston earthquakes, and upon the evaluators' own analyses of the seismicity data. The TFI had derived cumulative frequency curves for relevant zones using both the LLNL Probability of Detection Model and Stepp's method for estimating completeness intervals together with maximum likelihood fitting. The results of both analyses had been supplied to the evaluators. Gil Bollinger had independently analyzed the data using Stepp's method, and the resulting maximum likelihood cumulative frequency curves had also been supplied to the evaluators. Subsequent to elicitation, some of the evaluators had been able to supply revised estimates for presentation at the workshop.

The purpose of this session was to enable the evaluators to confirm their preliminary estimates or revise them based either upon prior reevaluation or as a result of debate during the session, and to develop composite distributions. Since the seismic source zones are common to all the experts, the concept of composite maximum magnitude and seismicity rate distributions remains valid. M_u and rate estimates were presented by the TFI in the form of comparative summary plots, which show the evaluators' modal, lower bound, and upper bound estimates for each of the magnitude recurrence parameters. These proved to be an effective means of critically comparing the individual estimates and discussing differences arising from alternative interpretations of the data or differing recurrence analysis methods. The evaluators had given rate estimates at M_0 and at M_u-0.5 (=M_1). To enable comparison, the individual M_1 rate estimates were interpolated to the rate at a common upper magnitude, taken as the arithmetic mean of the evaluators' M_1s, using the b-slopes implied by the M_0 and M_1 rates given by each evaluator. These b-values were presented so that the evaluators could check that their estimates were consistent and reasonable. Composite distributions were shown only for M_u, as rate estimates had not been available from all of the evaluators before the workshop.

We worked through the zones in turn, considering M_u and the occurrence rates at the same time. When necessary, evaluators summarized the rationale and justification for particular estimates. Revised summary plots that include changes made by the evaluators during and subsequent to this workshop session and that show the actual shapes of the distributions and all of the composites are contained in Fig. 4.2.6-3.

The main results of this session are as follows.

The maximum magnitude estimates for most of the zones can be adequately described by a single composite distribution, formed by summing the normalized individual distributions (Fig. 4.2.6-3). The estimates for some zones, notably 1D, 1E, and Zone 3, are clearly bi-modal. Bi-modal distributions for M_u represent differing interpretations of the fundamental tectonic processes responsible for earthquakes in these zones, and so should be reflected in the weighting of the logic trees. The rate estimates for almost all the zones can be well characterized by a single composite distribution. In all but one of the few cases of bi-modal composite distributions, the bi-modal shapes appear to stem from differences in assignment of maximum magnitude and perhaps interpretation of the rate data, rather than differences in interpretation of tectonic processes. Even though it was concluded that composite distributions appear to be adequate representations of the ranges of magnitude recurrence parameters, it was also decided that we would verify this by comparing hazard results computed using individual estimates with those based upon composite distributions.

Significant systematic differences were evident in many of the rate estimates, and in particular between those based upon the completeness intervals estimated by Gil Bollinger and those based upon the TFI's recurrence analyses. The chief cause of these differences appears to be differing interpretations of catalog completeness, which are subsequently being further investigated by Gil Bollinger and Don Bernreuter. In addition, the uncertainty on Gil Bollinger's rate estimates are formal estimates of 5 and 95% confidence bounds, and are systematically narrower than those of the other evaluators.

4.2.7 Feedback Comments

At the end of the second day of workshop 3, the EVAs were asked to prepare notes summarizing their comments on the process. Recalling that the purpose of this project is to produce a guidance document for performing a PSHA, the role of this feedback was to get some insights on the aspects of the process with which the EVAs felt comfortable and those with which they did not, and to understand what worked and what did not. On the strength of this information we can develop a guidance document that is more focused and more in tune with the needs of the experts. The EVAs brought these comments in writing the next day for discussion in an interactive session between the EVAs, the TFI team and the other participants. The discussion was moderated by a member of the TFI team. First we reproduce the comments of each expert verbatim (in italics), and then add clarification and additional comments generated during the discussions.

4.2.7.1 Gil Bollinger:

Feedback on Implementation Process

Zone: Very good overall, but confusion on zone nomenclature and definition. Logic trees not available soon enough after meeting. Recommend meeting minutes distributed promptly after each meeting.

Mmax — Estimates surprisingly similar - real disagreement minimal - Procedures by EVAs seem well-developed and stable. Ditto for uncertainty estimates.

Rates — Need for considerable improvements:

Documentation for recurrence curves and their genesis much more extensive and complete.

Labeling of curves more carefully and completely done.

Prior to submittal, find out what the EVAs want/require and tell them what you'll be submitting and why. Tailor your submittal of recurrence curves to the EVAs needs rather than a "shotgun approach" of multiple scenarios - many of which raise more questions than they provide insights - why produce and mail material that will not be used or found helpful? Rather, check with the EVAs first. A portion of the first meeting should be devoted to this tope - advise EVAs prior to coming with their requirements in mind.

<u>*Uncertainties*</u> *— Some early group discussion of these procedures/techniques by the entire group would be helpful to make certain everyone is on the same page even if they're using very different process.*

Additional comments expressed during the feedback interaction.

Conduct of the workshop should focus quickly on content.

White papers are a must. They are very useful to the EVAs and should be an integral part of the process.

Ask the EVAs to participate by presenting their interpretations of the methodologies and describe their tools specifically for the estimation of the uncertainties.

Should have a dedicated person only to take notes at the workshops and elicitations.

Minutes should contain a log of all decisions made during the workshop.

Workshop #2 could have had 1 more day to explore in more details the needs of the experts for estimating the seismicity rates and uncertainty.

4.2.7.2 Martin Chapman:

Probability — Logic trees need to be diagrammed and branches needs to be defined in detail, with the results distributed to all workshop participants as soon as possible following the workshop.

Seismicity rates/per unit area somehow need to be considered simultaneously with development of same process.

Sensitivity — Testing of contentious options at an early stage might be helpful.

Additional comments expressed during the feedback interaction.

Use maps of smoothed seismicity (contours) for a few smoothing parameters to help in defining zones boundaries.

Capability for doing all types of seismicity and hazard, and ground motion calculation "on-the fly" during the workshops and during elicitations would be very useful to EVAs, to explore different zone configurations.

4.2.7.3 Kevin Coppersmith:

Not present

4.2.7.4 Klaus Jacob:

Dissemination of information (Workshop #1) can be less extensive if it results in spending additional time and resources on Workshop #2, elicitation, and Workshop #3.

After each Workshop or elicitation meeting it is essential that the resulting data, documents (logic trees, etc.) be available to the EVAs for review and feedback to assure quality control and avoidance of misunderstandings.

Make sure that <u>all</u> members of the TFI and EVAs teams use <u>consistent</u> and <u>unique</u> identifiers. If this principle is not followed rigorously confusion is inevitable in projects of complexity.

In my judgment it is insufficient to only solicit seismicity input from EVAs without feeding back to the EVAs the results (in form of hazard curves) of their input [even if only a single attenuation law is used]. Without each EVA knowing what the effect of his/her input on the resulting hazard is the EVA cannot take full responsibility (and therefore responsible ownership)of his/her input. <u>This feed-back loop must be closed in future projects</u>. !!!

I strongly recommend that the inter expert variation (all branches of proposed models) be preserved in parallel with composite models. As pointed out by some EVA (K. Coppersmith) and TFI consultants (Allin Cornell), in real projects, this will be the only way to allocate "ownership" and hence responsibility for input/output.

White papers were very helpful.

Additional comments expressed during the feedback interaction.

Feedback loop must be devised so that EVAs understand and see clearly the impact of their choices, in particular by making comparison with data.

4.2.7.5 Pradeep Talwani:

Label recurrence curves so that they are user friendly.

Perhaps explain methodology in some detail (short write up).

Provide some feedback as to the consequence of our choices on the resultant estimation of seismic hazard values.

I was not too clear on how the recurrence curves were attained specially when the resulting b and a values were unrealistic (see 2 above). In other works, it would be useful to end up with physically realistic values. Or is something that the EVAs should do.

I also want to give some kudos! I appreciated the very helpful attitude of Bill, Jean, and Rosa in trying to ensure that I had all I needed to do my job!!!

4.3 Ground Motion Attenuation in Eastern North America

4.3.1 Introduction

4.3.1.1 Background

In 1994, there was a trial application of the SSHAC methodology to the problem of estimation of ground motions for Eastern North America. The results of this trial application were summarized by Boore et al. (1996).

The 1994 trial application demonstrated several important aspects of this type of study. The preliminary estimates were made independently by each expert. In the feedback workshop, the interaction between the experts lead to a reduction in the expert-to-expert uncertainty.

One significant source of uncertainty that remained was the conversion from mb to moment magnitude (Mw). In the 1994 study, the cases were defined in terms of mb, but most of the ground motion models are defined in terms of Mw. Therefore, the experts were required to first convert from mb to Mw before applying the proponent models. This lead up to a 0.5 magnitude unit difference between the experts when the models were applied. This uncertainty in the magnitude conversion tended to obscure the underlying uncertainty in the ground motion attenuation.

The 1994 study had several limitations that prevented the results from being used to develop attenuation relations. First, there were some misunderstandings about the distance definition. The distance was defined to be the closest distance to the rupture plane (rupture distance), however, several of proponent model estimates were run for hypocentral distance or shortest horizontal distance to the surface projection of the rupture (Joyner-Boore distance). As a result, the short distance estimates (5 km rupture distance) could not be used. This limited the useable point estimates to distances greater than 20 km.

A second limitation of the 1994 study was that a limited number of distances and magnitudes were evaluated (Table 4.3.1-1). The 1994 study considered just two magnitudes (mb = 5.5 and mb = 7.0). Additional magnitudes are needed to define the magnitude scaling, particularly for the long periods. Without the 5 km distance (due to the misinterpretation of the distance definition discussed above), there were only 1-3 distances for the various spectral periods. Estimation of the ground motion at additional distances are also needed to adequately define the attenuation.

Input to a PSHA for vibratory ground motion includes the characterization of all significant earthquake sources and the ground motions they may generate at a site. Characterizing the latter requires describing motions developed by the various types of potential seismogenic sources - whether planar features such as faults or more general areal sources. Motions resulting from the different styles of faulting (strike-slip or dip-slip, and if the latter then normal or reverse faulting) should also be incorporated into the ground motion characterization. Thus the seismogenic sources to a degree define the technical issues which the ground motion characterization must address. Further, the seismic hazard is calculated using a computer code which incorporates both inputs. Therefore, the ground motion characterization was also formulated in a manner consistent with the input format to the computer codes which perform the hazard computation.

4.3.1.2 Project Objectives

The objective of this study is to develop response spectral attenuation relations for hard rock conditions in Eastern North America using the SSHAC expert elicitation methodology. This study builds on the 1994 SSHAC exercise, by addressing the shortcomings of the 1994 study and expanding the number of point estimates (magnitude-distance-frequency triplets) considered.

The resulting point estimates are then used to estimate attenuation relations based on regression analyses. The attenuation relations are developed for the individual experts and for a composite model which represents all of the experts estimates.

4.3.1.3 Products of the Expert Elicitation

Using the various information and data discussed below, the ground motion experts each developed a series of estimates of ground motions for a defined suite of earthquake magnitudes and distances, fault geometries, and faulting styles. The estimates included the median ground motion and its aleatory variability, and the epistemic (scientific knowledge) uncertainty on both. To clarify the meaning and the classification of the various types of uncertainty which are used in this study, the reader is referred to a detailed discussion in Appendix D.

These point estimates were fitted to yield attenuation equations for all four quantities. The independent variables used in the regression were selected by the expert and the analyses were performed by the TFI team.

Each expert formed his/her interpretations using the information and data presented in two Workshops. Additionally, the elicitation process included a formal interview, in which each expert presented and defended his preliminary point estimates. The TFI challenged each expert to defend and, as necessary, clarify his or her thought process to ensure that all relevant data and information were evaluated. As a computational aid, the TFI provided the experts with estimates of the ground motions from the proponent models that the experts selected for the study.

Following this Introduction, Section 4.3.2 details the process by which the ground motion experts' interpretations were developed. Section 4.3.3 presents the resulting ground motions estimates from the experts. Section 4.3.4 presents the attenuation relations developed from each expert's estimates.

Input to a PSHA for vibratory ground motion includes the characterization of all significant earthquake sources and the ground motions they may generate at a site. Characterizing the latter requires describing motions developed by the various types of potential seismogenic sources - whether linear features such as faults or more general areal sources. Motions resulting from the different styles of faulting (strike-slip or dip-slip, and if the latter then normal or reverse faulting) should also be incorporated into the ground motion characterization. Thus the seismogenic sources to a degree define the technical issues which the ground motion characterization must address. Further, the seismic hazard is calculated using a computer code which incorporates both inputs. Therefore, the ground motion characterization was also formulated in a manner consistent with the input format to the computer codes which perform the computation.

4.3.2 Structure of Elicitation Process

4.3.2.1 Expert Elicitation Guidance

The assessments of ground motion attenuation in ENA require a degree of data interpretation,. Expert elicitation is an ideal approach to integrating the range of data interpretations inherent in the assessments. The National Research Council and DOE have both sponsored examinations of the expert judgment elicitation process resulting in three key guideline documents utilized in the ground motion characterization (Savy *et al.* 1993; NRC, 1996; NRC, 1997; National Research Council 1997).

The expert elicitation process as it applies to ground motion interpretations originated over a decade ago in a Lawrence Livermore National Laboratory (LLNL) study to develop a methodology for characterizing seismic hazards in the Eastern U. S. (EUS). In the LLNL project, each member of a panel of experts was required to independently evaluate various data and each assigned weights to existing ground motion models. A parallel study was performed by the Electric Power Research Institute (EPRI) relying instead on three models with weights assigned by a single Technical Integrator after a meeting of the experts. Differences in the hazard results prompted a close comparison of the two studies, which identified differences in attenuation and its associated variability as a major cause of numerical differences. In turn, examinations of the elicitation process itself have led to further development and refinement of elicitation techniques (Savy *et al.* 1993; NRC 1997).

In recognition of an anticipated reliance on expert elicitation within the nuclear industry, the NRC prepared a Branch Technical Position (Kotra *et al.* 1996) on the use of the technique which was consistent with the approach followed in the PSHA. LLNL refined its elicitation procedures using the experience of the 1982 study (Savy *et al.* 1993) and prepared a set of recommendations directly relevant to eliciting interpretations on ground motion and its distribution. Boore *et al.* (NRC 1997) applied the SSHAC methodology in a demonstration project for EUS ground motion. The lessons from these previous studies were considered in the current study.

4.3.2.2 Elicitation Methodology

4.3.2.2.1 Project Plan

The Project Plan consisted of an elicitation and a feedback workshop. This format was developed to insure that the experts interacted, explained their own interpretations and questioned the interpretations of other experts. The key purpose of the workshop was to provide a common information base for the interpretations and a forum for interaction among the experts to achieve a common understanding of the data and existing ground motion models. A thorough understanding by all the experts of the technical limitations and advantages of the data was needed to ensure that differences in the final interpretations were based on differences in expert judgment and not incomplete knowledge.

As a direct result of lessons learned in the LLNL study (Savy *et al.* 1993), ground motion experts in the TIP PSHA were required to provide estimates of median ground motion, its variability, and the uncertainties associated with each for each of a selected set of magnitudes and distances. This was intended to focus the experts on the ground motions and uncertainties themselves, and not on evaluating weights to apply to known attenuation models (as ground motion elicitation was first practiced). Attenuation relations were to be developed using these values.

4.3.2.2.2 Roles of Participants

The TFI Team aided the experts in all phases of developing their ground motion interpretations. The TFI Team Leader role required an individual with recognized technical expertise. Responsibilities of the TFI leader included planning and conducting the technical workshop. The workshops were intended to be coordinated to respond to requests from the experts for technical information and also to further the process by which the experts reached their final interpretations. Most importantly, he facilitated the interaction between the experts during the workshop. He also led the formal elicitation interviews and provided feedback to the experts. The Facilitation Team Leader was to specifically avoid guiding the experts towards a personally preferred view of ground motion characterization.

The ground motion experts were required to function in two distinct roles, namely proponents and evaluators. Ultimately and most importantly, each was required to impartially view and evaluate all proponent models based on the information presented in the workshops. However, many of the models assessed were developed by members of the panel so these experts were also asked to act at specified times as proponents of their own models. As proponent experts, their role was to explain and argue for a particular model. The Technical Facilitation Team Leader provided specific instructions at the outset of the project to clearly define the roles of evaluators and proponents. Not all of the ground motion experts acted as proponents; experts selected for this role either developed the model or were widely identified professionally with the modeling technique. After acting as proponents, experts resumed their primary roles as evaluators.

As evaluator experts, each panel member was expected to assess all models and data presented and integrate them into an individual best estimate of the ground motion distribution and its uncertainty. The experts were to evaluate all models in light of their own technical judgment separate from cognitive bias towards classes of models.

4.3.2.3 Selection of Experts

Experts must represent the range of scientific disciplines required to perform the required evaluations and interpretations. Thus their professional expertise must cover the range of issues and technical foundation regarding the tectonic and seismic environment of ENA as well as ground motion estimation.

Since this study was building on the previous 1994 study, most of the experts were selected from those involved in the previous study. The 1994 study used seven expert evaluators: Abrahamson, Atkinson, Bernreuter, Campbell, Joyner, Silva, and Somerville. The TFI team consisted of Boore, Toro, Morris, and Cornell.

In the current study, Abrahamson and Savy made up the TFI team. We also considered others outside of the 1994 study who had been working recently on ground motion attenuation in ENA (Table 4.3.2-1).

For this trial implementation project, the budget allowed for five expert evaluators. We selected the evaluators with varying background and areas of expertise that would provide a good test of the methodology.

From the original seven experts, we selected Bernreuter, Campbell, and Somerville. We added Boore as an expert evaluator due to his expertise in the stochastic model (both single corner and double corner sources). We added Jacob as an expert evaluator since he has been involved in many engineering projects in the eastern U.S. and his estimates had been much larger than previous estimates which should challenge the methodology. The resulting five expert evaluators are:

- Bernreuter
- Boore
- Campbell
- Jacob
- Somerville

4.3.2.4 Compilation and Discussion of Data and Information

The experts were familiar with the proponent model that had been considered in the 1994 study so a separate data dissemination workshop was not held. There were some new models and revisions to previous models that were discussed at the feedback workshop. The new models were Frankel (1996) and Horton (1997). The Campbell model had been revised since the 1994 study. These new models were reviewed at the start of the Feedback workshop.

4.3.2.5 Elicitation Interviews

An initial workshop was held in December, 1996 to review the proponents models used in the 1994 study, identify additional proponent models that the experts wished to consider, and define the range of point estimates (magnitudes and distance pairs), for which the experts would estimate ground motion. A formal elicitation interview between the elicitation team and each expert was held before the feedback Workshop. The interviews were conducted in accordance with guidelines developed by the U. S. Nuclear Regulatory Commission (1997). The elicitation team consisted of N. Abrahamson and J. Savy. N. Abrahamson was present at all of the interviews. J. Savy was present at all but the Jacob and Bernreuter interviews.

The interviews were private and uninterrupted. In the interview, each expert was asked to explain the procedures he adopted to obtain median estimates, aleatory uncertainties, and the epistemic uncertainties on both. Each defended his selection of 'relevant' proponent models and also explained on what basis other models were rejected.

The elicitation interview was an important source of feedback for the experts. Inconsistencies in the treatment of uncertainty were identified and corrected by the experts.

The TFI calculated the preliminary ground motion estimates for each expert using weights supplied by the expert. A single computer program was developed by the TFI for use by all experts in weighting proponent models as a step towards forming their point estimates. This computer program (WT_AVE) was used to compute weighted model values (used as preliminary point estimates) for each of the experts. This allowed the experts to simply develop weights for the models freeing them to concentrate on evaluating the resulting point estimates. The weighted values were used solely for preliminary computations: the experts were charged to evaluate the preliminary estimates to form their final point estimates.

4.3.2.6 Feedback and Revision

Feedback for the experts occurred at two different times. As mentioned above, the elicitation interviews resulted in significant feedback in terms of identifying inconsistencies by the experts. The main source of feedback was the feedback workshop.

Following the feedback workshop, the experts revised their estimates. The TFI developed revised attenuation models based the experts' revised estimates.

4.3.2.7 Documentation

In this application of the SSHAC methodology, the experts' estimates were documented by the TFI in terms of the weights given to each model (and the magnitude, distance and frequency dependence of those weights). In a full application of the SSHAC methodology, each expert would document the reasoning behind his development of the point estimates.

4.3.3 Ground Motion Characterization

4.3.3.1 Review of Technical Issues

There are very few strong motion data available in eastern North America (ENA). The sparse strong motion data set is summarized in EPRI (1993). As a result of the sparse set, most ground motion models for ENA are based on numerical simulations or by correcting the more plentiful western North America (WNA) strong motion data for differences in the source, path, and site differences between the two regions.

4.3.3.2 Proponent Model and Data Needs Workshop

A workshop was held in December 20, 1996 to review the various proponent models and to define the point estimates to be developed by the experts.

At this workshop, Abrahamson reviewed the proponent models used in the 1994 study: EPRI (1993), Atkinson and Boore (1995), Somerville (1994). Revisions to the hybrid empirical model developed by Campbell were presented by Campbell. At the workshop, requests were made by the experts to include the Horton (1997) numerical simulation model which was used extensively in New York, and the Frankel (1996) point source stochastic model which was used in the development of the national seismic hazard maps. The complete set of proponent models is listed in Table 4.3.3-1. The proponent models considered in this study are described in Section 4.3.3.3.

As noted previously, there were several shortcomings of the 1994 study that made it difficult to develop ground motion attenuation relations from the expert estimates. These shortcomings were addressed in the initial workshop resulting in the changes described below.

First, the seismic source was defined in terms of moment magnitude rather than m_b. This eliminated the uncertainty in the magnitude conversion in terms of ground motion estimation. Because the earthquake catalogs for ENA tend to be given in terms of m_b, this magnitude conversion must be addressed in hazard calculations.

Second, specific fault rupture geometries were defined for the point estimates rather than just a distance (Figure 4.3.3-1). This reduced the misunderstanding in the distance definition although some confusion remained in the Horton proponent model.

Third, additional magnitude-distance pairs were included to allow determining the magnitude and distance scaling at each of the five response spectral periods, in the regression analysis. In particular, an additional distance was added at 120 km to identify possible flattening of the attenuation relation due to post-critical reflections from the Moho ("Moho bounce"). Additional magnitudes were also added to allow a quadratic magnitude scaling term to be estimated for longer periods. In all, four magnitudes were considered: M_W=5.0, 6.0, 7.0 and 7.5. All five response spectral periods are evaluated for the full matrix of cases. Three depths were also considered for the short distances (Table 4.3.3-2).

For the TIP project, the main contributors to the hazard will be in EPRI regions 3 and 5 (Figure 4.3.3-2) which have similar attenuation to the Mid-continent model developed in the EPRI (1993) study. Therefore, the Mid-continent model was selected as the reference velocity model in this study (Tables 4.3.3-3 and 4.3.3-4).

The site condition was defined as ENA hard-rock: 2800 m/s average shear wave velocity over the top 30 m; median kappa = 0.006 sec. This is consistent with the 1994 study.

It was also decided to include both strike-slip and reverse slip faulting in defining the cases. The final exercises are listed in Table 4.3.3-5.

4.3.3.3 Proponent Models

Brief descriptions of the ground motion models are given below. All models provide estimates for hard rock conditions (or were converted to hard rock conditions) as defined in Section 4.3.3.2.

4.3.3.3.1 Campbell Hybrid Empirical

The Campbell hybrid empirical model uses the point source stochastic model to adjust empirical attenuation models developed for WNA to be applicable to ENA. The point source stochastic model is used to account for differences between typical Q and kappa values in WNA and ENA. Details of this model are given in Appendix E.

4.3.3.3.2 Somerville Numerical Simulations

The Somerville model is a finite source numerical simulation based on empirical source functions with region specific path effects incorporated using ray theory (Somerville et al. 1990). The "empirical source functions" include scattering and kappa effects. The empirical source functions used in the Somerville proponent model are from a 1979 Imperial Valley aftershock (M=5, 11/15/79). Therefore, the source functions have scattering effects representative of WNA which are implicitly assumed to be applicable to ENA. The site effect (parameterized by kappa) is corrected from WNA to ENA by imposing a flat Fourier amplitude spectrum on the empirical source functions at high frequencies (f > 15 Hz) and then applying a kappa correction to the spectrum.

4.3.3.3.3 Horton Numerical Simulations
The Horton model is a simplified finite source model with three subevents. Each subevent is a single-corner w2 point source. The wave propagation is computed using wavenumber integration. Scattering is introduced using empirical scattering functions derived from the Saguenay earthquake. Therefore, this model has ENA-specific scattering.

4.3.3.3.4 Frankel Numerical Simulations (1996)
The Frankel model is based on the point source stochastic model with a single-corner w2 spectrum and 1/R attenuation (Boore 1983). The median stress drop is 150 bars. The point source distance, R, is hypocentral distance. For distances less than 10 km, Frankel uses a constant ground motion defined at R = 10 km.

4.3.3.3.5 EPRI (1993)
The EPRI (1993) model is based on the point source stochastic model with a single-corner w2 spectrum and ray theory wave propagation. The median stress drop is 120 bars. The point source distance, R, is the "Joyner-Boore" distance measure, which allows the model to include effects of source distance.

4.3.3.3.6 Atkinson and Boore (1994)
The Atkinson and Boore (1994) model uses the stochastic model with an empirical two-corner source model and empirical attenuation. The median stress drop is 180 bars. The point source distance corresponds to hypocentral distance.

4.3.3.4 Elicitation Interviews

In the formal elicitation interviews, each expert explained the procedures he used to obtain estimates of the median motion (m), aleatory uncertainty (s), and the epistemic uncertainties on both (sm, ss). Each expert developed weighting schemes for the proponent models and explained the reasoning for the weights given to each model. In most cases, the weights were not the same for all magnitudes, distances, and frequencies but varied according to the experts evaluation of the strengths and weaknesses of each model.

The elicitations all revealed that sm and ss were not well-understood by the experts. In particular, there was confusion how these epistemic uncertainties should vary as the number of proponent models considered increased. One result of the elicitations was that each expert assumed that the distribution of uncertainty on m and s was symmetric since they did not have significant evidence to the contrary. Ultimately, each expert developed weighting schemes only for m and s from which the 5th and 95th percentile values were computed. Given these limits and symmetric distributions, sm and ss could be computed.

4.3.3.5 Feedback Workshop

To facilitate comparisons between the individual experts' point estimates, a series of plots of these estimates and the proponent model estimates on which they were based was shown. An example is shown in Figure 4.3.3-3. A full set of plots (one for each case and each frequency) was given to the experts.

The feedback workshop considered three of the 132 cases. These three cases included magnitude moderate and large magnitude events at short distances and a large magnitude event a large distances. These three events were used to focus the discussion of the important differences in the proponent models. The strengths and weaknesses of the proponent models were discussed in the context of these three cases.

Much of the discussion focused on the 1 second spectral value. This value is particularly sensitive to the one-corner frequency vs. two-corner frequency model assumption: the two-corner model of Atkinson and Boore gives much lower median values than the one-corner assumption used in the other models. Additional recent results were provided to the experts that supported the two-corner model. In considering the one- and two corner models, some of the experts favored the one-corner model because it is more conservative in the 1-second range. This sort of conservatism is not the intent of the study, but it is difficult to avoid.

4.3.3.6 Experts' Weights and Point Estimates

The experts estimated median ground motion, aleatory uncertainty, and associated epistemic uncertainties for a matrix of event magnitudes, distances, and faulting styles and at five spectral frequencies. The matrix of point estimates, 132 cases in all (Table 4.3.3-5), covers a magnitude range of 5.0 to 7.5, distances from 0 km to 200 km, strike-slip and reverse dip-slip faulting, and both hanging wall and footwall for the latter style. The matrix of magnitude-distance pairs was selected to provide adequate constraints on the attenuation without overburdening the experts. The same five frequencies that were used in the 1994 study were used in this work.

Most experts developed a general set of weights applicable for all magnitudes, distances, periods, and mechanisms and applicable for both m and s. The experts did not explicitly provide weights to derive ss and sm. Rather, because each expert chose a symmetric distribution around m and s, the 5th and 95th percentile values were simply computed from the m and s estimates and, thence, the ss and sm values. The experts modified their general rules as they deemed appropriate, to emphasize or de-emphasize certain models. Each expert's rules are discussed below.

Bernreuter (Table 4.3.3-6): Weights for m estimates are independent of period, distance, and mechanism but are dependent on magnitude. No weights are applied to the Frankel stochastic model as it is approximately duplicated by the EPRI model. No weight is assigned to the Horton simulation model as it is not judged to be as well validated as other models. At low magnitude (M 5), the two remaining stochastic models (Atkinson and Boore and EPRI) receive 60% of the total weight (0.3 weight each) and the Campbell hybrid model receives 40% of the total weight (0.4 weight); no simulation results are available for the Somerville model at M 5. At M 6, weights on the stochastic models are unchanged at 60% of the total; the hybrid model and Somerville simulation models combined total 40% (weights of 0.2 each) and. At large magnitudes, all four models are equally weighted (0.25 each); thus weight is effectively decreased on the stochastic models to 50% of the total. Bernreuter judged that the EPRI model provides the best single estimate of s values and used these values alone.

Boore (Table 4.3.3-7): Weights are assigned independent of magnitude, distance, period, or mechanism; different schemes were used for m and s. For m, Atkinson and Boore is preferred overall insofar as it is a two-corner model (weighted 0.5). The single-corner EPRI model is given lower weight (weighted 0.3). The balance of the weight is equally distributed between the two simulation models (Somerville and Horton, weighted 0.1 each). No weight is assigned the hybrid or Frankel models. For the former, use of equivalent point source distances accounts for finite fault effects thus there is no need to use the hybrid model. Regarding the latter, the selection of stress drop is arbitrary and the model is not significantly different from the EPRI model. In computing s, weight was equally distributed between the Atkinson and Boore stochastic, the EPRI stochastic, and the Campbell hybrid models (weighted 0.33, 0.34, 0.33 respectively).

Campbell (Table 4.3.3-8): Weights on m are assigned independent of period or mechanism. In general, weight is equally distributed between the hybrid empirical, the stochastic, and simulation models (total weights of 0.33, 0.33, and 0.34). Preference is given to the Atkinson and Boore model over the EPRI and Frankel stochastic models (weights 0.17, 0.08, and 0.08 respectively) and the Somerville and Horton simulation models are equally weighted (0.17 each). The Campbell hybrid model is (in general) gradually downweighted at distances of 70 km and greater due to a lack of data constraining empirical WUS relations. At M 5 and 6 the weight is halved at 70 km (0.17), halved again at 120 km (0.08), and set to zero at 200 km. At M 7 and 7.5, the downweighting is not as severe: it is halved at 120 km (0.17), and halved again at 200 km (0.08). Campbell adopted s values independent of those predicted by the models; values selected are from the empirical western US attenuation relations considered in the hybrid model.

Jacob (Table 4.3.3-9): Weights are independent of period and distance; they are dependent on magnitude and mechanism. Jacob developed a weighting system in which each model was assigned a 'moderate' weight (value of 2), 'high' weight (value of 3), 'low' weight (value of 1), or was not weighted (not applicable or not available; value of 0). The weights were subsequently normalized by the sum of the weights for all models at each magnitude level for a specific mechanism. All weights are summarized in Table 4.3.3-9. Divergences from moderate weights for estimates of m include (typically):

Atkinson and Boore model upweighted at M 5, downweighted at M 7 and 7.5 for all mechanisms

Frankel model downweighted at M 7 and 7.5

Horton model upweighted for strike-slip, zero-weighted for footwall

Somerville model low or zero-weighted for most mechanisms and magnitudes

Divergences from moderate weights for estimates of s include (typically):

Atkinson and Boore model downweighted for strike-slip at all magnitudes

Campbell model upweighted for strike-slip at all magnitudes

Frankel model upweighted for all mechanisms at all magnitudes

Horton model downweighted or zero-weighted for all mechanisms and magnitudes

Somerville model downweighted or zero-weighted for all mechanisms and magnitudes

Somerville (Table 4.3.3-10): Weights are independent of period or mechanism and dependent on distance and magnitude. Weight is distributed primarily between the stochastic, hybrid, and Somerville simulation models. No weight is assigned to the Horton model. At low magnitude (M 5), 60% of the total weight is distributed between the stochastic models (Atkinson and Boore, EPRI, and Frankel) and 40% to the Campbell hybrid model. Simulations using the Somerville model were not computed at M 5. There is no distance dependence at M 5. At M 6 and distances greater than 20 km, 30% of the total weight is assigned to the stochastic models, 40% to the hybrid model, and 30% to the Somerville simulation model. At closer distances, the stochastic models are downweighted slightly to 20% of the total and the Somerville model is upweighted to 40% of the total. The same weights are applied at M 7 and 7.5 as at M 6, excepting the distance cutoff is changed to 70 km.

Examples of the proponent model median estimates for peak acceleration are shown in Figures 4.3.3-4a and b for magnitude 5 and 7, respectively. Similar comparisons for 1 second period spectral acceleration are shown in Figures 4.3.3-5a and b. The aleatory variability for the proponent models for peak acceleration and 1 second spectral acceleration are shown in Figures 3-6a and b.

4.3.4 Attenuation Relations

4.3.4.1 Introduction

To facilitate the use of the ground motion models in the hazard calculation, the experts' point estimates were parameterized by attenuation relations. The regression analysis to develop the attenuation relations was performed by the TFI team.

4.3.4.2 Regression Model Form

Based on an examination of the experts' point estimates general functional forms were selected. Different functional forms were used for the median estimates, the aleatory variability, and the epistemic uncertainties.

The independent variables used in all regressions correspond to:

M   Moment magnitude

R   Rupture Distance (in km)

The predicted values for m are in natural logarithm of g for spectral acceleration and natural logarithm of cm/s for peak velocity. The sal, sm, and ss are all in natural log units. "Rupture distance", defined as the closest distance from the site to the fault rupture was selected as the distance metric.

The adopted general forms for the regression model are given below in equation 4.1 to 4.4. As noted above, in some instances the experts added constraints to these general forms. These constraints are summarized in Table 4.3.4-1.

Median (m):

For M < m_1,

$$\mu = a_1 + a_2(M - m_1) + a_6(8.5 - M)^2 + [a_3 + a_5(M - m_1)] \cdot \ln\sqrt{R^2 + a_8^2} + a_7 F \quad \textbf{(4.1a)}$$

For M ≥ m_1,

$$\mu = a_1 + a_4(M - m_1) + a_6(8.5 - M)^2 + [a_3 + a_5(M - m_1)] \cdot \ln\sqrt{R^2 + a_8^2} + a_7 F \quad \textbf{(4.1b)}$$

Aleatory Variability (s_{al}):

For $M < b_4$,

$$\sigma_{al} = b_1 + b_2(M - b_4) \quad \textbf{(4.2a)}$$

For $M \geq b_4$,

$$\sigma_{al} = b_1 \quad \textbf{(4.2b)}$$

Epistemic Uncertainty in the Median (s_m):

$$\sigma_\mu = c_1 + c_2(M - c_6) + c_3 \ln(R+1) + c_4[\ln(R+1)]^2 + c_5 F \quad \textbf{(4.3)}$$

Epistemic Uncertainty in the Aleatory Variability (s_s):

For $M < d_4$,

$$\sigma_\sigma = d_1 + d_2(M - d_4)$$

For $M \geq d_4$,

$$\sigma_\sigma = d_1 \quad \textbf{(4.4b)}$$

Minimum values of 0.3 for σ_{al}, 0.15 for σ_μ and 0.05 for $\sigma\sigma_\mu$ are recommended on the models to keep the models reasonable.

4.3.4.3 Regression Results

Attenuation relations were developed for each expert's point estimates individually and for a composite model that combines all of expert's point estimates. In all cases the m_1 coefficient was constrained to:
$m_1 = 6.25$.

4.3.4.3.1 Individual Expert Attenuation Relations
The regression analysis was evaluated by comparing each expert's point estimates to the regression model fits. These comparisons (not shown) indicate that the regression analysis adequately models the experts' point estimates.

Coefficients a_i, b_i, c_i, and d_i are listed in Table 4.3.4-2. The process of fitting the experts' point estimates with a smooth equation leads to additional aleatory variability due to the misfit between the equation and the point estimates. To account for this additional variability, the total aleatory variability is given by the combination of the experts' estimate of the aleatory variability (parameterized by the regression equation as S_{al}) and the standard deviation of the fit to the median ground motion (listed as Sigma Fit in the Table 4.3.4-2). The total aleatory variability is given by

$$\sigma_{total} = \sqrt{\sigma_{fit}^2 + \sigma_{al}^2} \qquad (4\text{-}5)$$

Comparison of the regression model fits and the experts' point estimates are shown in Figures 4.3.4-1 to 4.3.4-4. These figures show that the range in the median ground motions from these models is generally less than a factor of 1.5. Examples of the resulting attenuation relations for the seven experts are compared for peak ground acceleration and for 1 Hz spectral acceleration for two magnitudes: 5.0 and 7.0. The models for the horizontal component median ground motions are compared in Figures 4.3.4-1 and 4.3.4-4. These figures show that the range in the median ground motions from these models is generally less than a factor of 1.5. The models for the horizontal component aleatory variability are compared in Figures 4.3.4-5 and 4.3.4-6 for peak acceleration and spectral acceleration at a period of 1 second. The range in the aleatory variability in the models is generally less than 0.1 natural log units. The epistemic variability in the median horizontal ground motion is compared in Figures 4.3.4-7 to 4.3.4-10. The range of the models is generally less than 0.1 natural log units except for Anderson's model which has much larger values due to his estimates of the epistemic uncertainty in the proponent model median estimates. Finally, the epistemic uncertainty in the aleatory variability is shown in Figure 4.34-11 and 4.3.4-12. The range of these models is generally less than 0.1 natural log units.

4.3.4.3.2 Composite Model

A single composite model is developed for the combined point estimates from all five experts. These composite models are also shown in Figure 4.3.4-1 to 4.3.4-12. For the composite model, the variability of the μ and σ_{al} between experts is added to the average of the epistemic uncertainty (σ_{μ} and σ_{σ}) given by the five experts.

4.4 Analysis

4.4.1 General Scope of Calculations

A preliminary set of analyses showed that the differences between the ground motion experts' models were not significant in terms of effect on the hazard at the two sites selected, i.e., Watts Bar and Vogtle. Consequently we used the composite ground motion models (See Section 4.3) for all calculations.

An analysis of the effect of using the composite zonation model rather than the individual expert's model, (Savy 1993) had shown that only small differences could be expected, and only in some extreme cases.

To show this difference, we selected one zonation expert's input (i.e., Bollinger) for which we calculated the hazard with his own seismicity rates and secondly with the composite seismicity rates. In another comparison, we performed a calculation with a composite seismic source set of models. The estimates are all for a minimum magnitude of M_{bLg} 5.0 and for rock conditions. A site specific estimate will require adding a correction to account for the geotechnical site specificity at Watts Bar and at Vogtle.

4.4.2 Input Used in the Analyses

A summary of all the seismic source characteristics is given in Tables 4.4-1 to 4.4-15. Tables 4.4-1 to 4.4-5 give the final estimates of the probability distributions of the upper magnitude cutoffs M_u (M_{bLg}), for Bollinger, Chapman, Coppersmith, Jacob and Talwani, respectively. Tables 4.4-6 to 4.4-10 give the final estimates of the probability distributions of the number of events, per year, $f(m = 4)$, for each expert's seismic source and for magnitude M_{bLg}4.0. Additional information is also given to permit comparison between the various zones. It includes the activity rate per square kilometer of the seismic sources and the return period of the events greater or equal to M_{bLg} magnitude 4.0.

Tables 4.4-11 to 4.4-15 give the rate $f(m_1)$ estimates for a magnitude m_1 equal to 0.5 unit less than the upper magnitude cutoff, for each seismic source.

Figures in Appendix F show the rates for each expert and the composite distribution.

The Appendix F shows for each expert, the probability distributions of the upper magnitude cutoff M_u, the estimate $f(4.0)$ and $f(m_1)$. In addition a plot of the combined probability distribution is given. Here, the combined input is obtained by superimposing all the individuals' input and normalizing.

The seismic source maps used for each expert are given in Section 4.2.6 (Tables 4.2.6-1 to 4.2.6-5) and in Figures 4.4.1 to 4.4-14.

Each of the maps shown in Figures 4.4-1 to 4.4-14 shows one alternative map representing the range of experts interpretation using the common building block sources, as shown in Tables 4.2.6-1 to 4.2.6-5.

4.4.3 Comparison of the Hazard for an Individual Expert and for the Composite Seismicity Rates

The seismic hazard was calculated using an individual expert's input seismic rates and using the composite rates; no special method was used to define the composite rates but rather, we used the combined probabilities as shown in Appendix F.

Figures 4.4-1 and 4.4-3 show the two sets of calculation, for the expert's rates and composite rates, respectively, for the case of the PGA, for the Vogtle site. The mean hazard is higher for the composite rates, with a slightly greater total uncertainty on the hazard estimate in the .2 g range of acceleration. The same observation can be made with the spectral acceleration, (see Figure 4.4-2 and 4.4-4.). The conclusion is reversed, for the case of the Watts-Bar site, where the expert's mean and hazard estimate total uncertainty is greater with the expert's seismic rates. It appears that the dominant sources to the hazard for the Vogtle site are several large zones around the site, and their seismicity rates are more sharply defined by each one of the experts than in the combined estimates. Furthermore, Bollinger's rate estimates are lower than the group of experts estimates, and consequently lower than the composite estimates.

For the Watts Bar site, the dominant sources are the portion of the ETSZ close to the site (Zone 4B2) and the large background [zone (5-1) and (5-2)] around it. Most of the experts gave higher emphasis to these zones than Bollinger did. As a result, the composite seismicity rates are on the average lower than for Bollinger for the dominant zones. Most of the experts had much smaller uncertainties than for Bollinger for the dominant zones. This also leads the uncertainty for the composite rates case to be smaller than Bollinger case. These observations apply to both PGA and uniform hazard spectra cases (see: Figures 4.4-5, 4.4-7 and 4.4-6, 4.4-8, for PGA and UHS respectively).

The differences that can be observed between the two cases: Individual expert's seismicity rates versus composite seismicity rates are in the order of 15 to 25% of the ground motion value for a given hazard level in the 10^{-4} to 10^{-5} hazard range, more for higher hazard (lower ground motion values).

4.4.4 Comparison of the Hazard Estimates for an Individual Expert and the Composite Zonation Maps

The composite maps are very similar to the maps of all the experts, since they use all the same building blocks as those used for the experts maps. As a result, the composite maps are essentially the same as the experts maps but with different weights. In this test, we have limited the number of alternative maps from all experts to those which could have an impact on the hazard, i.e., those including the dominant source zones. The weights assigned to the composite maps were calculated using the TFI weights shown in the Tables 4.2.6-2A to 4.2.6-2D.

The final results show little difference between the individual expert's maps and composite maps when using the composite seismicity rates. Compare results in Figures 4.4-3 with 4.4-9 and 4.4-4 with 4.4-10 for Vogtle and Figures 4.4-7 with 4.4-11 and 4.4-8 with 4.4-12 for Watts Bar.

4.4.5 Comments on the Use of Composite Models

The use of composite models is appealing since it would allow us to incorporate the alternative range of alternatives and possible interpretation into a single model for the seismicity rates. For the zonation maps, we learned that by necessity, to be able to encompass the entire range of interpretation, the set of composite maps essentially had to contain all the maps which contain the dominant source zones, otherwise some classes of interpretations could be under-represented, and important dependencies between source zones would be lost. However, because we concentrated on the elements which were common between all the experts interpretations, and because we formulated a set of common building (source zones) blocks, this had the effect of creating convergence in the modeling of the dominant source zones among experts.

As a result, the final results using both composite maps and composite rates appear to be very robust in the sense that even with an expert's individual set of maps, the results would not be greatly different. Not to jump to hasty conclusion, it is important to emphasize that the individual maps are, in fact, already aggregated since they are formed with the minimum set zones, the building block source zones which are the results of the full integration of all the experts' inputs.

4.4.6 Comparison with the 1993 Eastern US Update for Watts Bar

A study conducted subsequent to this one compared PSHA results for the Watts Bar Site; the report is presented in Appendix G.

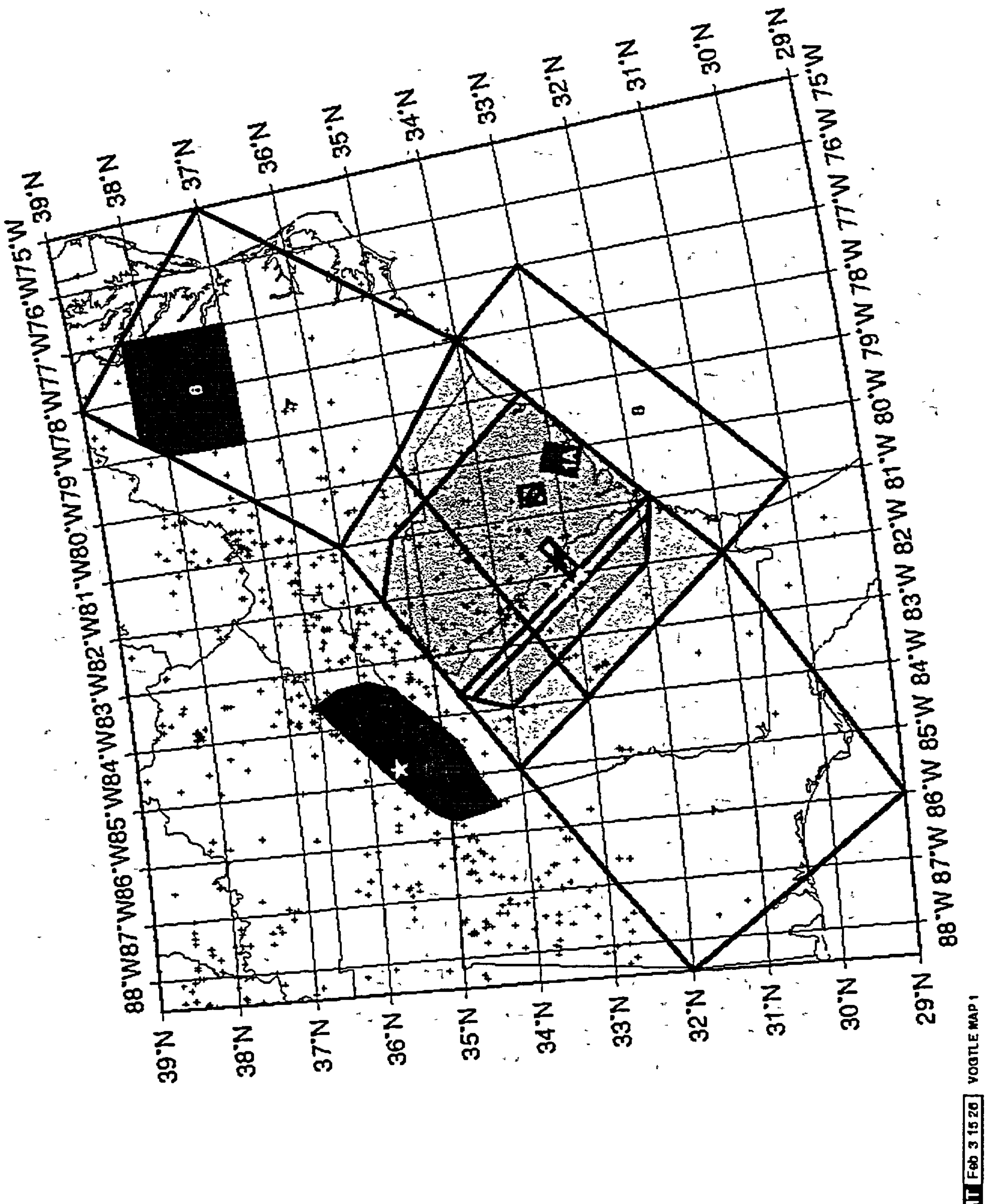


Figure 4.2.6-1 Vogtle Map 1 — Zonation Maps That Define the Various Alternative Interpretations.

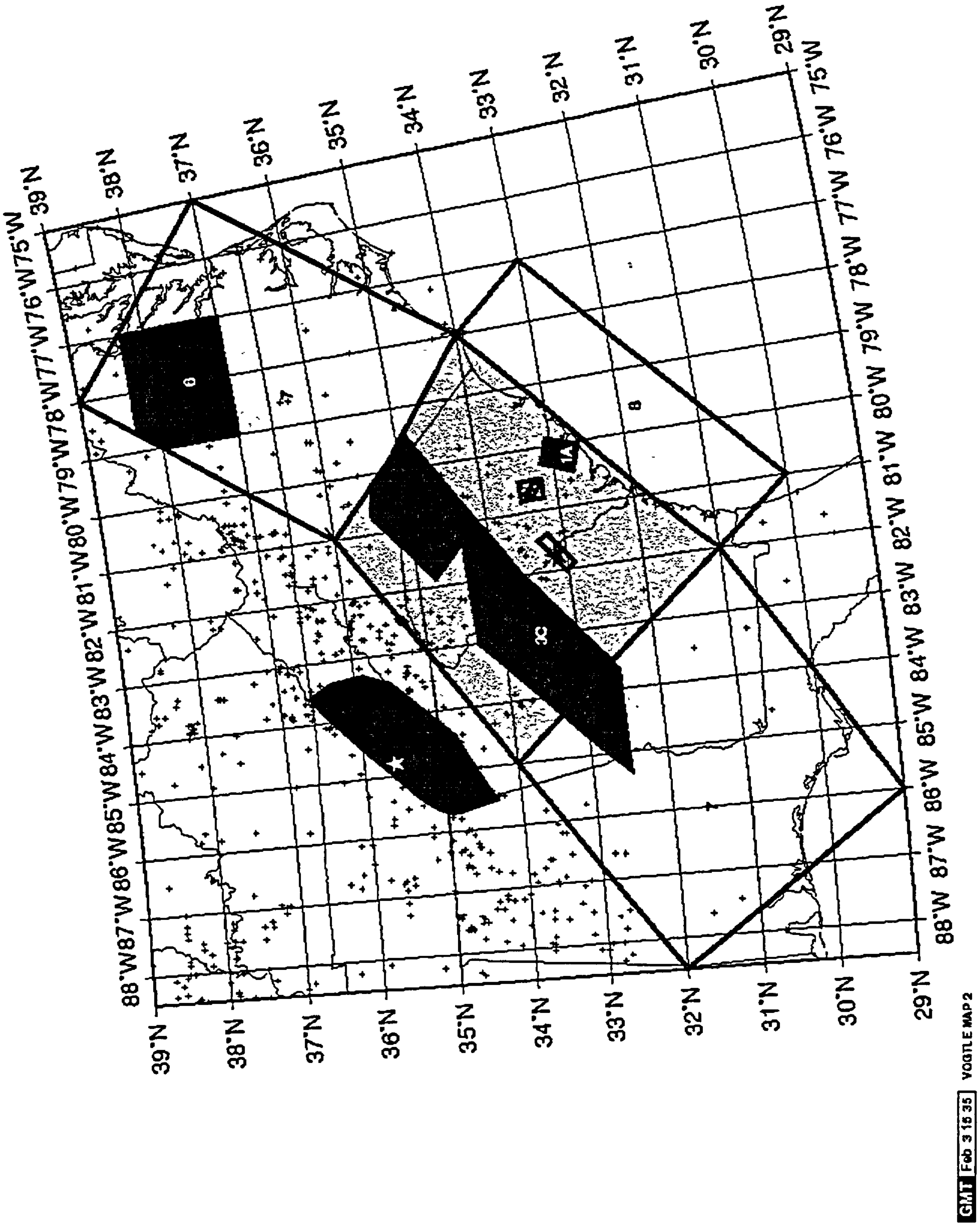


Figure 4.2.6-1 *(cont'd)* **Vogtle Map 2 — Zonation Maps That Define the Various Alternative Interpretations.**

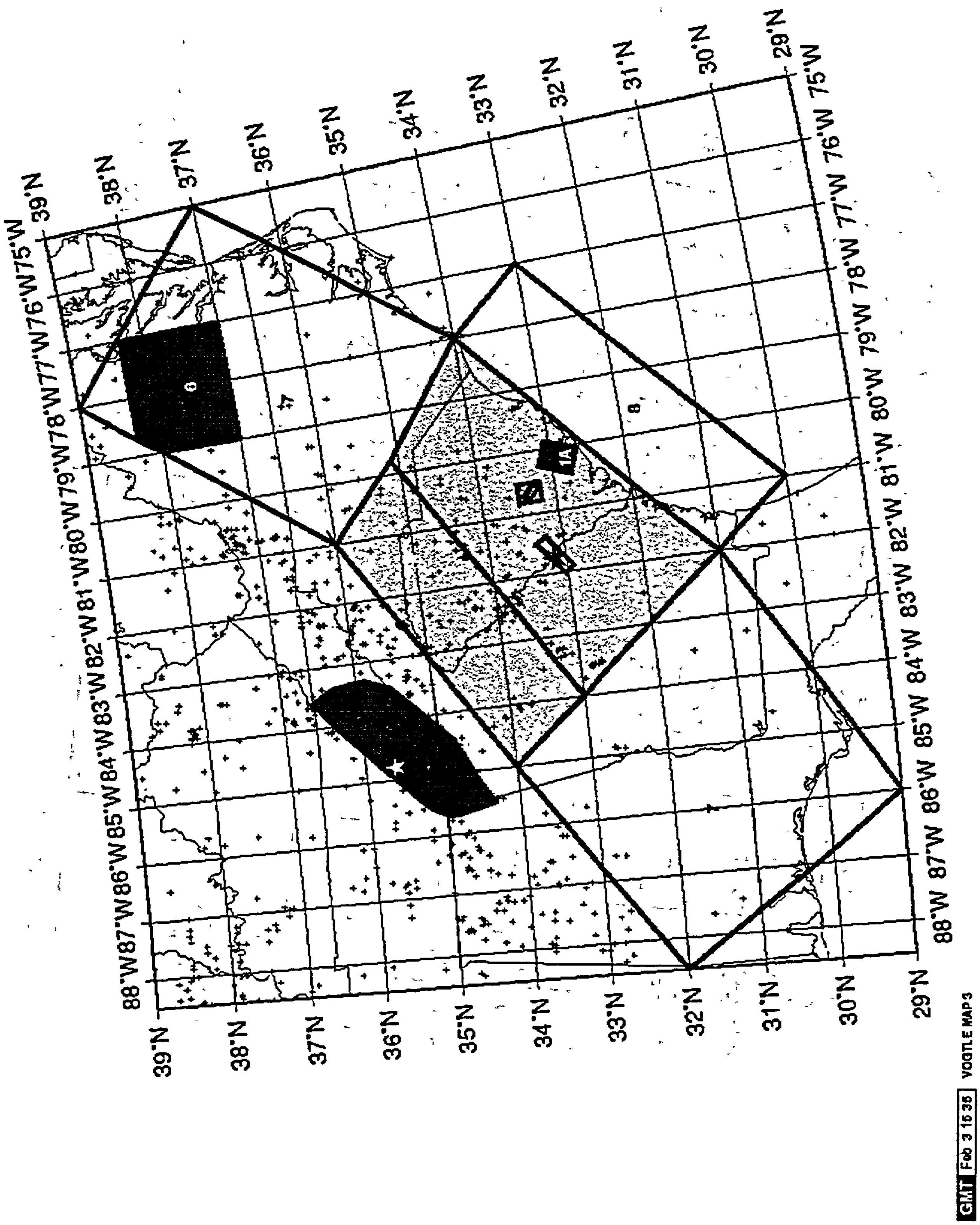


Figure 4.2.6-1 *(cont'd)* Vogtle Map 3 — Zonation Maps That Define the Various Alternative Interpretations.

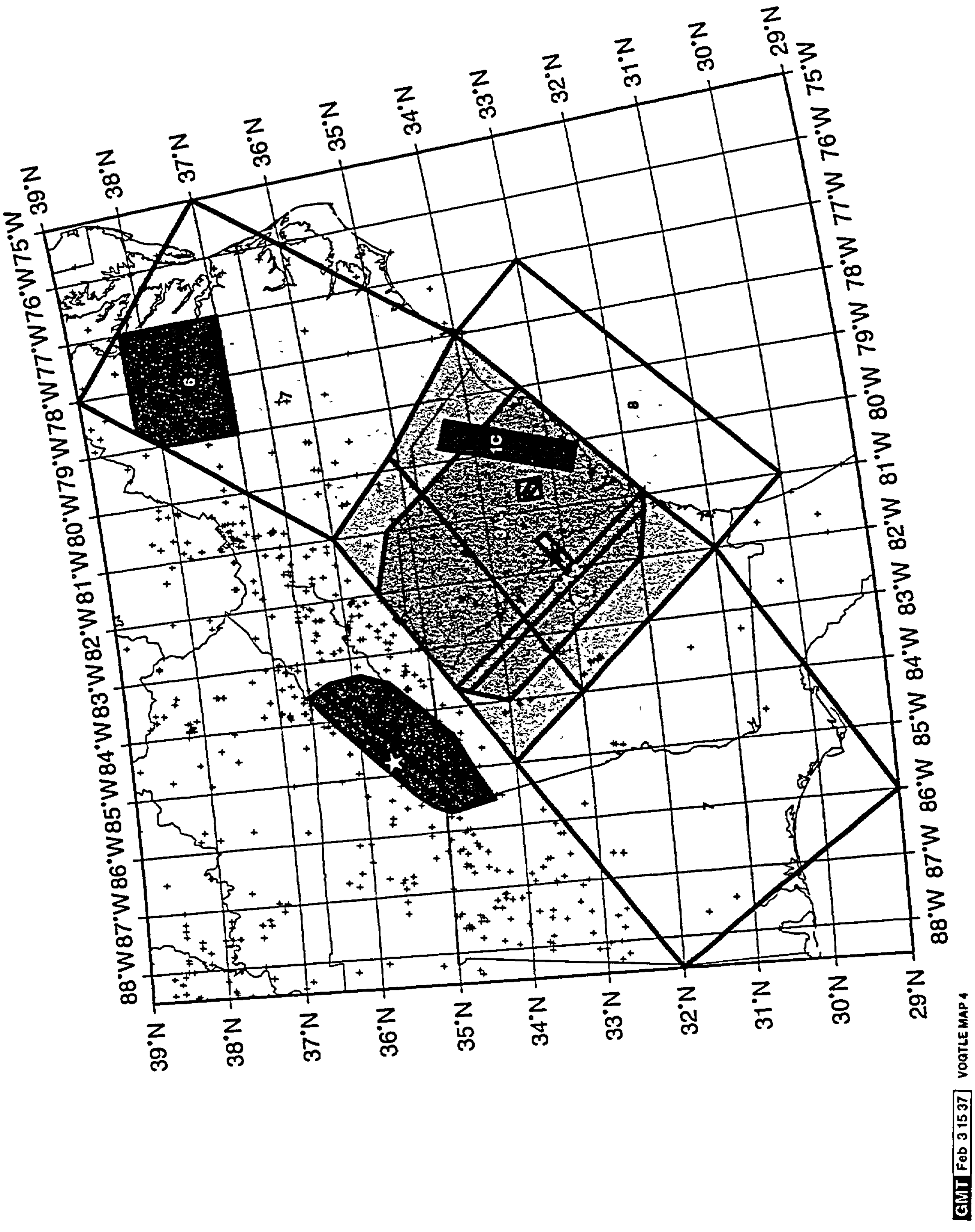


Figure 4.2.6-1 ***(cont'd)*** **Vogtle Map 4 — Zonation Maps That Define the Various Alternative Interpretations.**

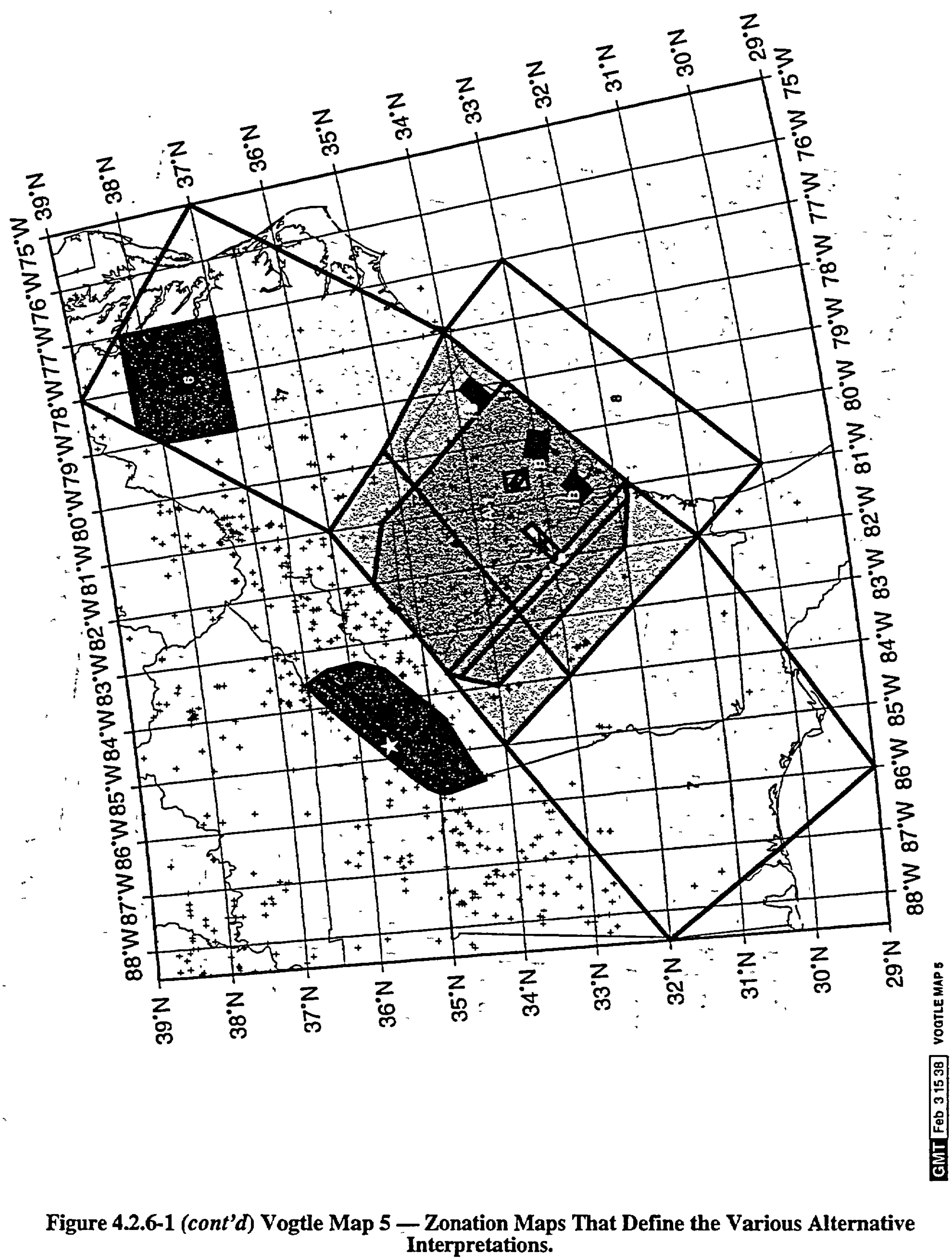


Figure 4.2.6-1 *(cont'd)* Vogtle Map 5 — Zonation Maps That Define the Various Alternative Interpretations.

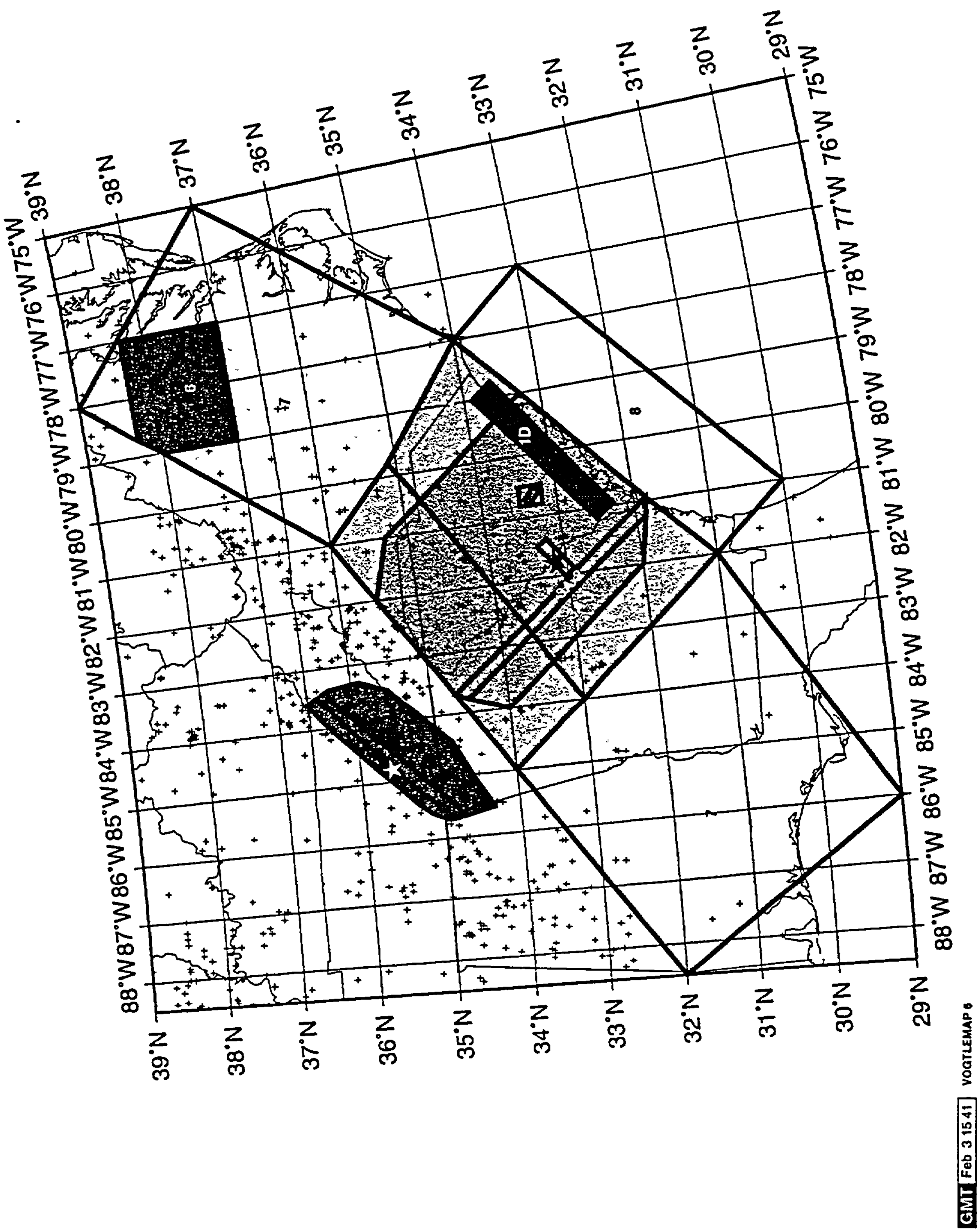


Figure 4.2.6-1 *(cont'd)* **Vogtle Map 6 — Zonation Maps That Define the Various Alternative Interpretations.**

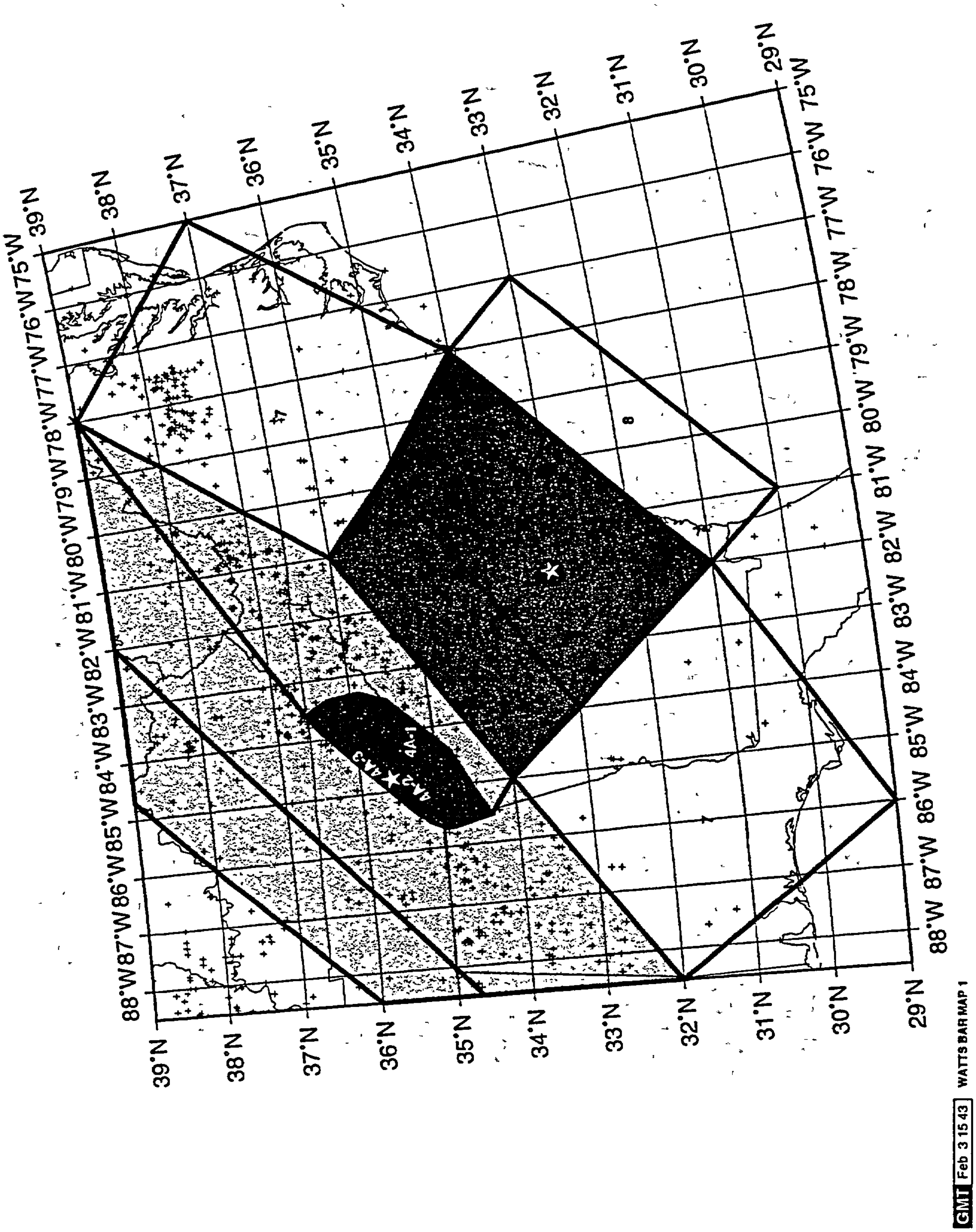


Figure 4.2.6-1 *(cont'd)* Watts Bar Map 1 — Zonation Maps That Define the Various Alternative Interpretations.

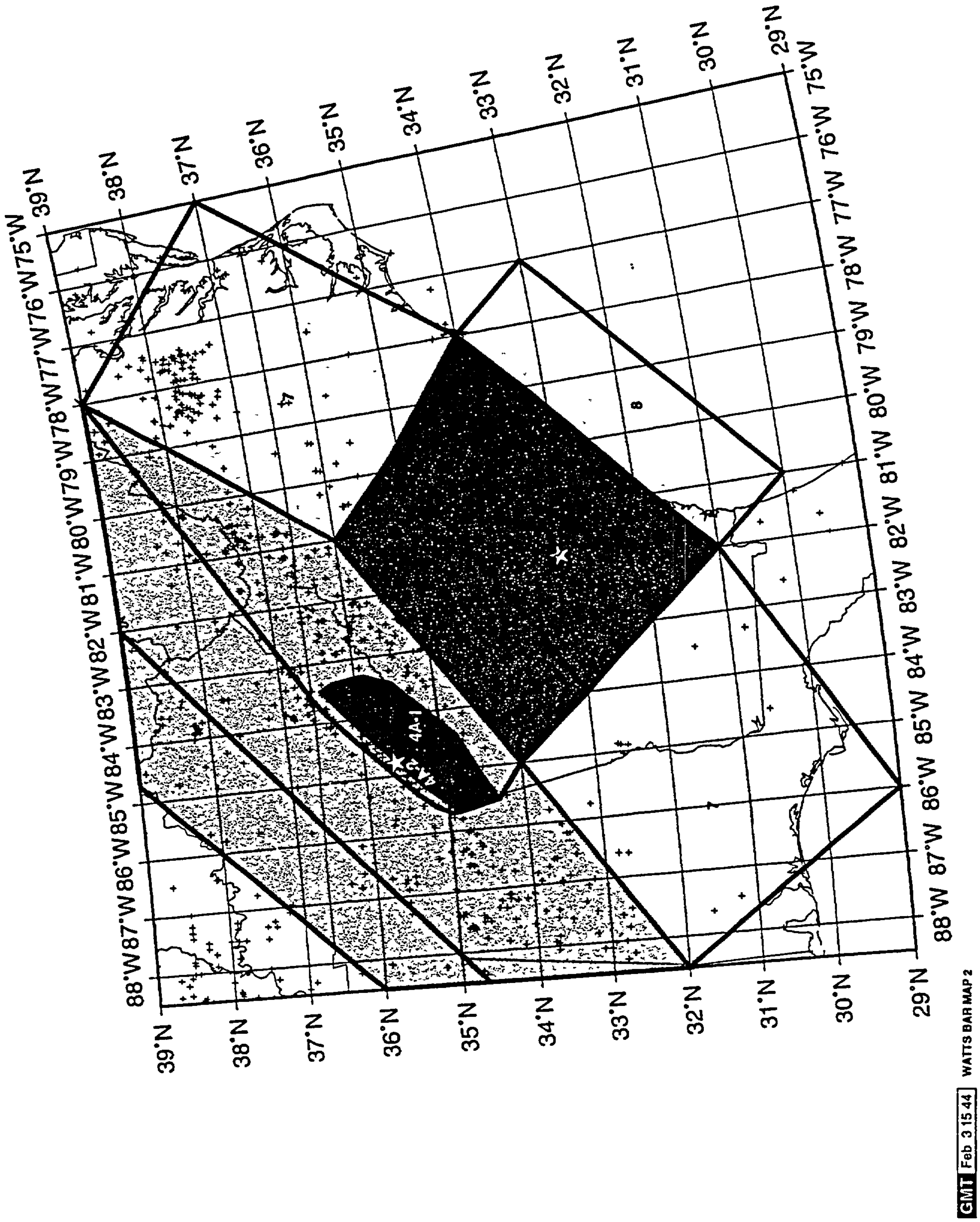


Figure 4.2.6-1 *(cont'd)* **Watts Bar Map 2 — Zonation Maps That Define the Various Alternative Interpretations.**

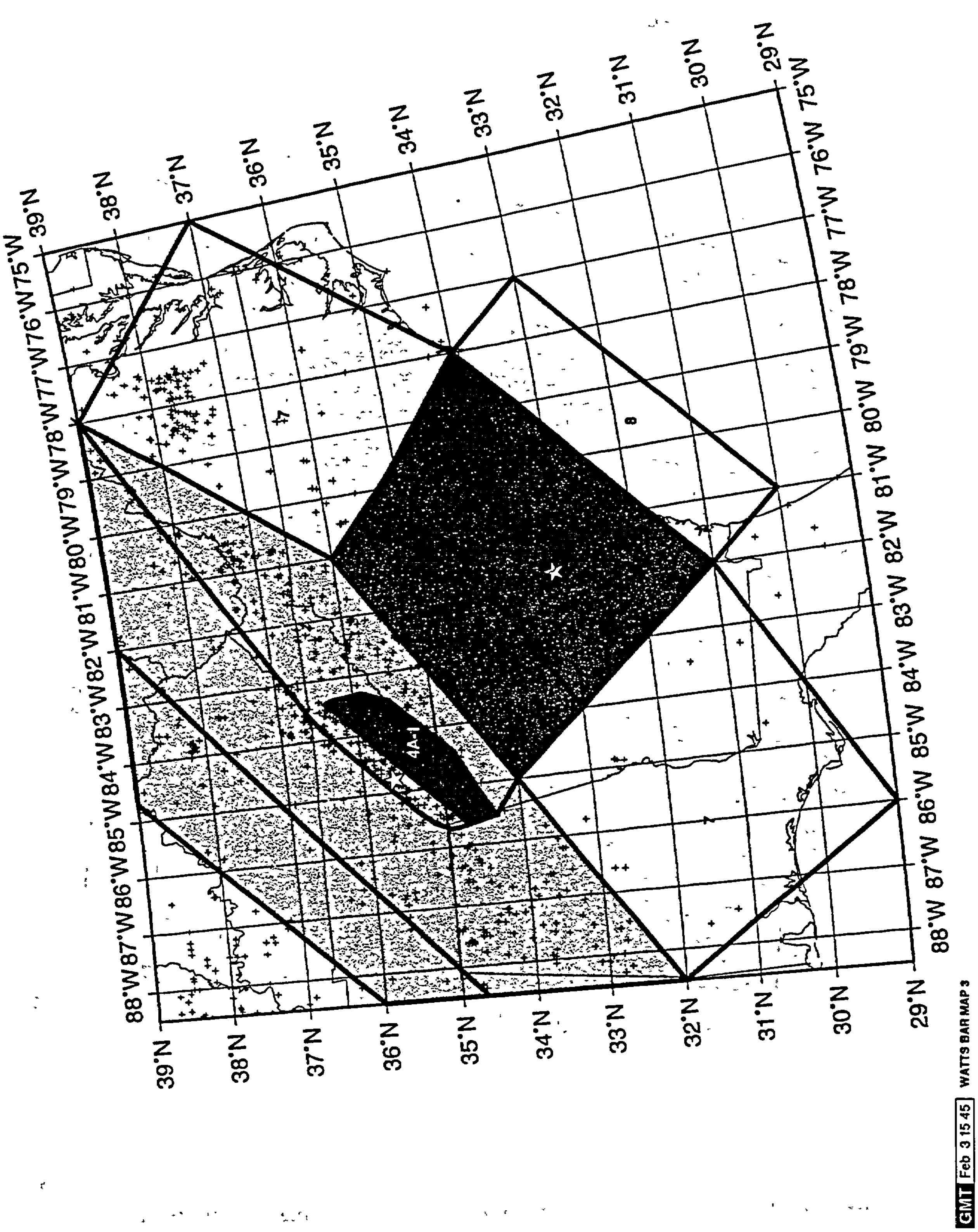


Figure 4.2.6-1 *(cont'd)* Watts Bar Map 3 — Zonation Maps That Define the Various Alternative Interpretations.

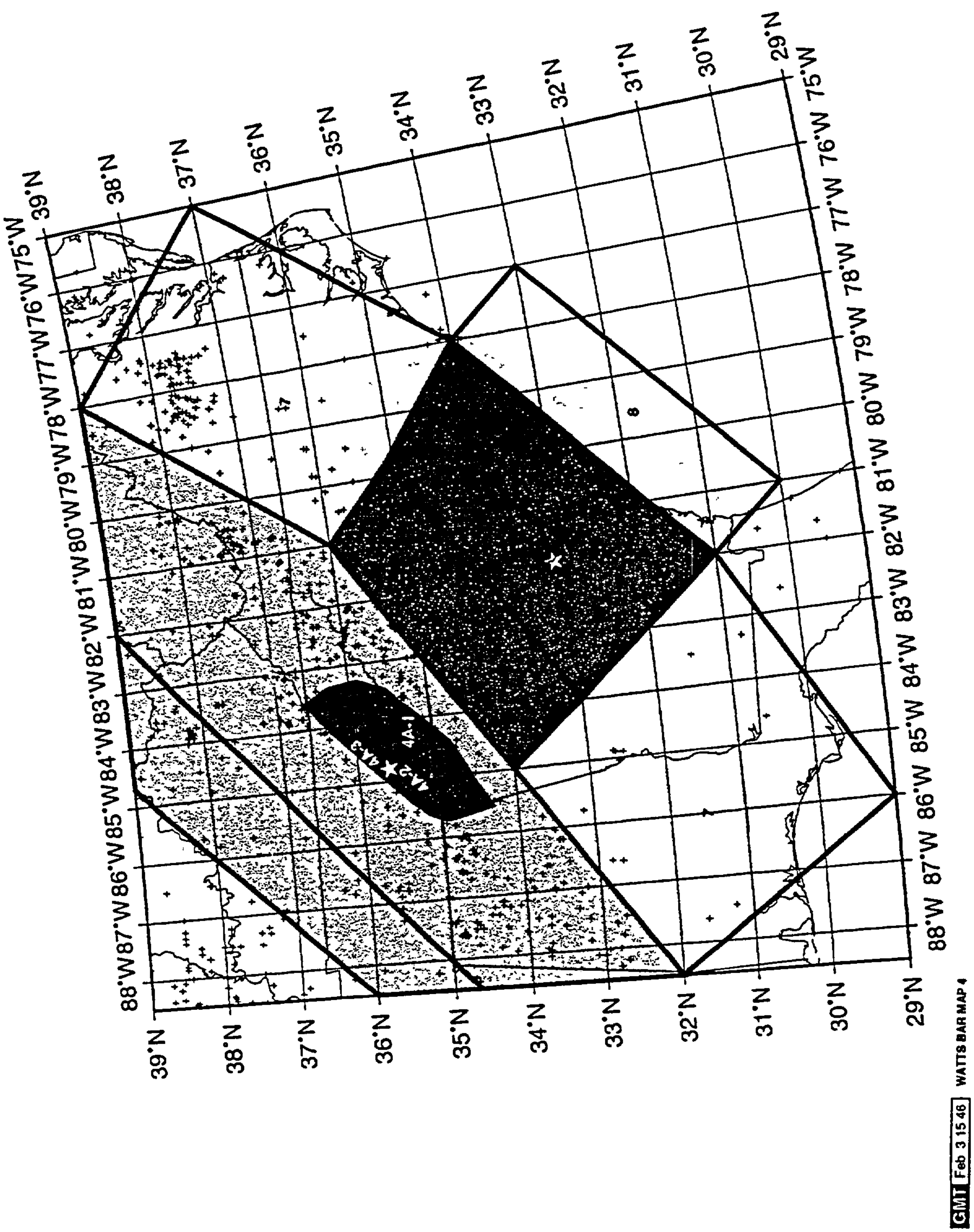


Figure 4.2.6-1 Watts Bar Map 4 — Zonation Maps That Define the Various Alternative Interpretations.

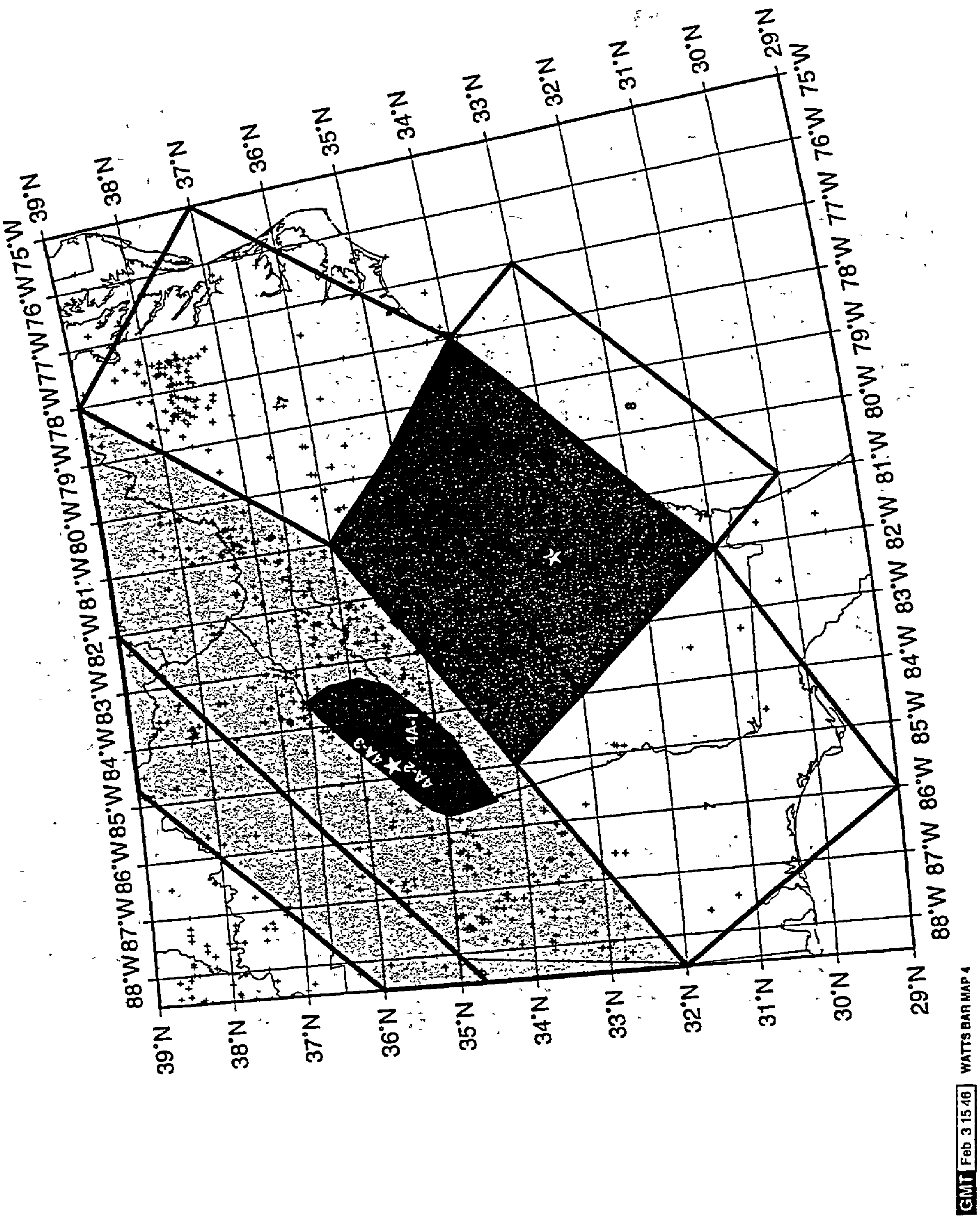


Figure 4.2.6-1 ***(cont'd)*** **Watts Bar Map 5 — Zonation Maps That Define the Various Alternative Interpretations.**

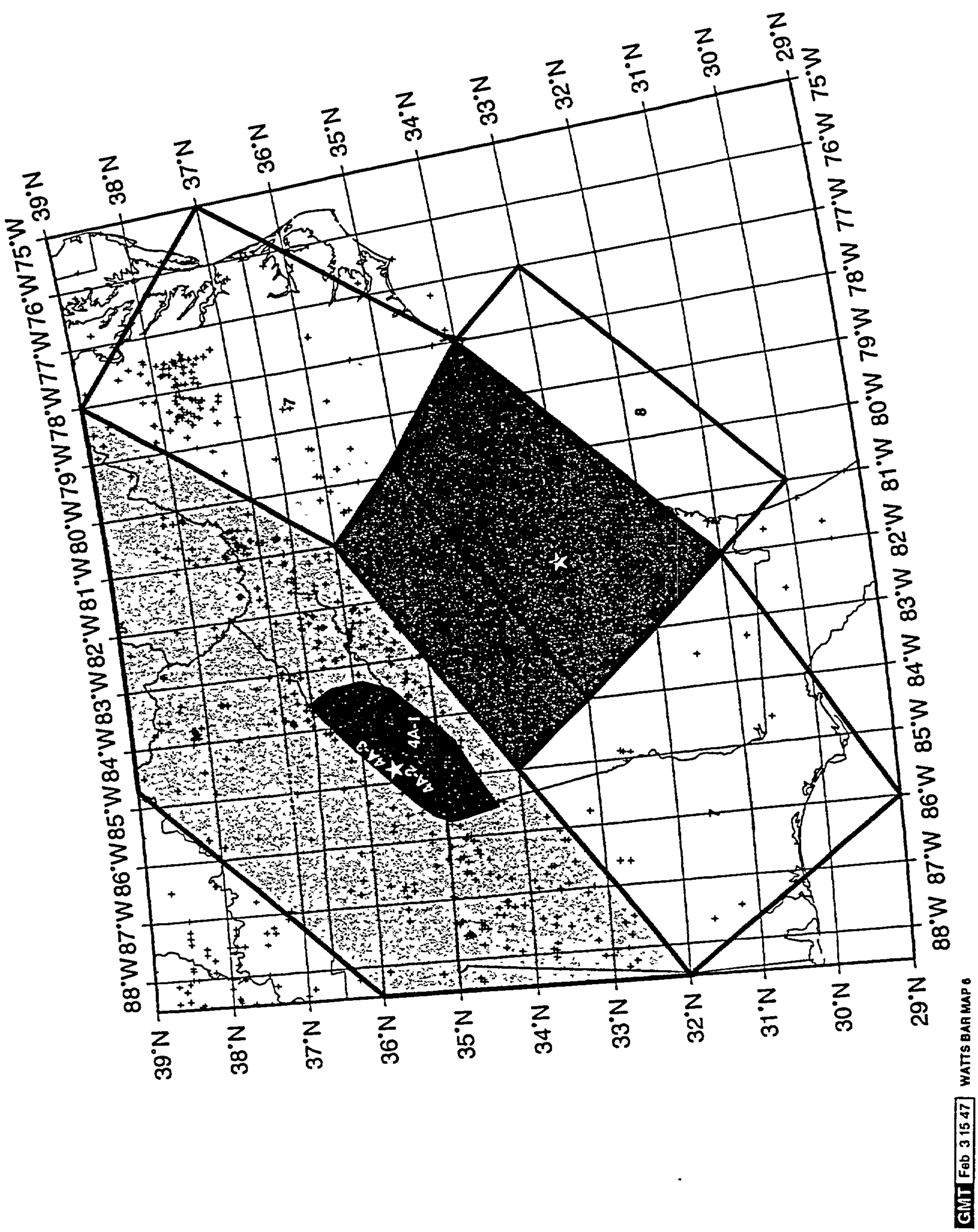


Figure 4.2.6-1 *(cont'd)* **Watts Bar Map 6 — Zonation Maps That Define the Various Alternative Interpretations.**

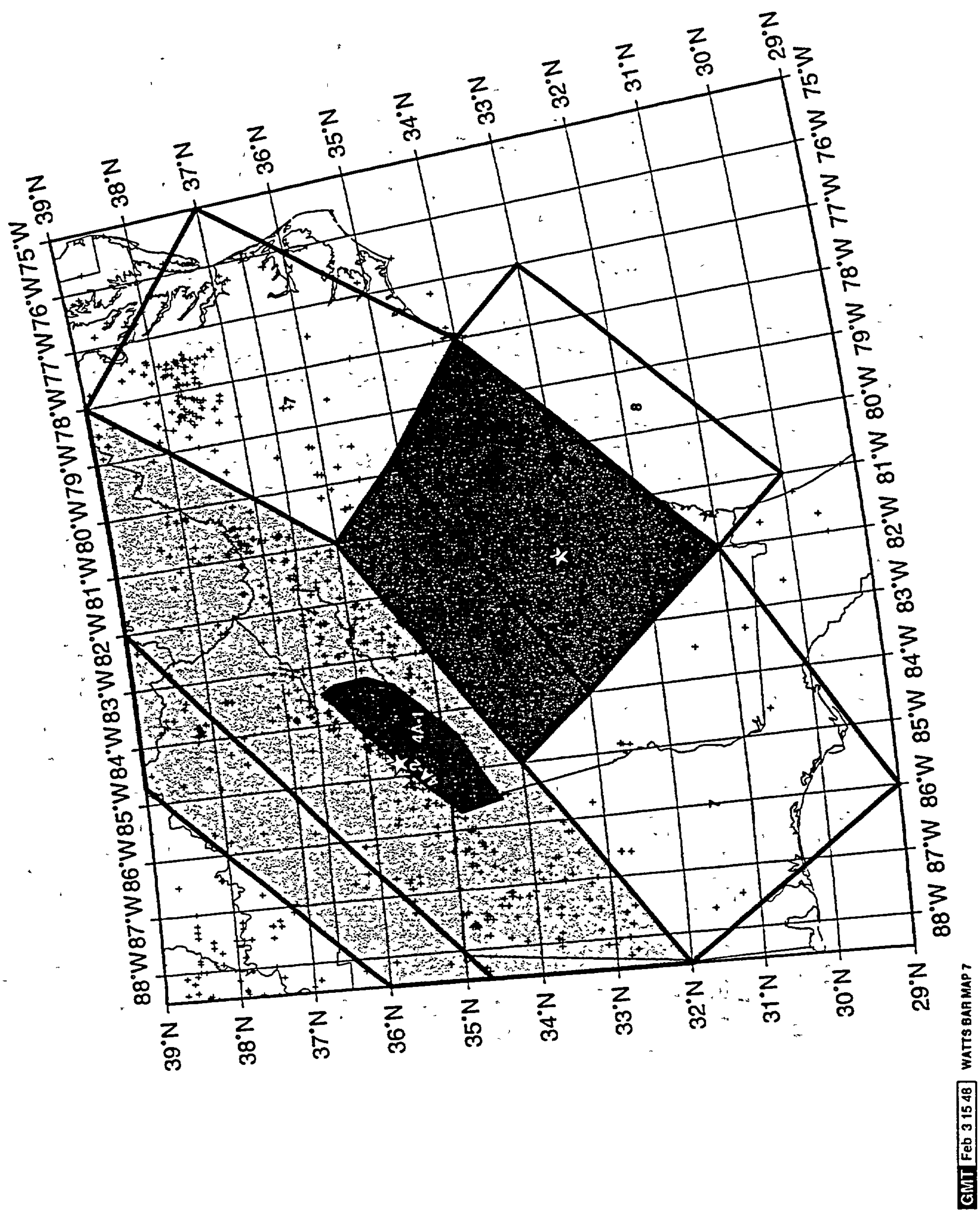


Figure 4.2.6-1 ***(cont'd)*** **Watts Bar Map 7 — Zonation Maps That Define the Various Alternative Interpretations.**

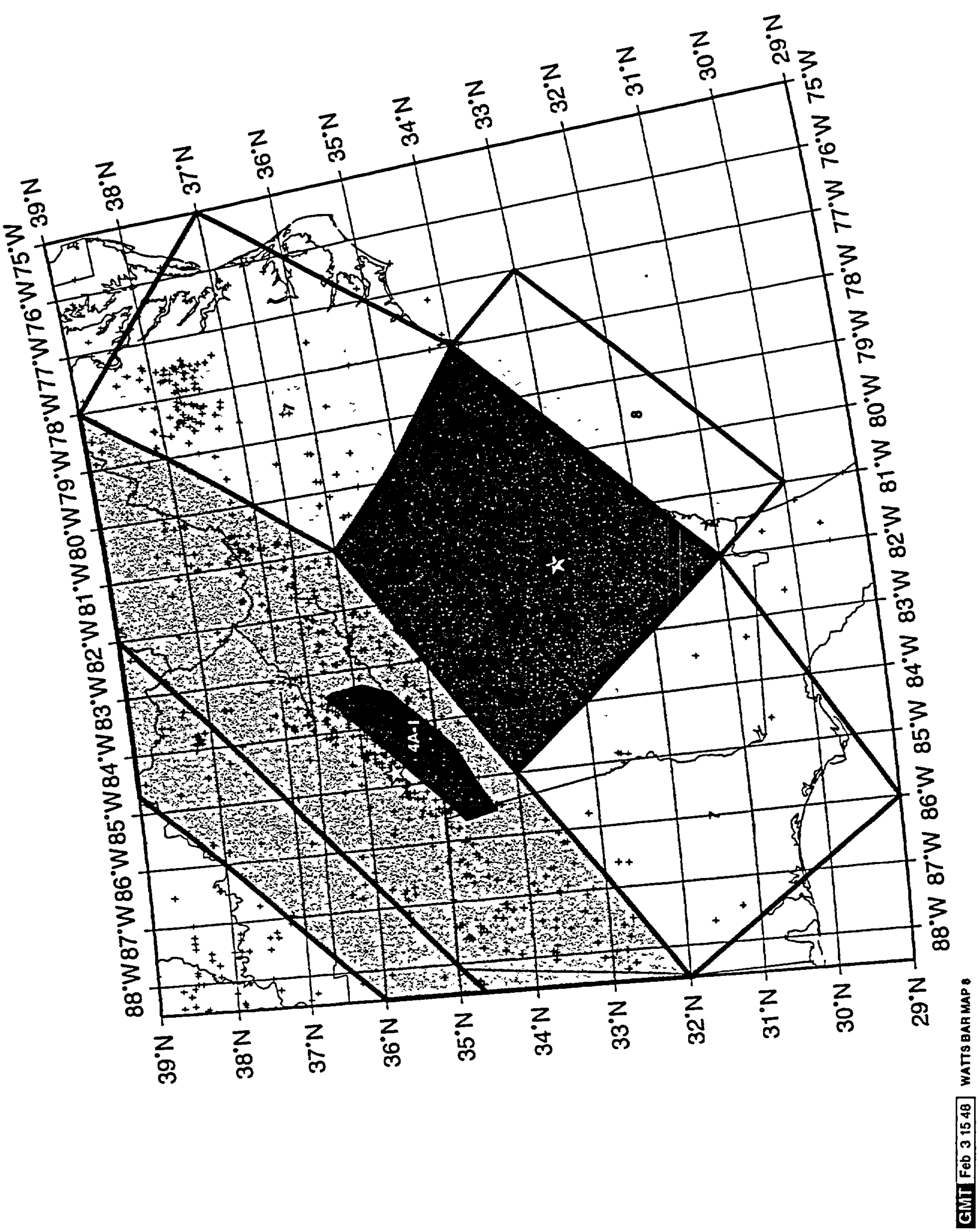
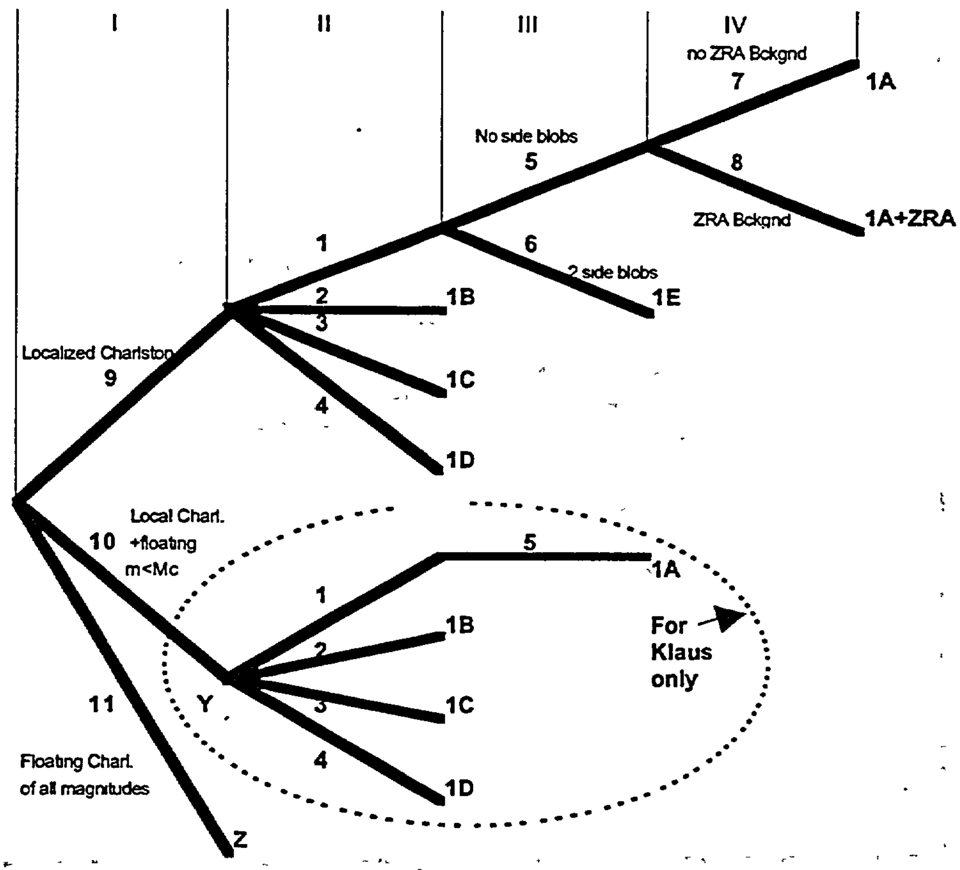


Figure 4.2.6-1 *(cont'd)* Watts Bar Map 8 — Zonation Maps That Define the Various Alternative Interpretations.

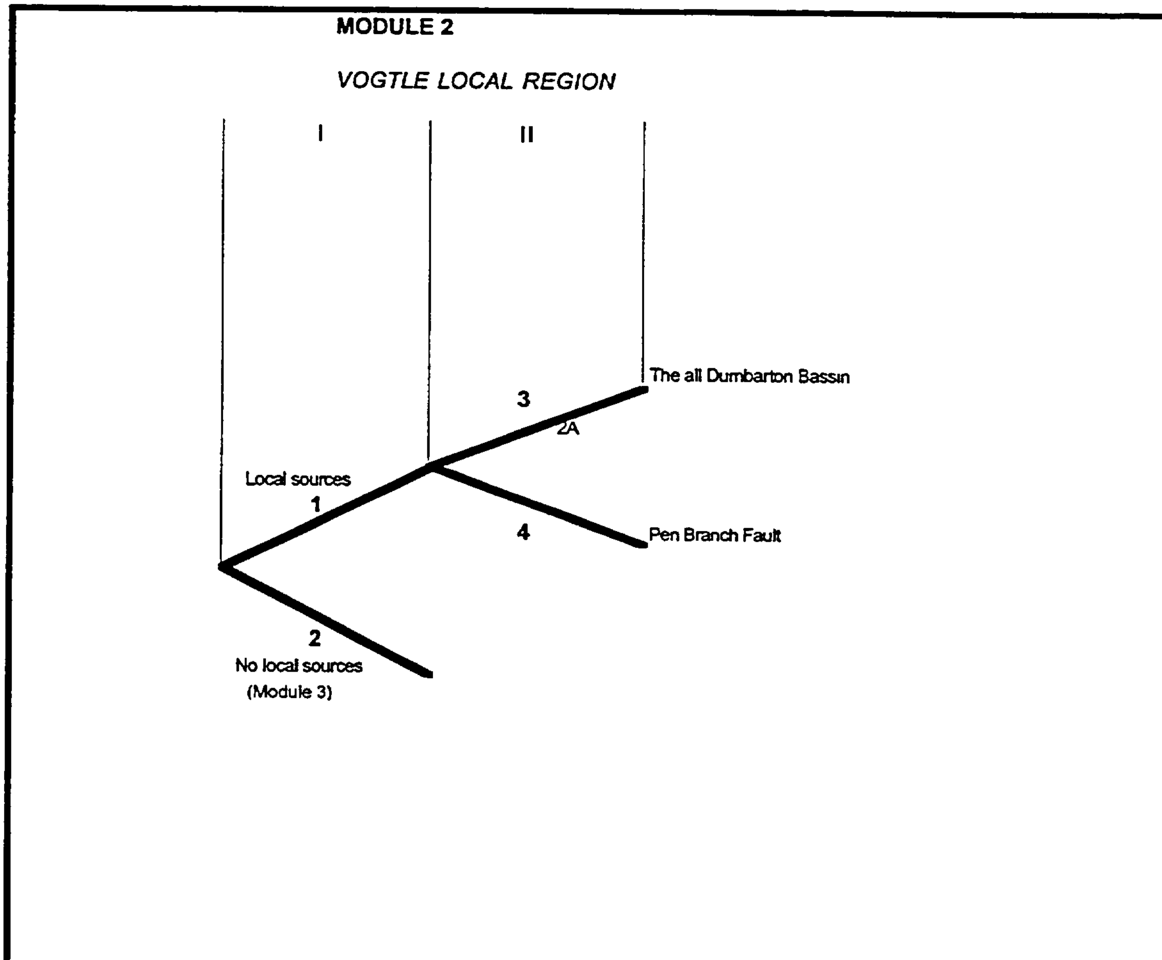
MODULE 1

CHARLESTON



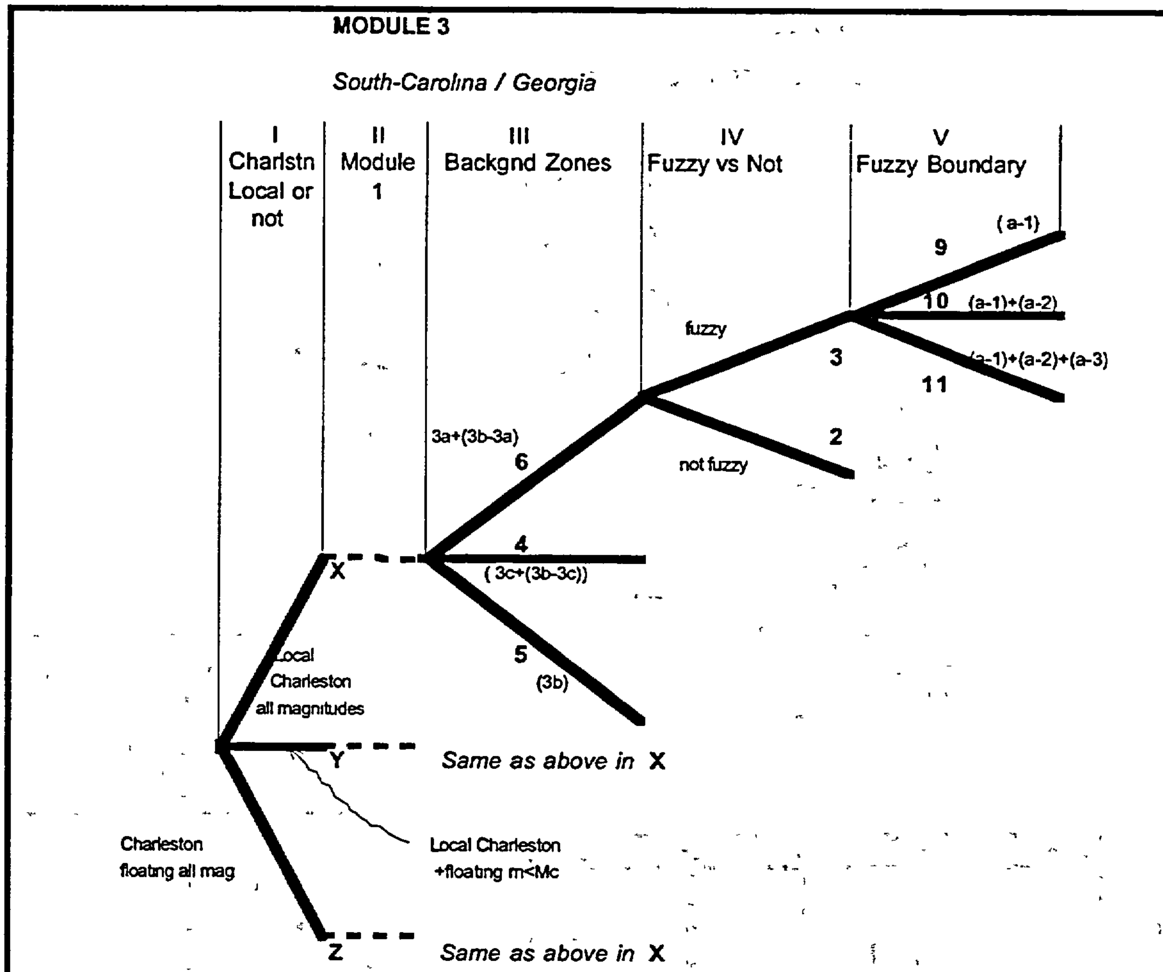
Issue	Branch	Bolling.	Chapm.	Copper.	Jacob	Talwani	Avg.	Min	Max	*TFI*
I	9	1	1	0.9	0	1	0.78	0	1	0.78
	10	0	0	0	1	0	0.2	0	1	0.2
	11	0	0	0.1	0	0	0.02	0	0.1	0.02
II	1	1	0.8	0.611	0 15	1	0.7122	0.15	1	0.72
	2	0	0	0.111	0.4	0	0.1022	0	0.4	0.1
	3	0	0.2	0.278	0.05	0	0.1056	0	0.278	0.1
	4	0	0	0	0.4	0	0 08	0	0.4	0.08
III	5	0.75	1	0.8	1	0.83	0.876	0 75	1	0.85
	6	0.25	0	0.2	0	0.17	0.124	0	0.25	0.15
IV	7	1	1	0 64	1	0.8	0 888	0.64	1	0.95
	8	0	0	0 36	0	0 2	0 112	0	0 36	0 05

Figure 4.2.6-2A Logic Tree Representation of Experts' Interpretations for Module 1: Charleston Issue.



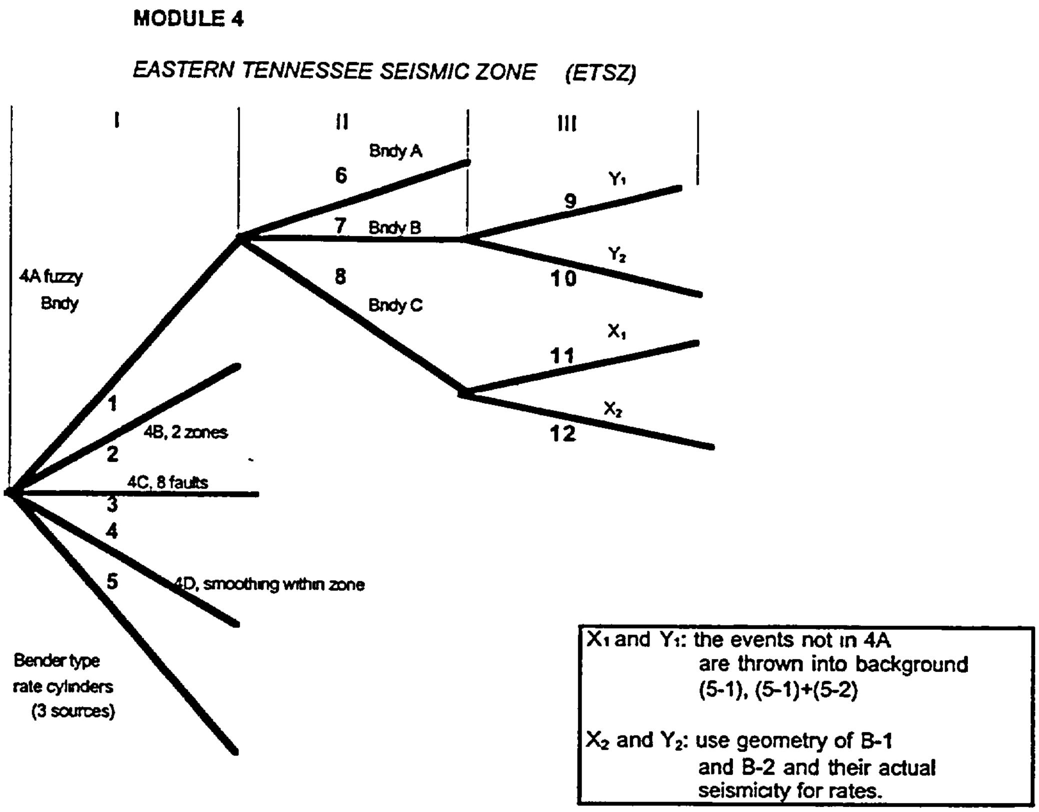
Issue	Branch	Bolling.	Chapm.	Copper.	Jacob	Talwani	Avg.	Min	Max	TFI
I	1	1	0	0.5	0.1	0	0.32	0	1	0.33
	2	0	1	0.5	0.9	1	0.68	0	1	0.67
II	3	1	0.7	0.9	0.1	N/A	0.675	0.1	1	0.67
	4	0	0 3	0.1	0 9	N/A	0 325	0	0.9	0 33

Figure 4.2.6-2B Logic Tree Representation of Experts' Interpretations for Module 2: Vogtle Local Region.



Issue	Branch	Bolling	Chapm	Copper	Jacob	Talwani	Avg.	Min	Max	*TFI*
III	6	0.8	1	0.6	0.4	0	0.56	0	1	0.7
	4	0.2	0	0.2	0.2	1	0.32	0	1	0.2
	5	0	0	0.2	0.4	0	0.12	0	0.4	0.1
IV	3	1	0.7	1	0.5	0.8	0.8	0.5	1	0.8
	2	0	0 3	0	0.5	0.2	0.2	0	0.5	0.2
V	9						0	0	0	
	10						0	0	0	
	11						0	0	0	

Figure 4.2.6-2C(a) Logic Tree Representation of Experts' Interpretations for Module 3: South Carolina-Georgia Issue.

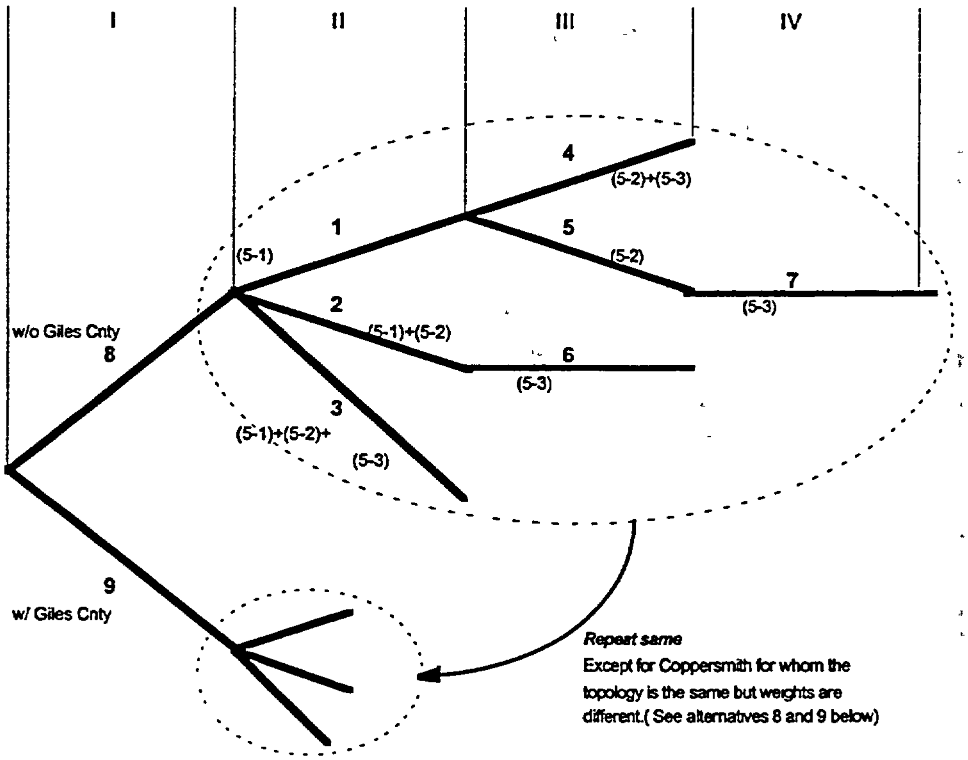


Issue	Branch	Bolling.	Chapm.	Copper.	Jacob	Talwani	Avg.	Min	Max	*TFI*
I	1	0.4	0.4	0.3	0.2	0.6	0.38	0.2	0.6	0.5
	2	0.3	0.3	0.1	0.2	0.2	0.22	0.1	0.3	0.2
	3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.15
	4	0.1	0	0.3	0.2	0	0.12	0	0.3	0.1
	5	0	0 1	0.1	0.2	0	0 08	0	0.2	0.05
II	6	0.4	0.1	0.04	0.2	0.07	0.162	0.04	0.4	0.1
	7	0.35	0.2	0.7	0.55	0.43	0.446	0.2	0.7	0.5
	8	0.25	0.7	0.26	0.25	0.5	0.392	0.25	0.7	0.4
III	9	O	1		0	0	0.2	0	1	1
	10	1	0		1	1	0.6	0	1	0
	11	0	1		0	0	0.2	0	1	1
	12	1	0		1	1	0 6	0	1	0

Figure 4.2.6-2C(b) Logic Tree Representation of Experts' Interpretations for Module 4: Eastern Tennessee Seismic Zone Issue.

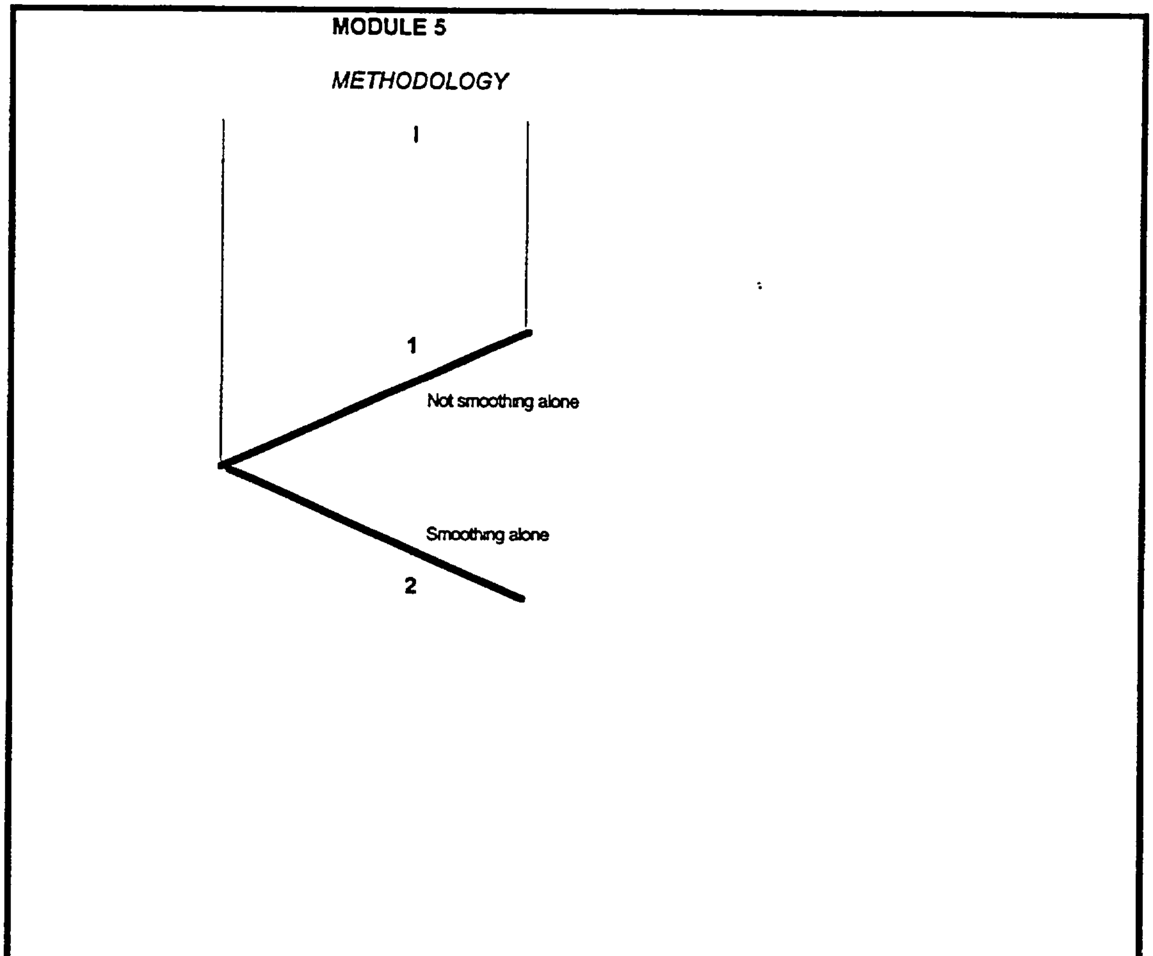
MODULE 4 Continued

BACKGROUND TO EASTERN TENNESSEE SEISMIC ZONE (ETSZ)



Issue	Branch	Bolling	Chapm	Copp 8	Copp. 9	Jacob	Talwani	Avg.	Max	*TFI*
I	8	1	1	0.7		0.2	0.2	0.62	1	0.8
	9	0	0		0.3	0.8	0.8	0.38	0.8	0.2
II	1	0.7	0.5	0.4	0.8	0.2	0.2	0.47	0.8	0.5
	2	0.3	0.5	0.4	0.1	0.6	0.6	0.42	0.6	0.4
	3	0	0	0.2	0.1	0.2	0.2	0.12	0.2	0.1
III	4	0	0.2	0.6	0.6	0.2	0.2	0.3	0.6	0.3
	5	1	0.8	0.4	0.4	0.8	0.8	0.7	1	0.7
	6	1	1	1	1	1	1	1	1	1
IV	7	1	1	1	1	1	1	1	1	1

Figure 4.2.6-2C(b) (cont'd) Logic Tree Representation of Experts' Interpretations for Module 4: Eastern Tennessee Seismic Zone Issue.



Issue	Branch	Bolling.	Chapm.	Copper.	Jacob	Talwani	Avg.	Min	Max	*TFI*
I	1	0.9	0.8	0.95	0.6	0.95	0.84	0.6	0.95	0.85
	2	0.1	0 2	0.05	0 4	0.05	0.1875	0 05	0 4	0.15

Figure 4.2.6-2D Logic Tree Representation of Experts' Interpretations for Module 5: Seismicity Rate Estimation Methodology.

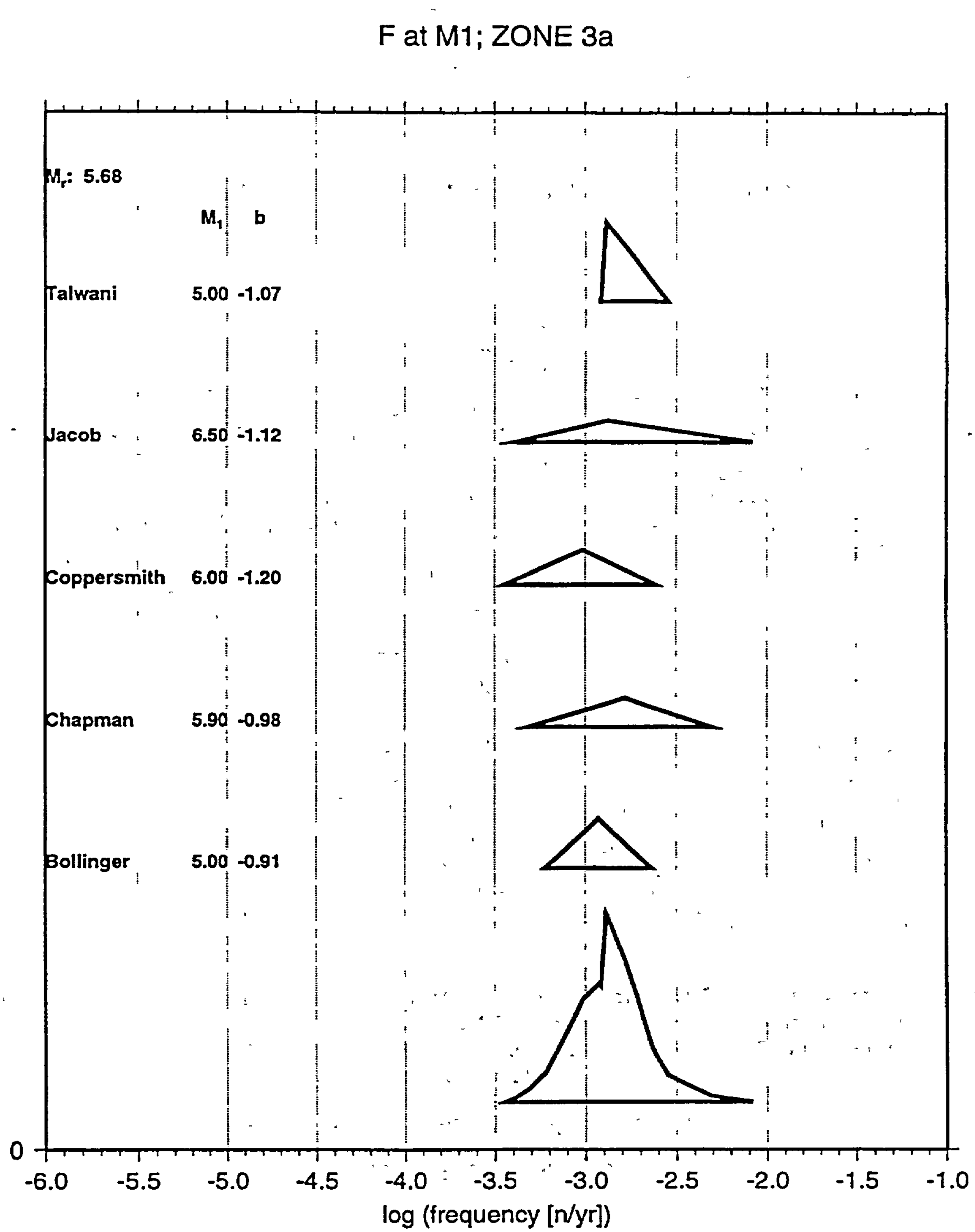


Figure 4.2.6-3 Example of Rates of Probability Distribution for One Zone, and Integration Into a Composite Probability Distribution.

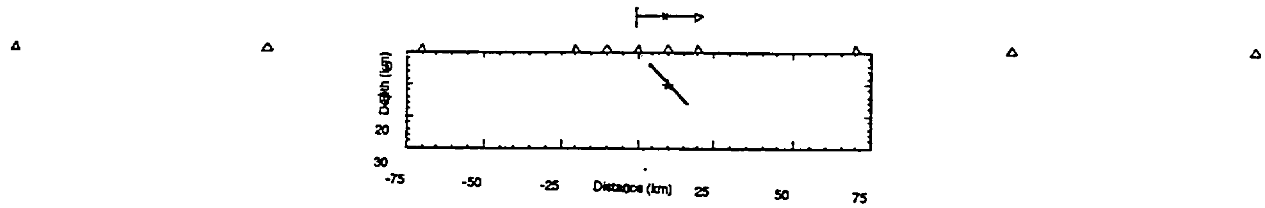
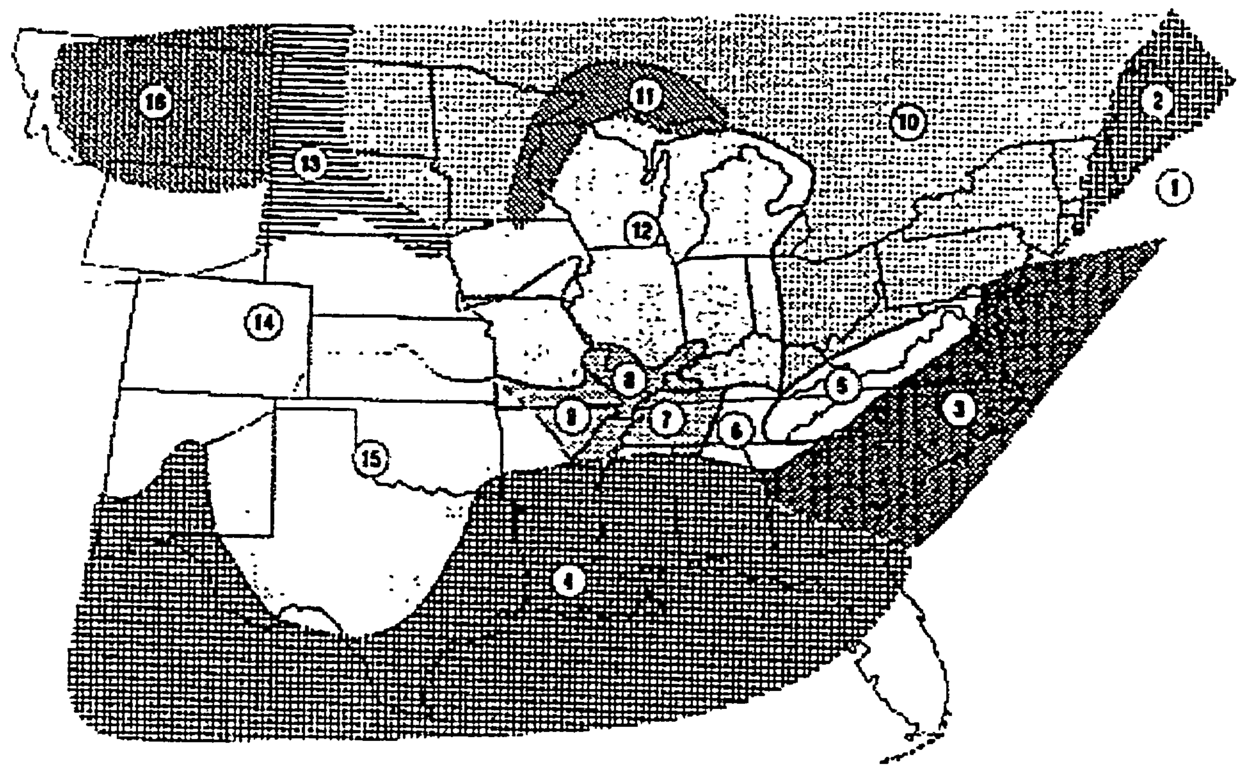


Figure 4.3.3-1 Definition of Observation Points for Ground Motion Estimates.



Legend: 1. Offshore New England, 2. Northern Appalachians, 3. Atlantantic Coastal Plain, 4. Gulf Coast Plain, 5. Southern Appalachians, 6. Central Tennessee, 7. Western Tennessee, 8. New Madrid Rift, 9. Ozarks, 10. Northern Grenville-Superior, 11. Lake Superior Basin, 12. Mid-continent, 13. Northern Great Plains, 14. Central Plains, 15. Southern Great Plains, 16. Williston Basin

Figure 4.3.3-2 Crustal Structure Regionalization for the EUS.

(Woodward-Clyde 1991)

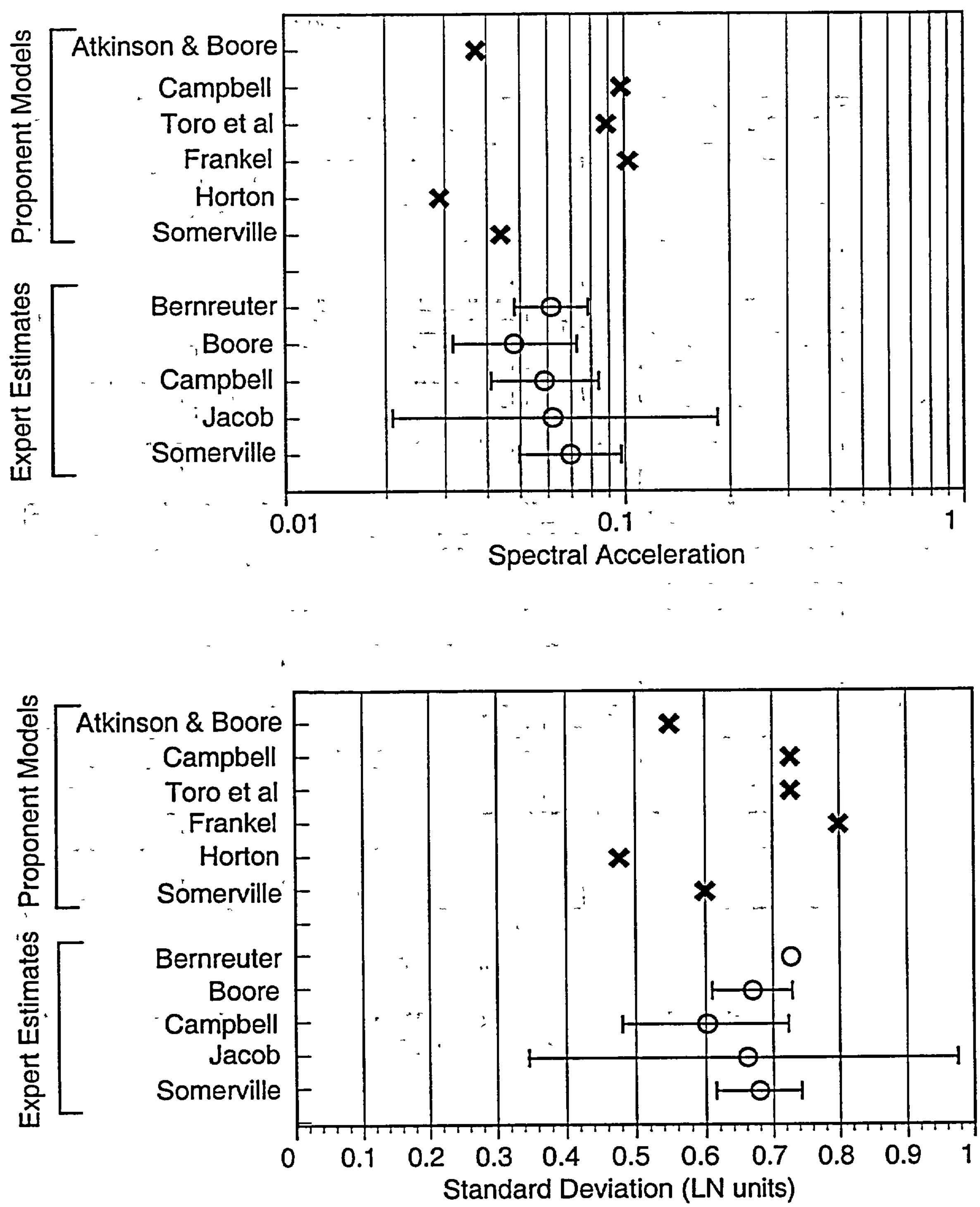


Figure 4.3.3-3 Example of Material Given to the Experts for the Seismic Rate Estimates.

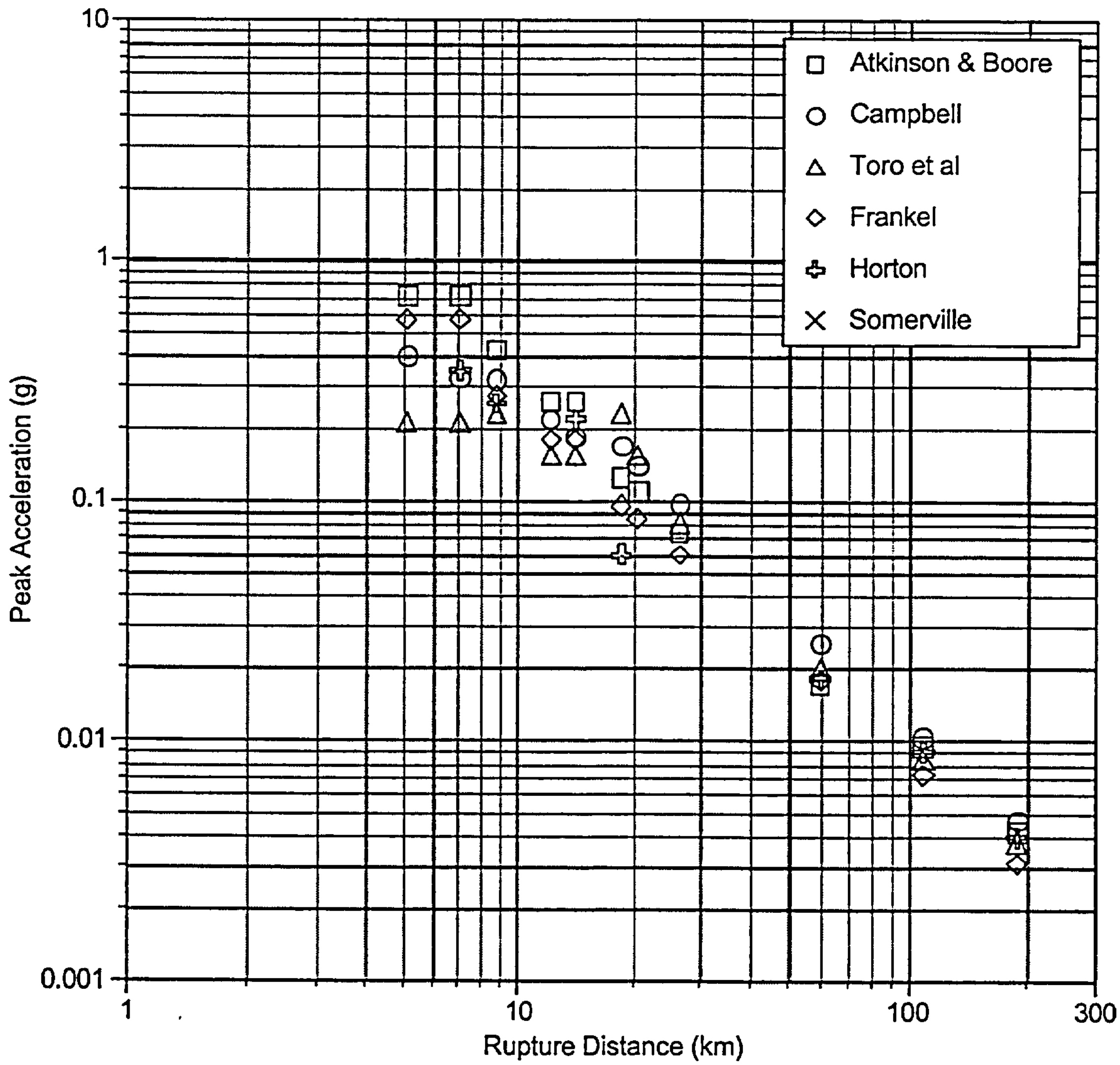


Figure 4.3.3-4a Examples of Proponents Models Median Estimates of the Peak Ground Acceleration for M_w5.

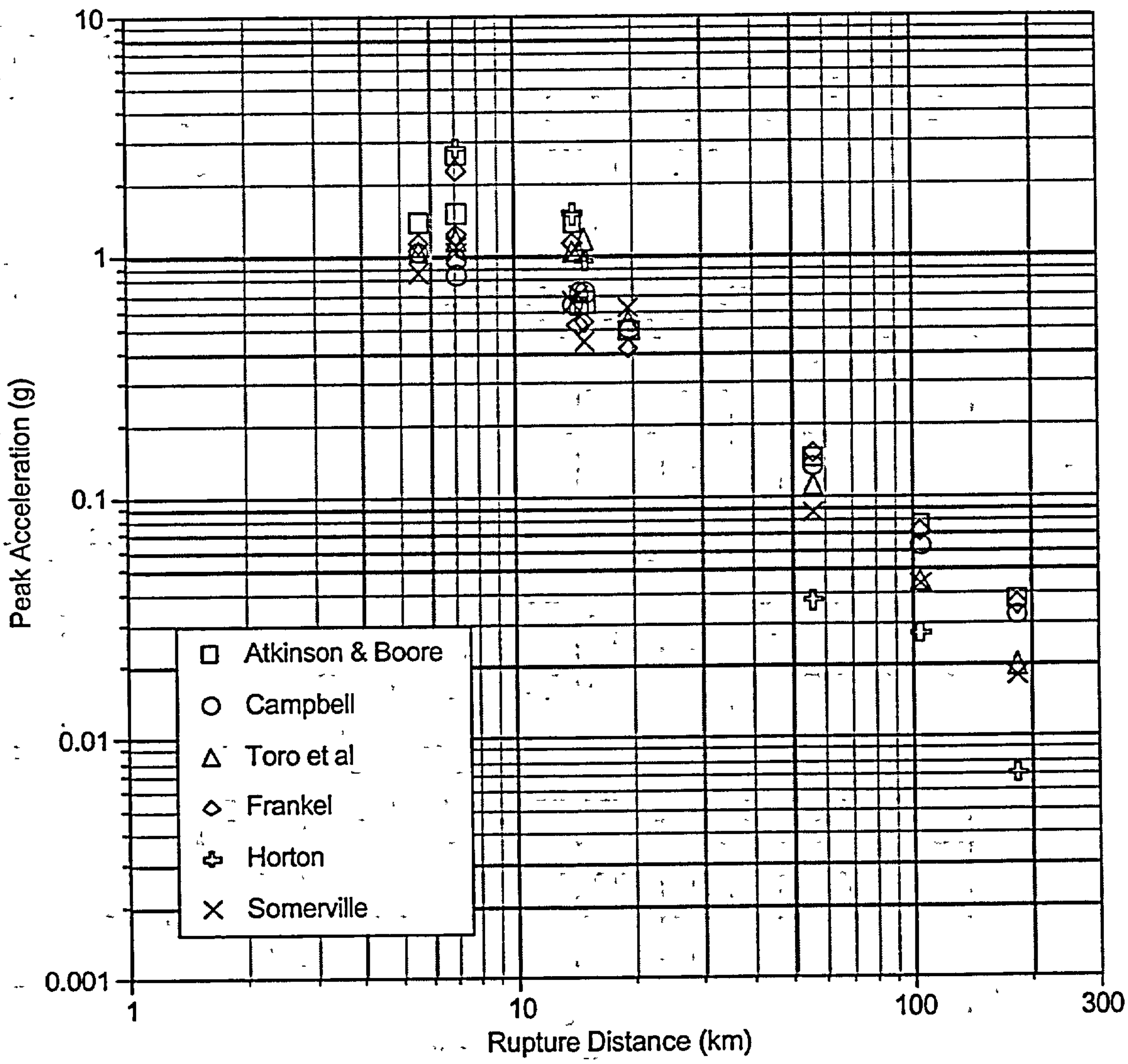


Figure 4.3.3-4b Examples of Proponents Models Median Estimates of the Peak Ground Acceleration for M_w7.

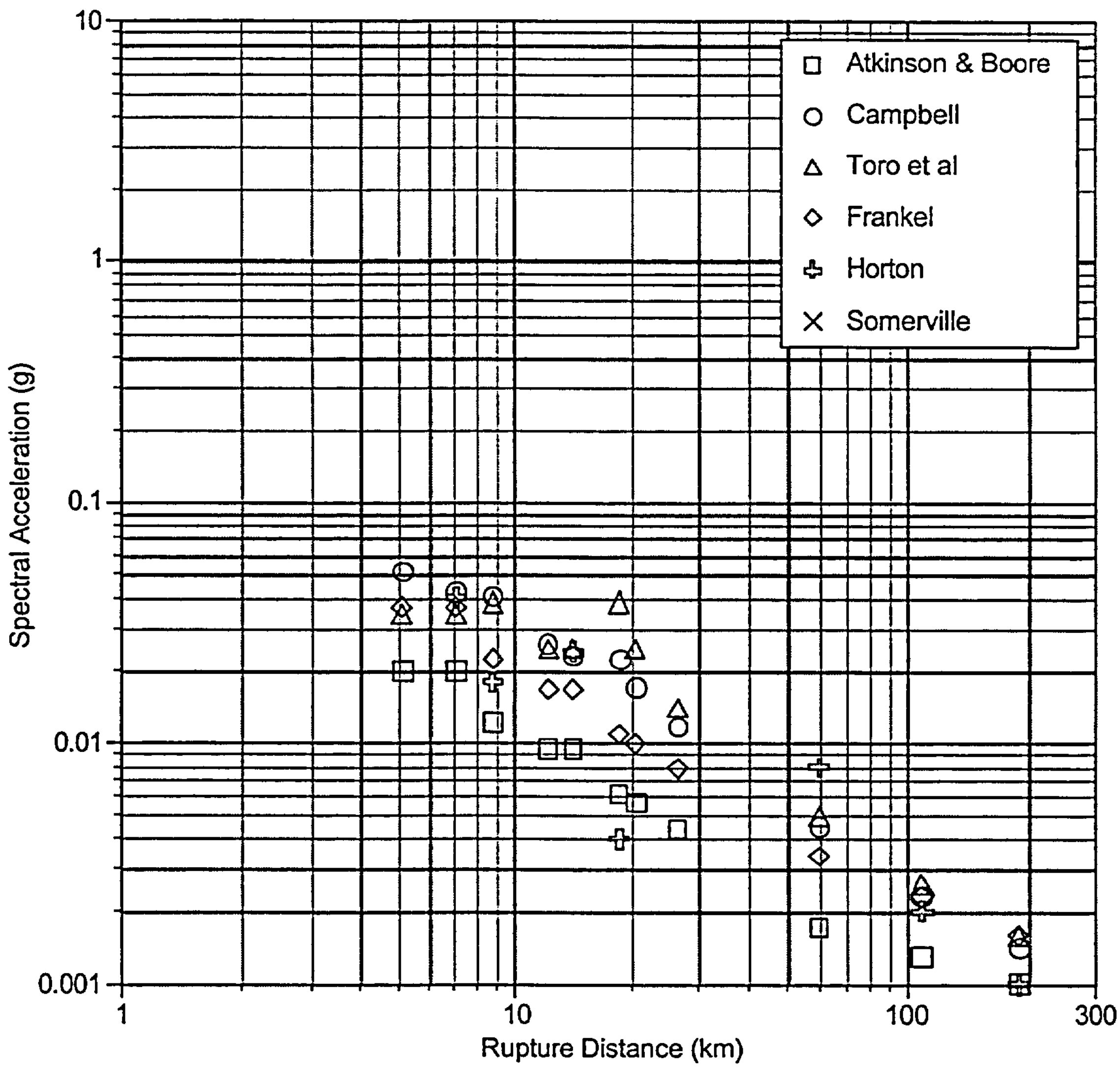


Figure 4.3.3-5a Examples of Proponents Models Median Estimates of the 1-Second Period Spectral Acceleration for M_w5.

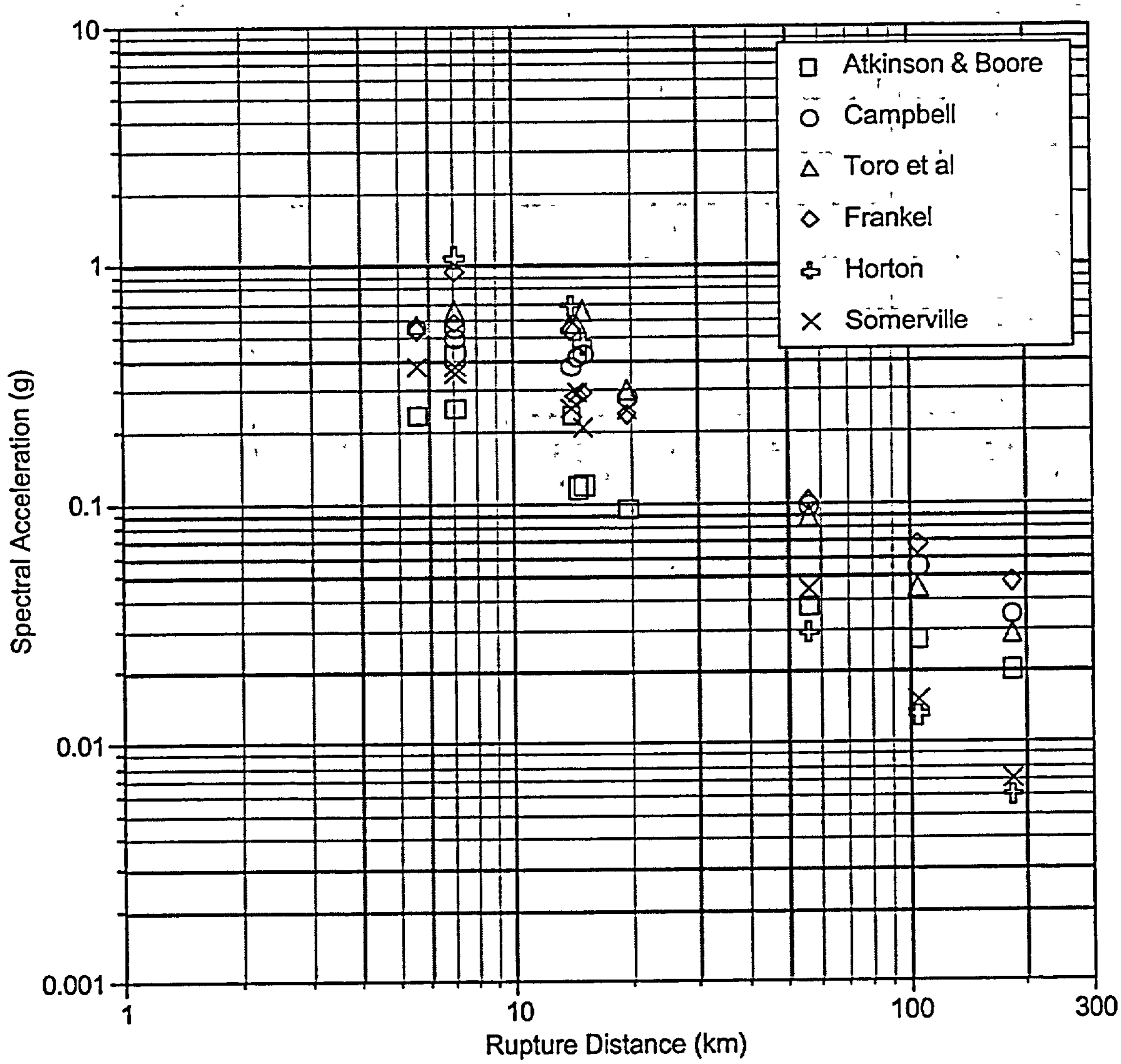


Figure 4.3.3-5b Example of Proponents Model Median Estimates of the 1-Second Period Spectral Acceleration for M_w7.

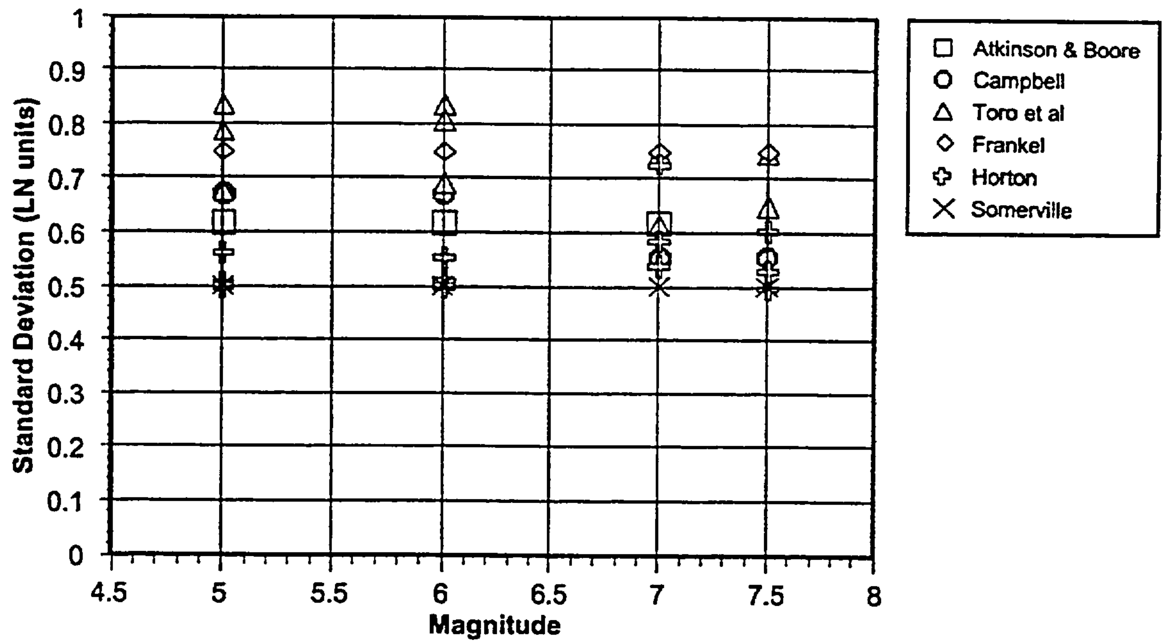


Figure 4.3.3-6a Examples of Proponents Estimates of the Aleatory Variability for the Peak Ground Acceleration Estimates.

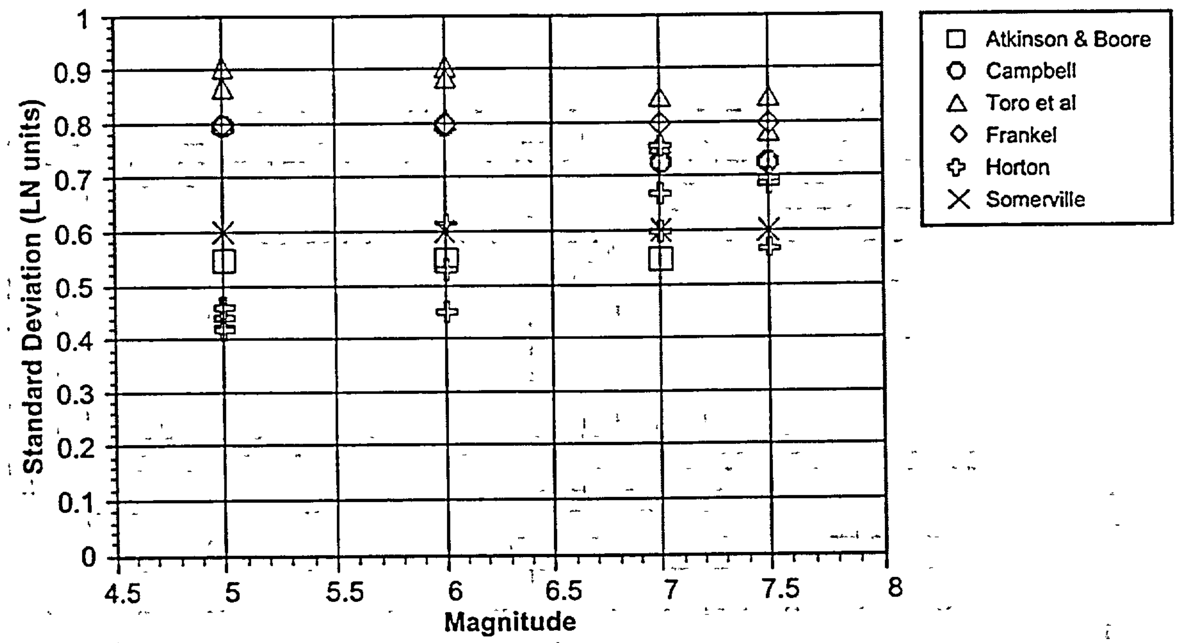


Figure 4.3.3-6b Examples of Proponents Estimates of the Aleatory Variability for the Peak Ground Acceleration Estimates.

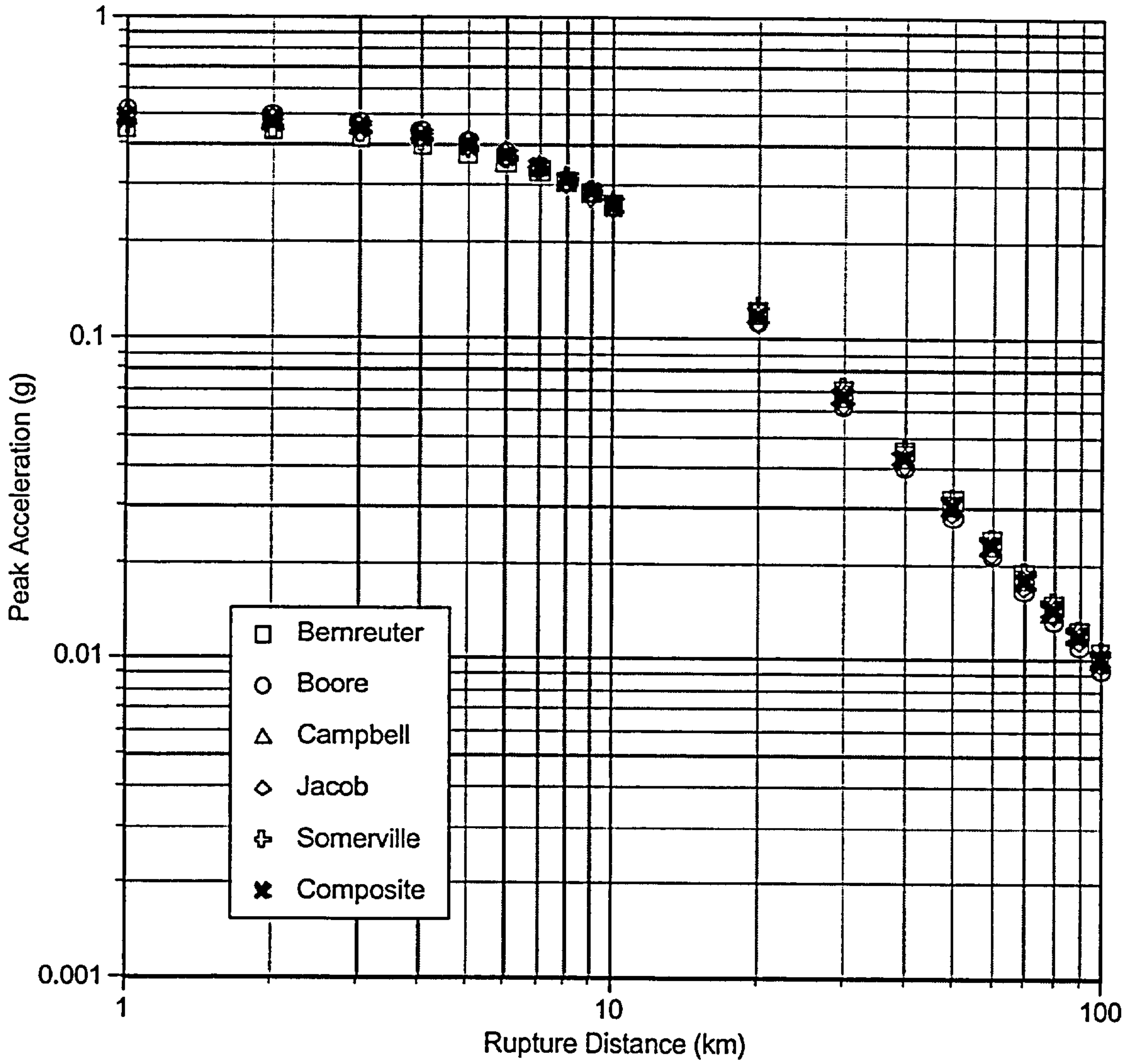


Figure 4.3.4-1 Comparison of Regression Model Fits for the 5 Experts of the Study and the Composite Model, for the Horizontal Component Median Peak Ground Acceleration for Magnitude M_w7.

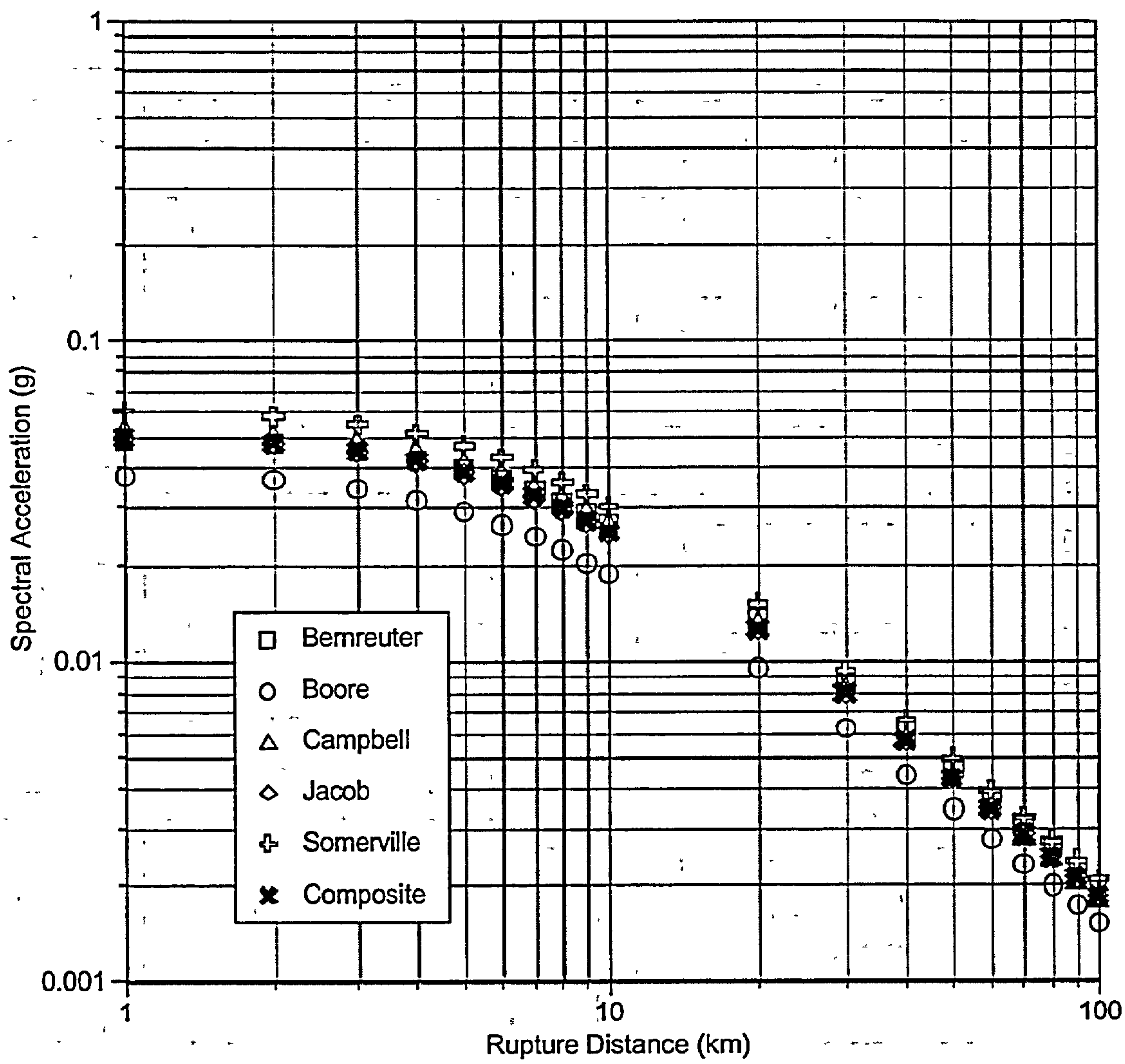


Figure 4.3.4-2 Comparison of Regression Model Fits for the 5 Experts of the Study and the Composite Model, for the Horizontal Component Median Peak Ground Acceleration for Magnitude M_w5.

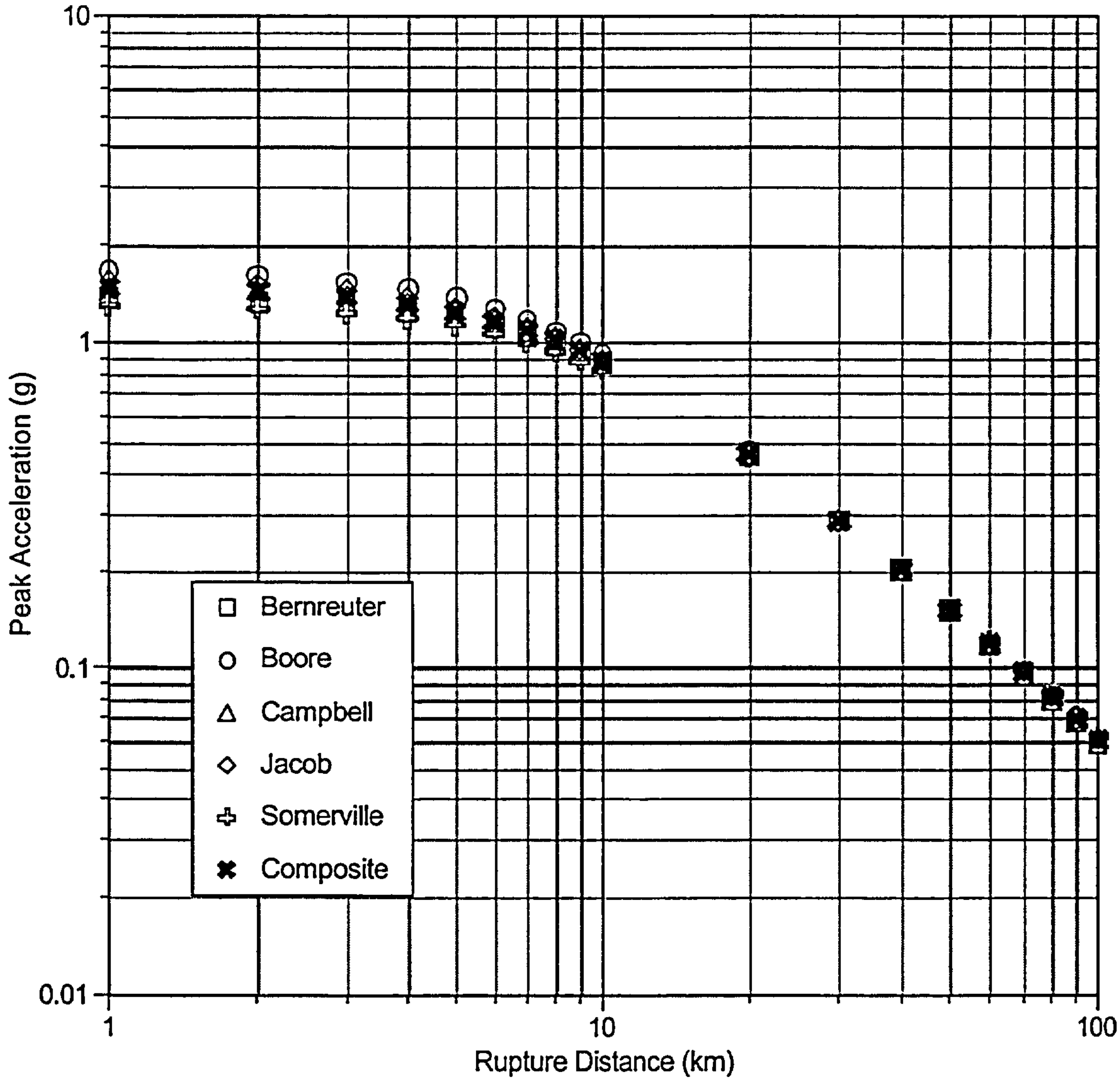


Figure 4.3.4-3 Comparison of Regression Model Fits for the 5 Experts and for the Composite Model, for the Horizontal Component Median 1-Second Period Spectral Acceleration for Magnitude $M_w 7$.

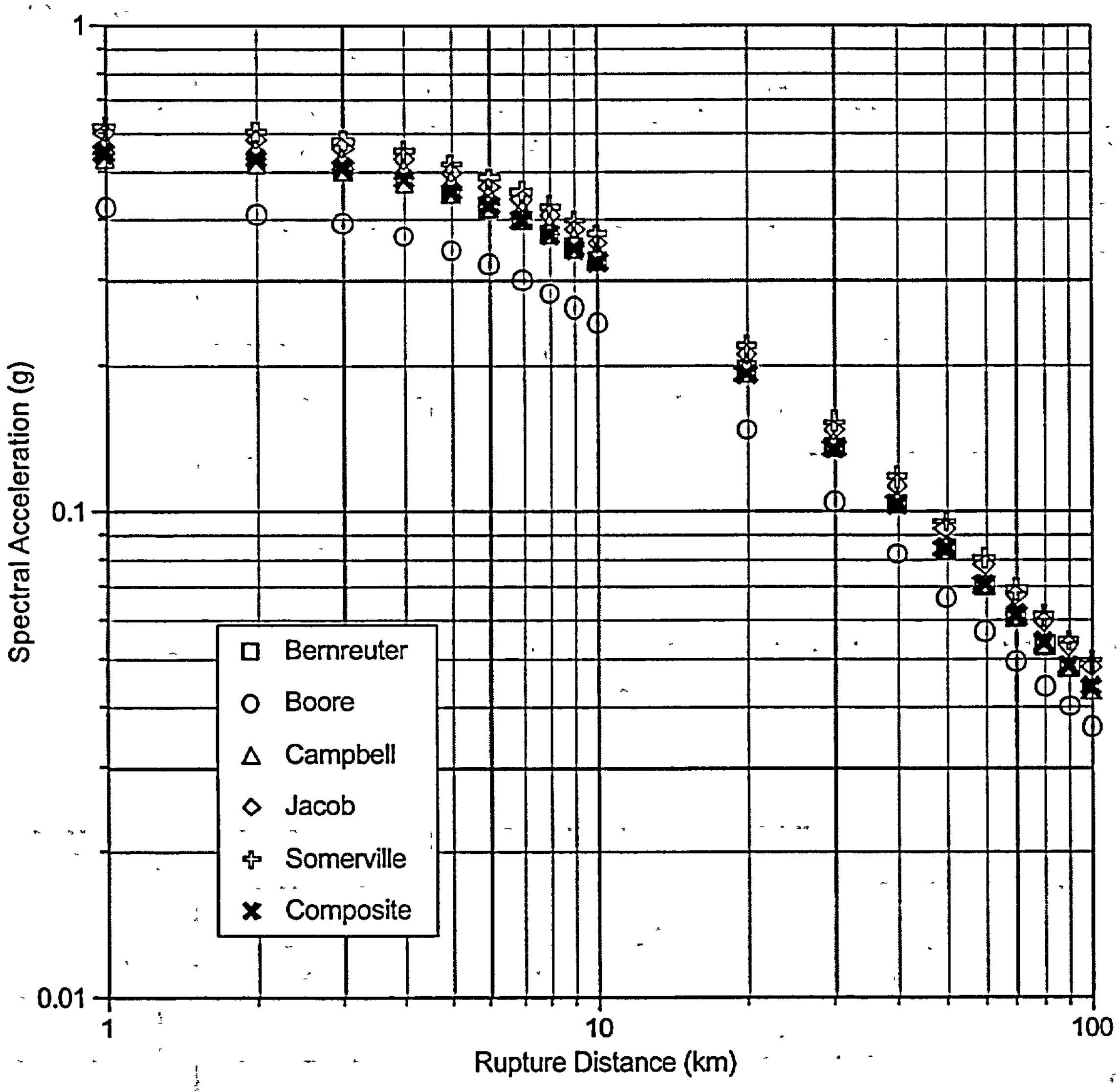


Figure 4.3.4-4 Comparison of Regression Model Fits for the 5 Experts and for the Composite Model, for the Horizontal Component Median 1-Second Period Spectral Acceleration for Magnitude M_w5.

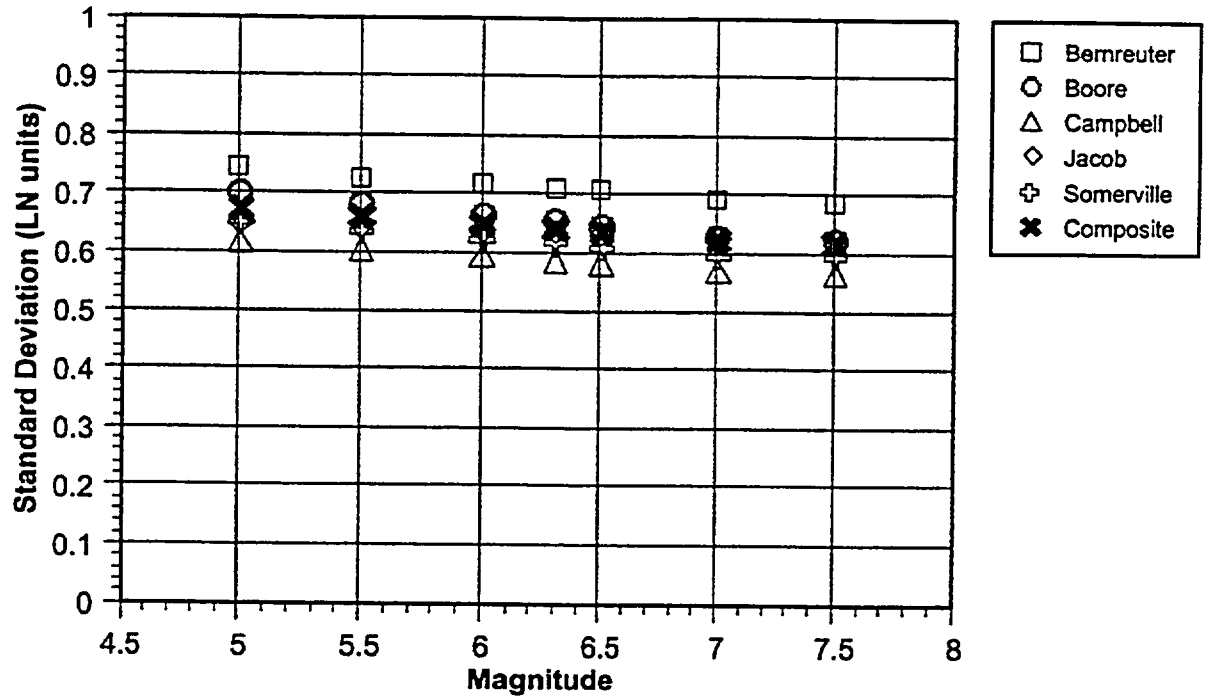


Figure 4.3.4-5 Comparison of the Models of Aleatory Variability for the Horizontal Component of the Peak Acceleration.

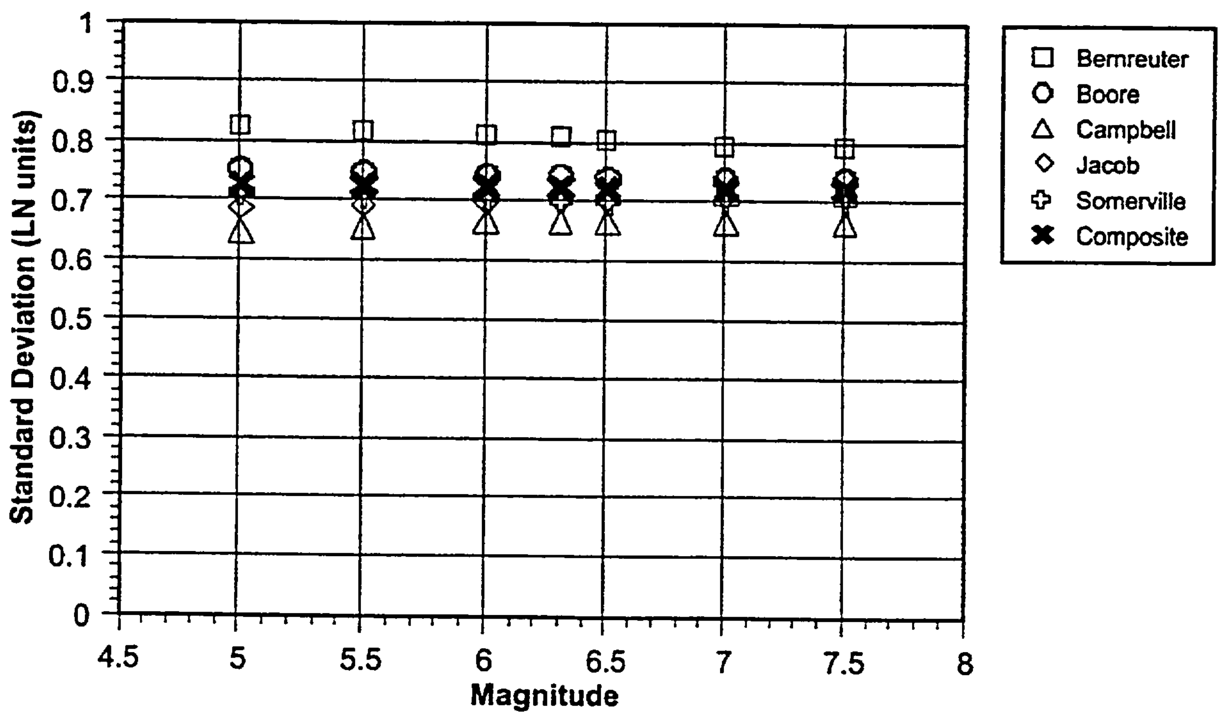


Figure 4.3.4-6 Comparison of the Models of Aleatory Variability for the Horizontal Component of the 1-Second Period Spectral Acceleration.

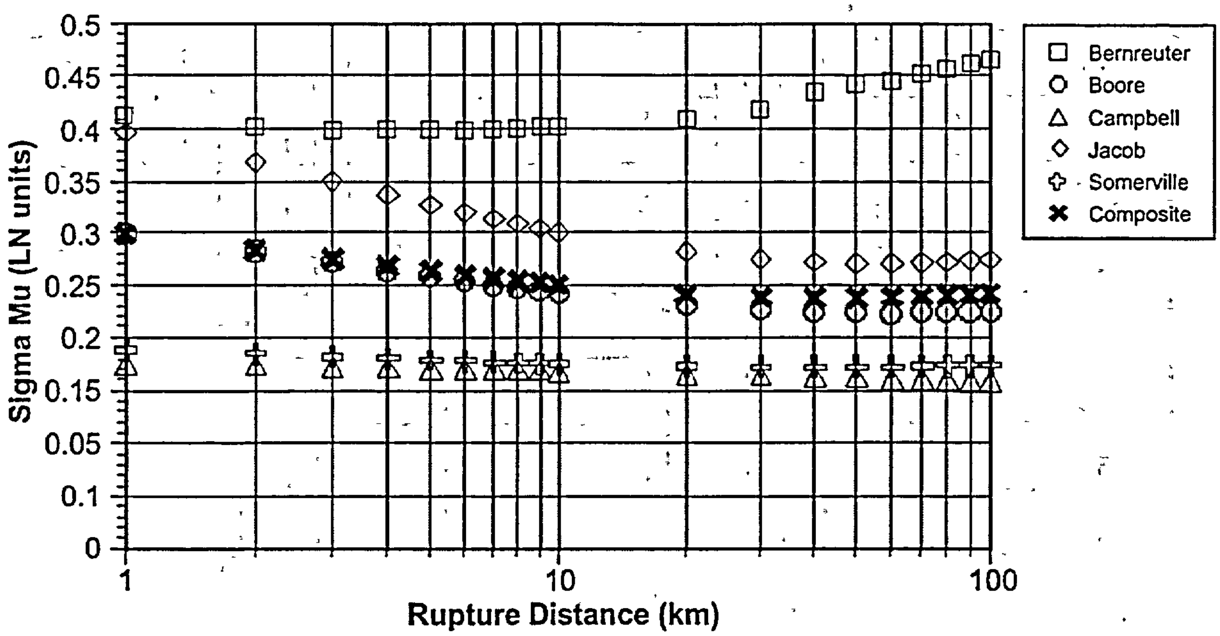


Figure 4.3.4-7 Comparison of the Models of the Epistemic Variability for the Median Estimates of the Horizontal Component of the Peak Ground Acceleration for Magnitude M_w5.

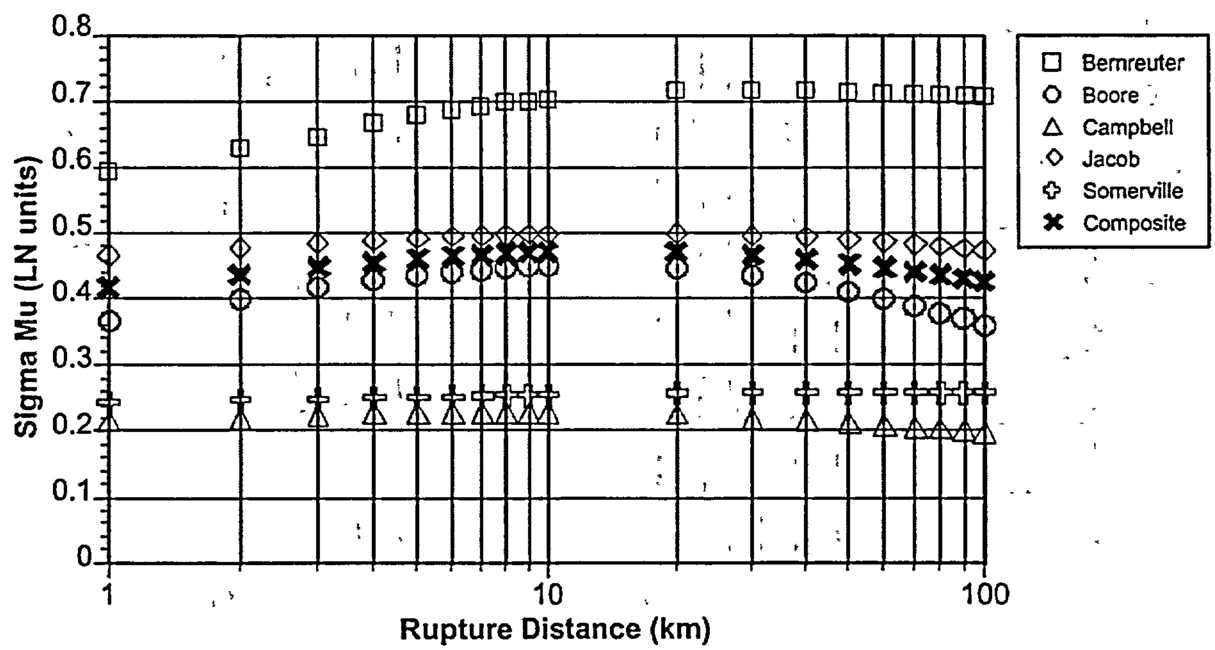


Figure 4.3.4-8 Comparison of the Models of the Epistemic Variability for Median Estimates of the Horizontal Component for the 1-Second Period Spectral Acceleration for Magnitude M_w5.

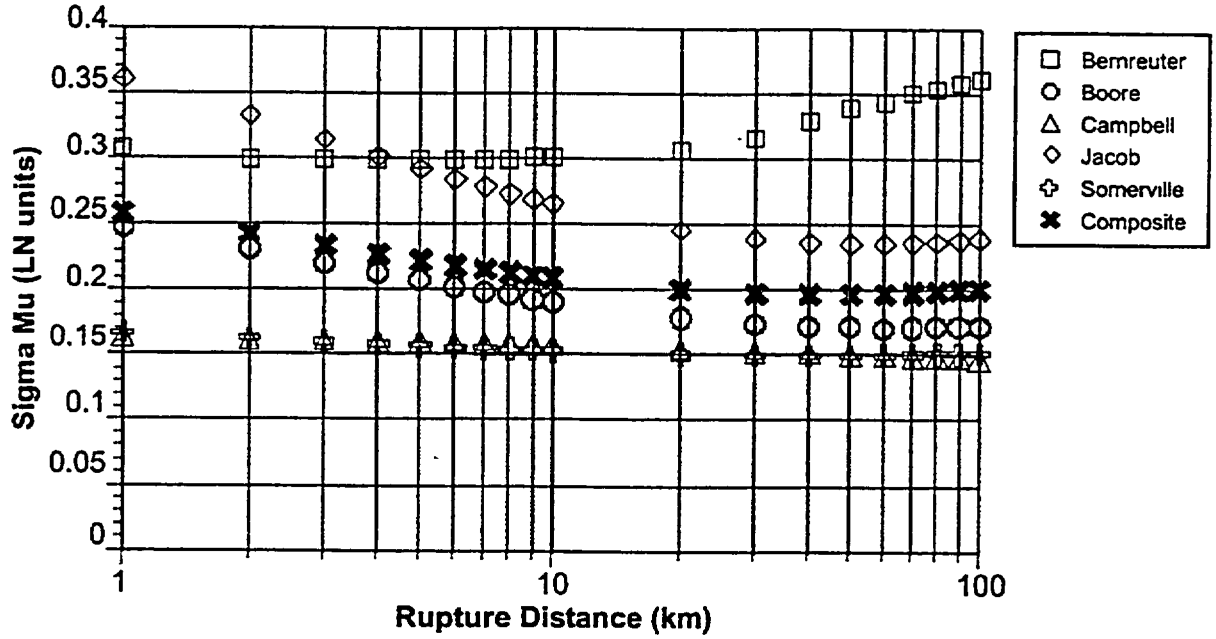


Figure 4.3.4-9 Comparison of the Models of the Epistemic Variability for the Median Estimates of the Horizontal Component of the Peak Ground Acceleration for Magnitude M_w7.

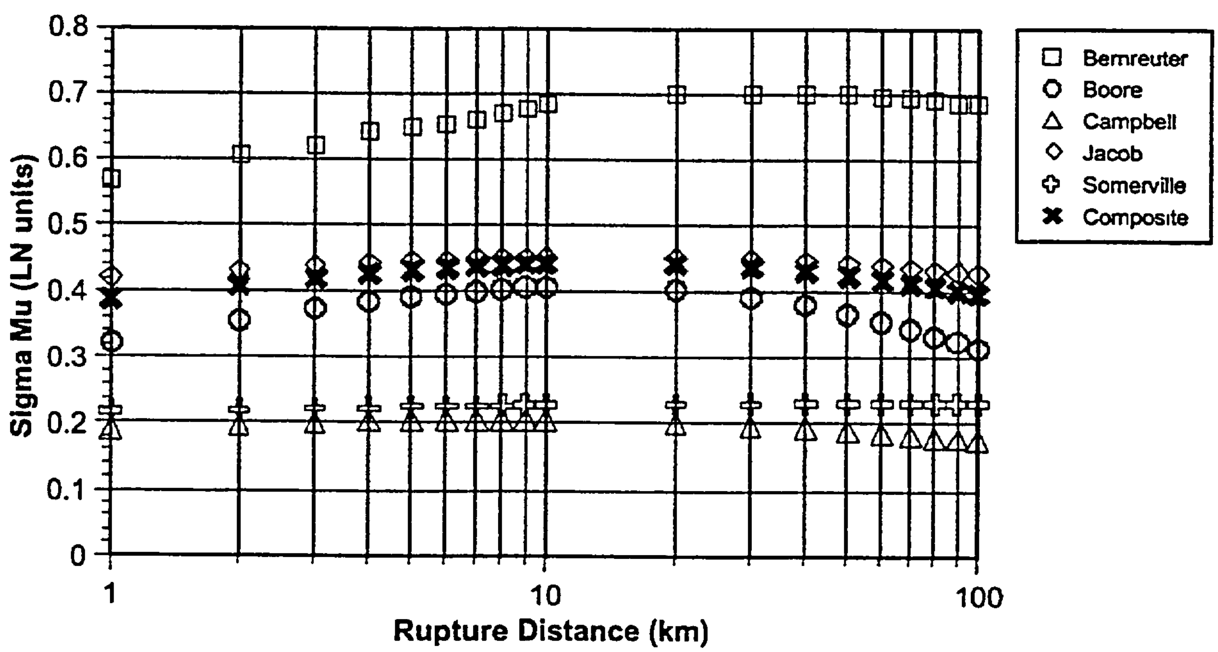


Figure 4.3.4-10 Comparison of the Models of the Epistemic Variability for Median Estimates of the Horizontal Component for the 1-Second Period Spectral Acceleration for Magnitude M_w7.

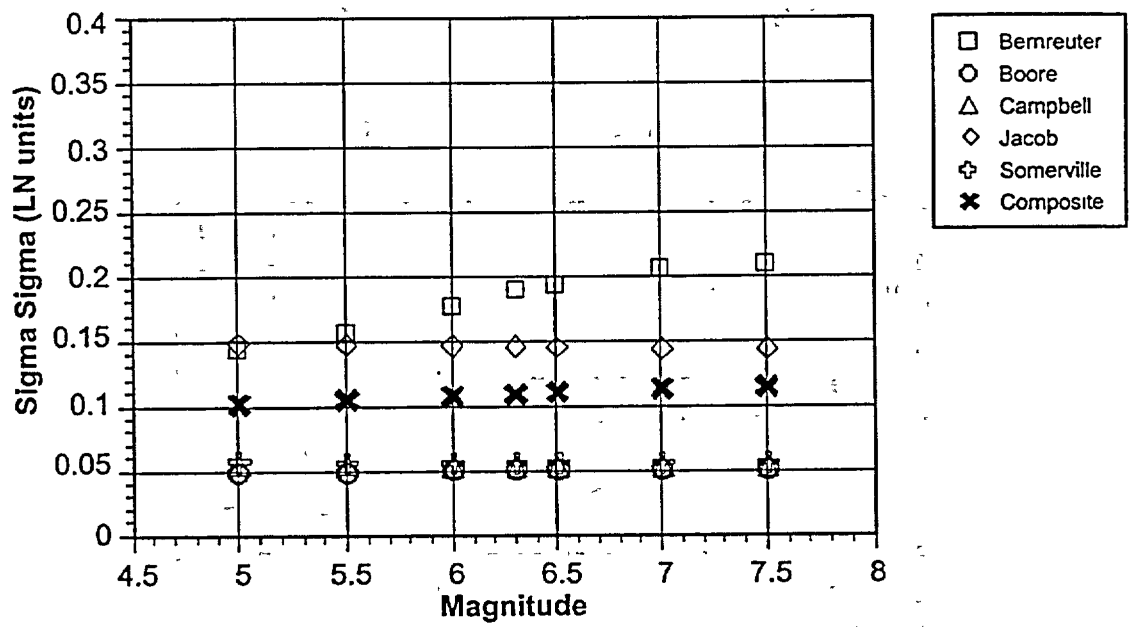


Figure 4.3.4-11 Comparison of the Models for the Epistemic Variability for the Median Estimates of Peak Ground Acceleration.

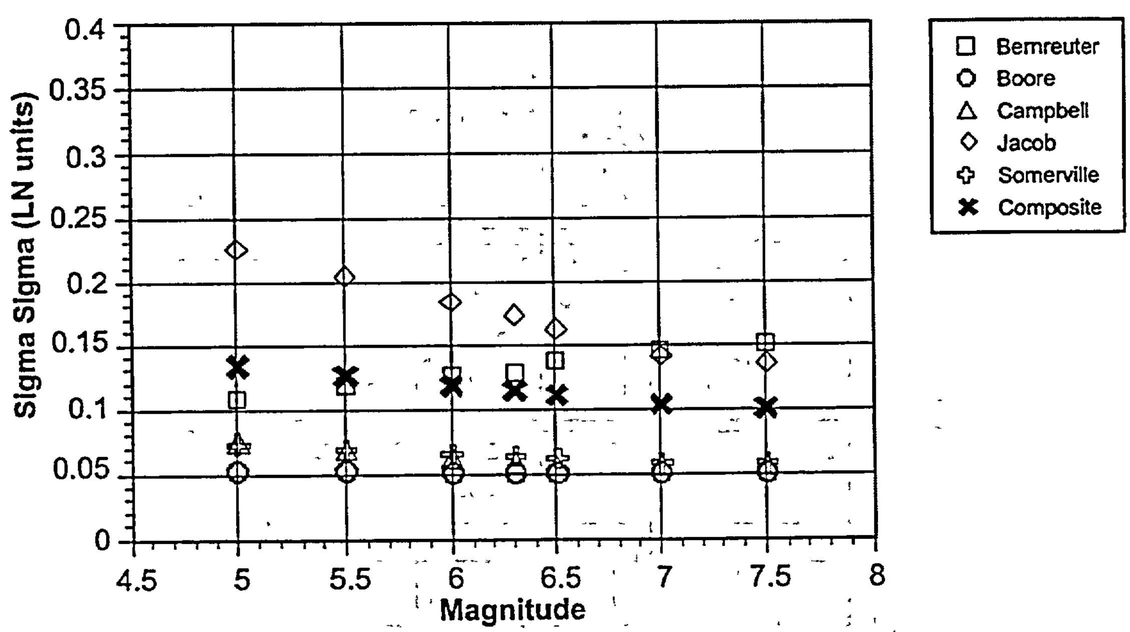


Figure 4.3.4-12 Comparison of the Models for the Epistemic Variability for the Median Estimates of the 1-Second Period Spectral Acceleration.

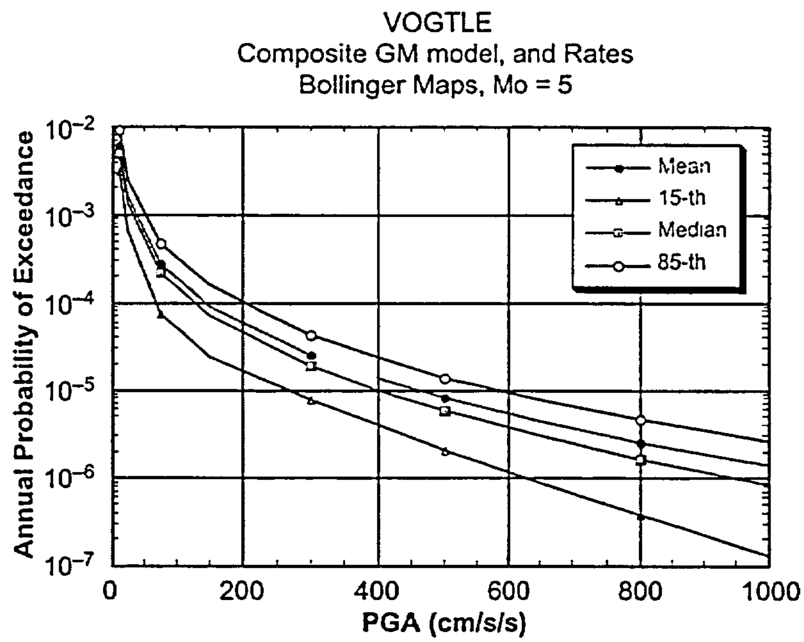


Figure 4.4-1 Probabilistic Hazard Estimates for Vogtle. PGA for Bollinger's Zonation Maps and Seismicity Rates, and Composite Ground Motion Model.

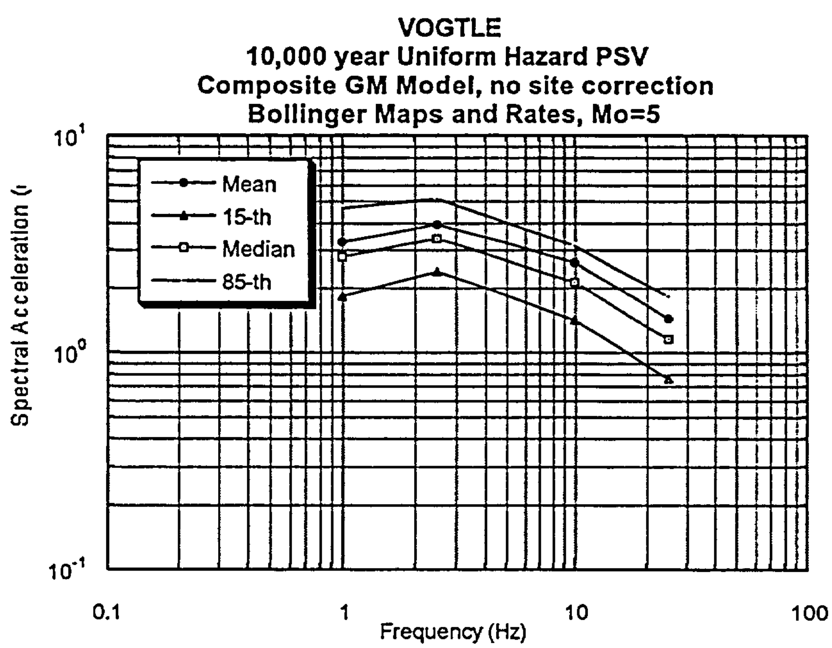


Figure 4.4-2 Probabilistic Hazard Estimates for Vogtle. Uniform Hazard Spectra for Bollinger's Zonation Maps and Seismicity Rates, and Composite Ground Motion Model.

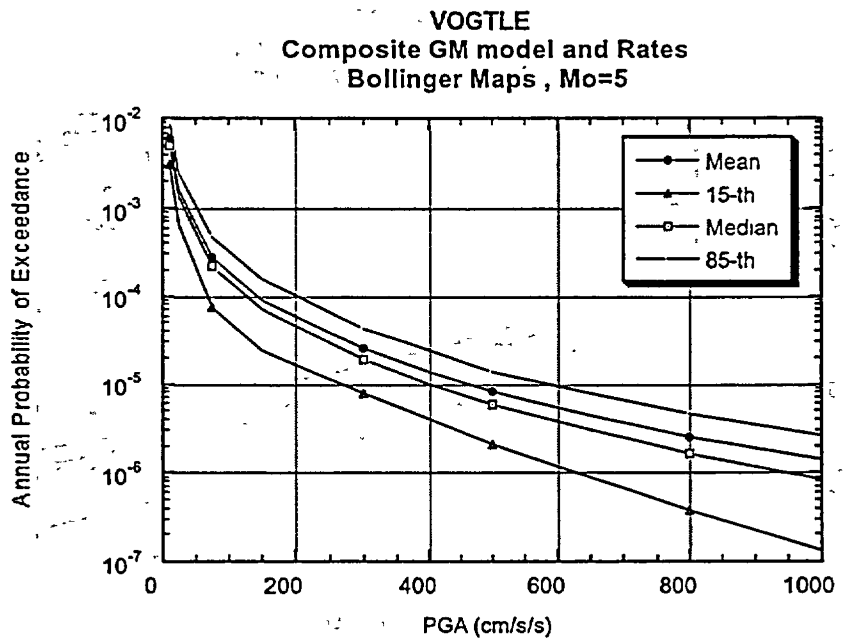


Figure 4.4-3 Probabilistic Hazard Estimates for Vogtle. PGA for Bollinger's Zonation Maps, Composite Seismicity Rates, and Composite Ground Motion Model.

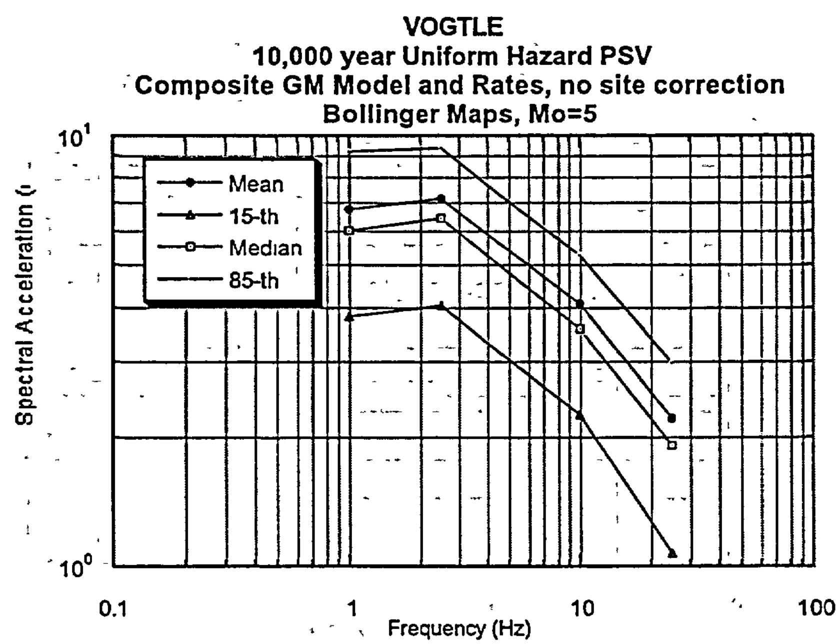


Figure 4.4-4 Probabilistic Hazard Estimates for Vogtle. Uniform Hazard Spectra for Bollinger's Zonation Maps and Composite Seismicity Rates, and Composite Ground Motion Model.

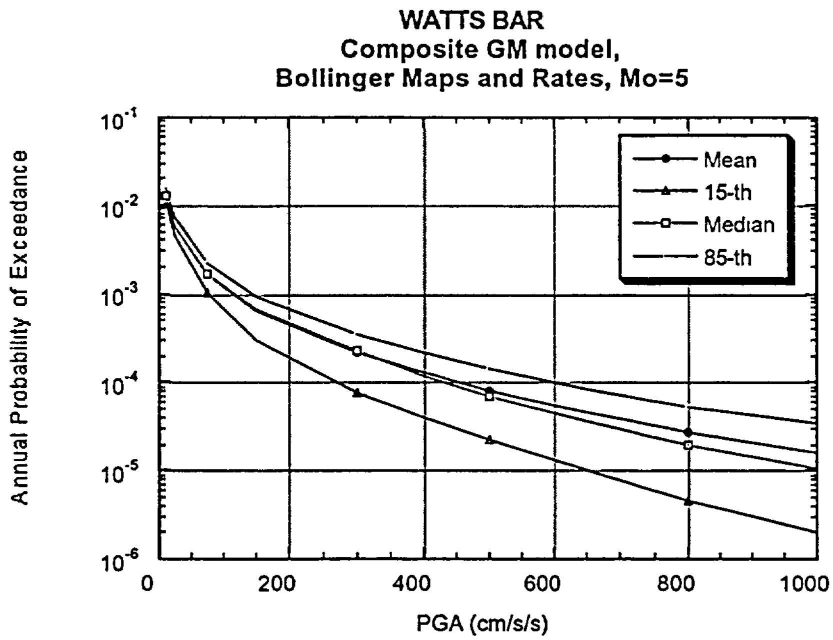


Figure 4.4-5 Probabilistic Hazard Estimates for Watts Bar. PGA for Bollinger's Zonation Maps and Seismicity Rates, and Composite Ground Motion Model.

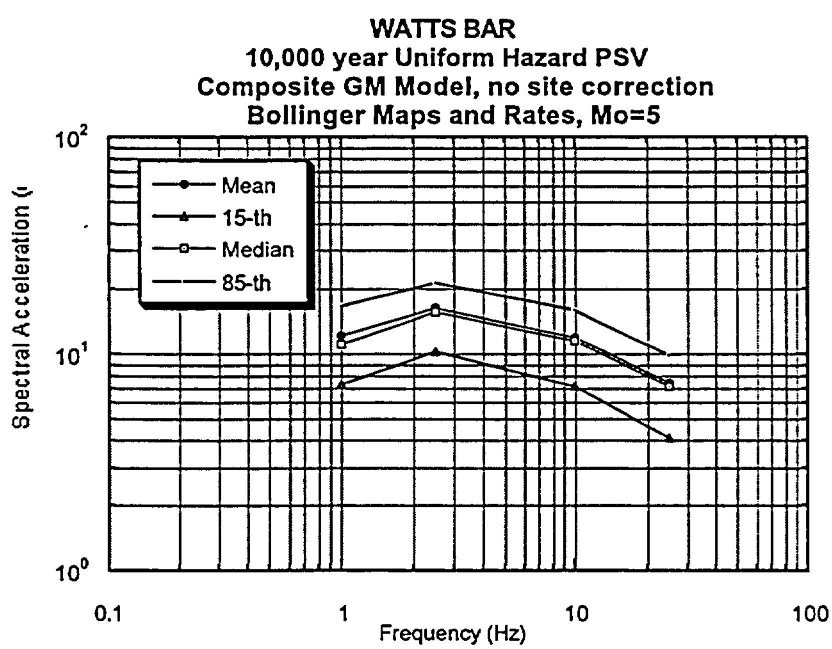


Figure 4.4-6 Probabilistic Hazard Estimates for Watts Bar. Bollinger's Zonation Maps and Seismicity Rates, and Composite Ground Motion Model.

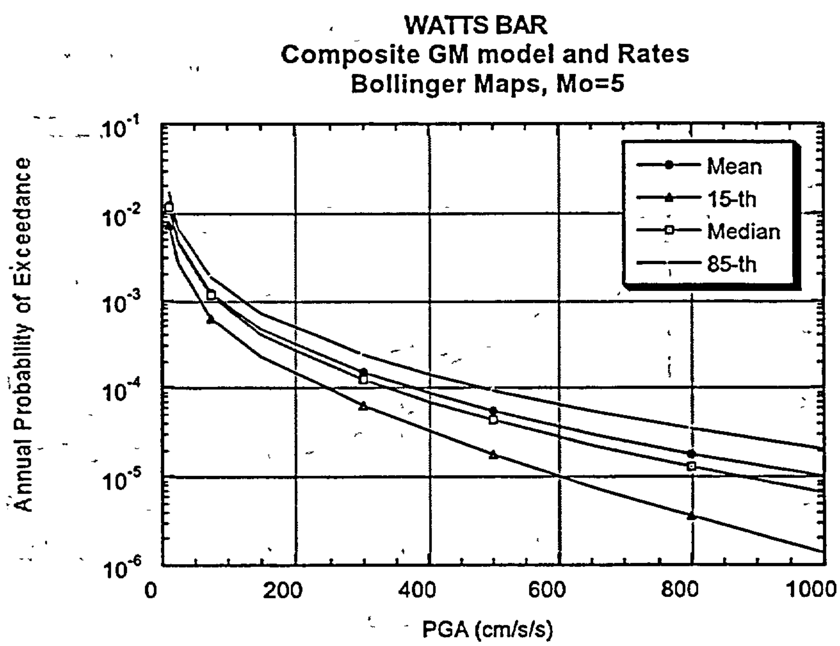


Figure 4.4-7 Probabilistic Hazard Estimates for Watts Bar. PGA for Bollinger's Zonation Maps, Composite Seismicity Rates, and Composite Ground Motion Model.

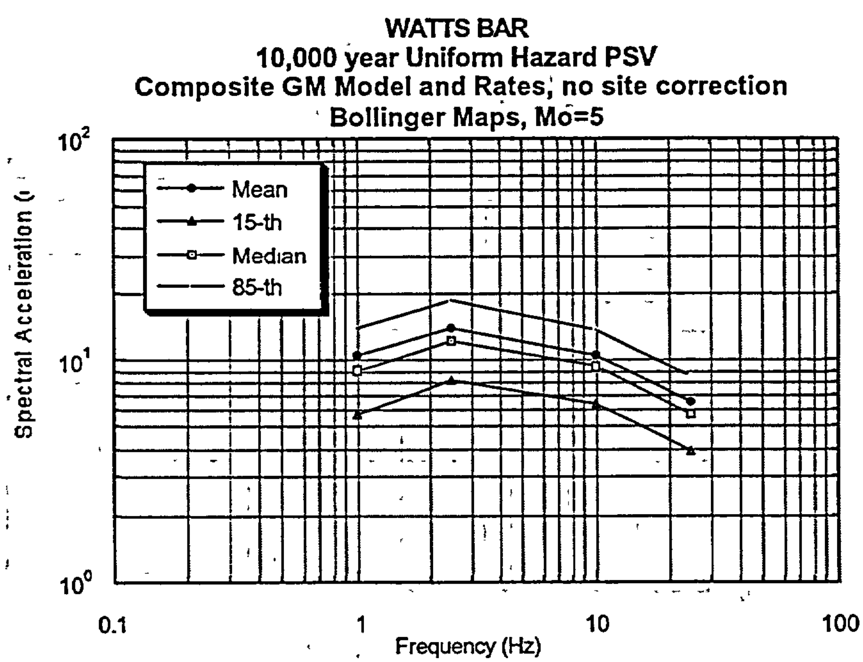


Figure 4.4-8 Probabilistic Hazard Estimates for Vogtle. Uniform Hazard Spectra for Bollinger's Zonation Maps, Composite Seismicity Rates, and Composite Ground Motion Model.

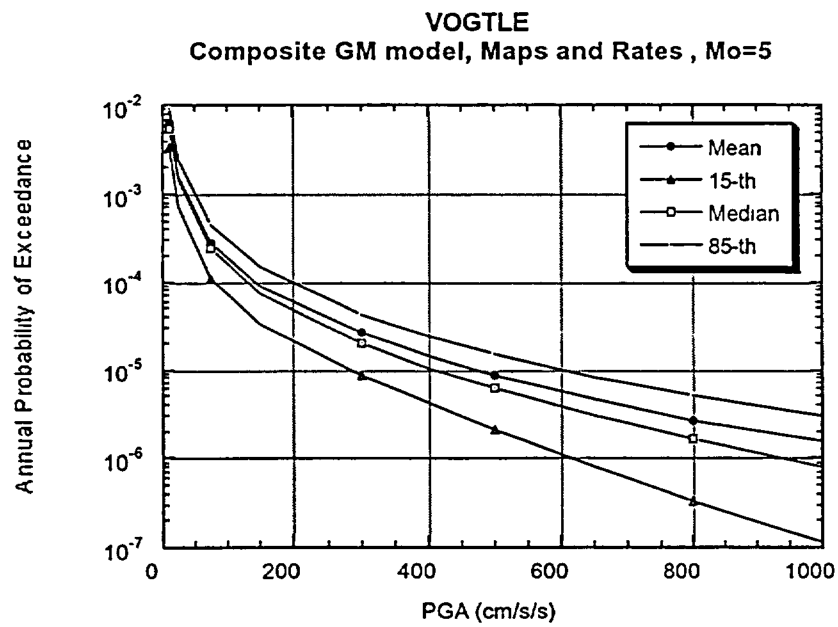


Figure 4.4-9 Probabilistic Hazard Estimates for Vogtle. PGA for Composite Models of Zonation Maps, Seismicity Rates, and Ground Motion Attenuation.

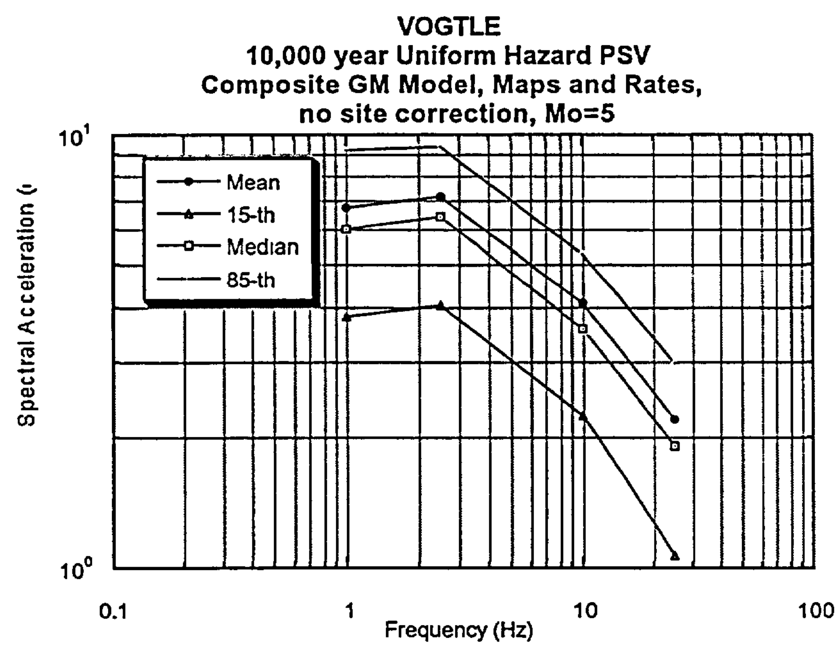


Figure 4.4-10 Probabilistic Hazard Estimates for Vogtle. Uniform Hazard Spectra for Composite Models of Zonation Maps, Seismicity Rates, and Ground Motion Attenuation.

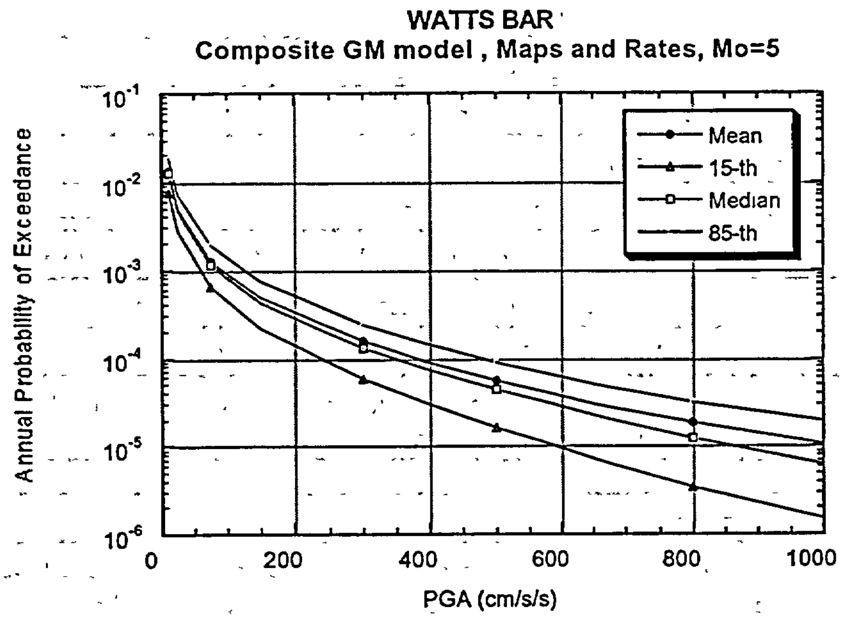


Figure 4.4-11 Probabilistic Hazard Estimates for Watts Bar. PGA for Composite Models of Zonation Maps, Seismicity Rates, and Ground Motion Attenuation.

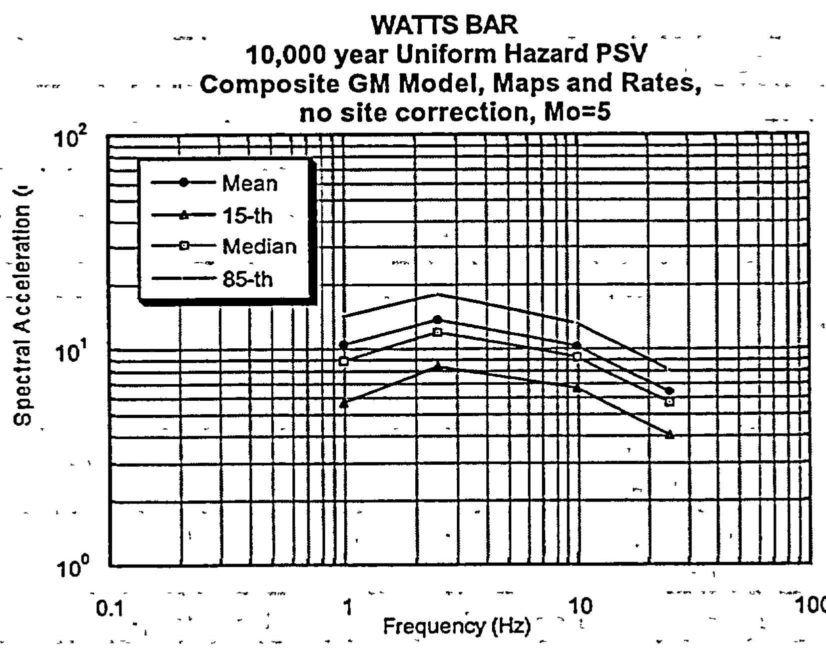


Figure 4.4-12 Probabilistic Hazard Estimates for Watts Bar. Uniform Hazard Spectra for Composite Models of Zonation Maps, Seismicity Rates, and Ground Motion Attenuation.

Table 4.1-1 Expert Evaluators Selection Criteria

1. Knowledge		
I	1.	Experience in tectonic modeling of the EUS.
II	2.	Specialized knowledge of the local geology, seismicity and tectonics of the site.
III	3.	Expertise in probabilistic seismic hazard in the South east US.
IV	4.	Qualified by training and experience.
V	5.	Knowledge of the spectrum of the relevant technical issues and alternative viewpoints.
VI	6.	Familiar with, or willing to learn, broad aims and requirements of PSHA.
VII	7.	Specialized unique knowledge concerning specific scientific issues of relevance.
VIII	8.	Participated in NRC/LLNL/EPRI characterization of the Savannah River site.
IX	9.	Current peer-reviewed publications on relevant topics, such as South East US tectonics, fault mechanics, paleogeology, etc.
2. Lack of bias, credibility		
X	1.	Willing and able to forego proponent role and adopt role as impartial evaluator of data driven hypotheses. Main attributes are impartiality and flexibility.
XI	2.	Level of comfort with probability concepts
XII	3.	Professionally well respected by peers.
3. Interaction abilities		
XIII	1.	Communication and interpersonal skills.
4. Availability		
XIV	1.	Willing and motivated to serve on the panel.
XV	2.	Willing to invest time in panel meetings, and adequate preparation
5. Balance of the Panel		
XVI	1.	Represents the entire community of experts for the relevant issues. Full spectrum of scientific issues.
XVII	2.	"New blood". Balance in panel between experience in PSHA and fresh approaches brought by new individuals.
XVIII	3.	Panel balance with respect to technical expertise: geology, seismology and tectonics of the site.
XIX	4.	Balance of controversial and non-controversial views(proponents).
XX	5.	Panel balance with respect to specific project goals and aims. (i.e. demonstration, finalization and writing up of a guidance document for the methodology).

Table 4.1-2 Weights Assigned to Each of the Criteria of Table 4.1-1

	INDEX OF THE CRITERIA FOR THE SELECTION OF THE EVALUATING EXPERTS															Weighted grade	Relative ranking
	KNOWLEDGE CRITERIA									BIAS, CREDIBILITY			INTER-ACTION	AVAILABILITY			
CRITERIA INDICES	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV		
RELATIVE IMPORTANCE	10	8	7	8	7	8	5	3	2	10	6	4	10	10	6		
NORMALIZED WEIGHT	0 09	0 07	0 06	0 07	0 06	0 07	0 04	0 03	0.02	0.1	0 06	0 04	0 2	0.06	0.04	1	
TOTAL WEIGHT PER CLASS	0 5									0 2			0 2	0 1		1	

Table 4.1-3 Pool of Experts Considered

Alexander	Chapman	Furlong	Jacobs	Lee	Perkins	Seeber	Stephenson	Toksoz
Algermissen	Cluff	Goen	Johnston	Lettis	Phinney	Shandra	Stepp	Van Price
Amick	Coppersmith	Gomberg	Kafka	Litehiser	Pomeroy	Shedlock	Street	Wentworth
Armbruster	Costain	Hanson	Kagan	Long	Powell	Sholz	Swan	Wheeler
Bodin	Dewey	Hatcher	Kimball	McWhorter	Quittmayer	Sibol	Sykes	Youngs
Bollinger	Ebel	Herrmann	Klimkiewcz	Mitchel	Rial	Simpson	Talwani	Zoback, Marilu
Braile	Ellis	Holt	Krinitzsky	Newell	Rice	Smith	Thenhaus	Zoback, Marc
Calhoun	Frankel	Jackson	Lawson	Obermeier	Schwartz	Statton	Thompson	

Table 4.1-4 Final Selection of Expert Evaluators for the Seismic Source Characterization

GIL BOLLINGER,	Consultant, formerly professor of seismology Virginia Polytechnic Institute, Blacksburg, Virginia.
MARTIN CHAPMAN	Professor of geophysics, Virginia Polytechnic Institute. Blacksburg, Virginia.
KEVIN COPPERSMITH	Geologist, GEOMATRIX Consultants, San Francisco. California.
KLAUS JACOB	Geophysicist, Lamont Doherty Earth Observatory of Columbia University, Palisades, New York.
PRADEEP TALWANI	Professor of geophysics, University of South Carolina, Columbia, South Carolina.

Table 4.2.2-1 Detailed Road Map for the Performance of the TIP Project

1. Select Expert Evaluators (EVAs)

Define selection criteria for pool

Build pool of experts

Define selection criteria for evaluators

Rank and select according to criteria

Set contracts

2. Workshop #1
Augusta Ga, June 17-18

Scope

—First set the stage for the characterization of the general regional seismic environment

—Second, concentrate on specific sites:

—Vogtle and Watts Bar (influenced by Charleston and E. Tennessee seismic zones, respectively).

—Concentrate on defining the geometry of seismic sources

Communicate that the goal is to formulate a consensus set of geometry models simple enough to allow an interactive, group treatment of the occurrence rate information.

Preparation

— Review existing information.

— Draft issues. TFI identify issues and proponents

— Interact with evaluators and other potential workshop presenters

— Workshop participants to better define issues.

— Assign tasks for presentations and preparation of material

Conduct of Workshop 1

— Information exchange

— Discuss proponents' models

— Discuss issues and data interpretations

Table 4.2.2-1 Detailed Road Map for the Performance of the TIP Project *(cont'd)*

Assign tasks to experts and analysts for writing white papers on special issues and data Interpretations (Including processing of catalogues, smoothing, etc...). Select a small set of issues and separate individuals develop the pros and cons.

— Debrief experts to get input on what worked and what did not.

3. Exchange And Review Of White Papers By All Participants

Specific, focused on one side of the issues

Exchanges take place by phone, small meetings, E-mail, etc.

4. Expert Evaluators Formulate Ranges Of Models (Geometry Only)

Each expert evaluator formulates own range of zonation models, including formulation of alternative models for the expression of the uncertainty.

The evaluators prepare a simple but complete documentation of their interpretations, to be available to all the participants prior to the workshop # 2.

Generic simple calculations, sensitivity.

TFI will visit the experts to help make sure that level of effort is fairly uniform.

5. Workshop #2. Source Geometry Models (Denver, CO, Sept. 5-6)

Scope

— Finalize the consensus range of geometry models for the region and specific sites

— Develop regional rates information for the consensus sources

— Prepare for site specific characterization

Preparation
See steps 3 and 4 above
Conduct of Workshop # 2

—Expert Evaluators present their range of regional models

- Presentation, documentation
- Interaction
- Challenge, clarifications, update

— TFI develops ranges of consensus regional models, interactively with EVAs 'are asked to weigh (weight?) the various maps and/or set probabilities of existence, probabilities of activity for the sources in each consensus map.

Table 4.2.2-1 **Detailed Road Map for the Performance of the TIP Project** *(cont'd)*

5. Start writing guidance document

Site specific information exchange

— review existing information

— identify issues relative to site specific case

— proponents views, presentations

TFI develops a consensus "near-site" geometry to permit concentrating on only a few simple rate parameters (a, b, or rate(m1), rate(m2), and max magnitude distributions)

Conduct a mock-up, yet realistic,(i.e. On a single simple parameter) elicitation.

Assign tasks for discussion of selected issues: white papers, pros and cons
Example: seismicity parameters, completeness of the catalogues, uncertainty in the rate estimates, (all types of uncertainties), smoothing, algorithms for estimation etc.

De-briefing the EVAs, collect comments, evaluations, recommendations.

Get directions from experts on follow-up calculations.

6. Analysts And Selected Experts Prepare Seismicity Rate Information

The purpose is to develop necessary information for the Eva to formulate their estimates with all the uncertainties, possibly through the use of alternative models

Standard analyses of catalogues for zones

Sensitivity on catalogues for zones

Sensitivity on other parameters. (smoothing)

Preliminary Hazard analysis with consensus map and analyst's seismicity rates, sensitivity analysis de-aggregation. (Distances close, boundaries etc.,

Focus on site specific estimates

7. Expert Evaluators Review Seismicity Rate Information

Eva's get to review the information generated in 6 above

8. Workshop #3, Local Rates of Seismicity
Analysts/TFI presents regional seismicity rate models.
Interaction, discussion and finalize with experts.

Analyst presents a sensitivity analysis, based on agreed upon models so far, to determine which are the most important rate parameters for the sites considered.

Table 4.2.2-1 Detailed Road Map for the Performance of the TIP Project *(cont'd)*

Expert evaluators, present models for site specific estimates. For a few selected common source zones (say Giles County, Charleston...). This is analogous to concentrating on estimating the ground motion for one pair of M-R at a time.

TFI develops consensus model ranges for regional seismicity rates.

Experts present their site specific models

TFI develops site specific consensus rate characterization:

— zonation (background, zones boundaries)

— seismicity rates.

Debrief the Evas. Collect comments, evaluation, recommendations.

9. Analysts Finalize. Perform Update Calculations

Update calculations

Brief documentation

Send to evaluators for review and comments

Obtain evaluation of the process from the Evas. What worked and what did not. Recommendations

Table 4.2.3-1 List of Participants at Workshop 1

PSHA SOURCE CHARACTERIZATION TRIAL IMPLEMENTATION: KNOWLEDGE DISSEMINATION WORKSHOP

June 17-19, 1996

Augusta, Georgia

Technical Facilitator/Integrator (TFI) Team	
Don Bernreuter	Lawrence Livermore National Laboratory
Bill Foxall	Lawrence Livermore National Laboratory
Jean Savy	Lawrence Livermore National Laboratory
Allin Cornell	Consultant, CAC Corp., California
Expert Evaluators (EVAs)	
Gill Bollinger	Consultant, Buffalo, Wyoming
Martin Chapman	Virginia Polytechnic Institute
Kevin Coppersmith	Geomatrix Consultants
Klaus Jacob	Lamont Doherty Earth Observatory
Pradeep Talwani	University of South Carolina
Nuclear Regulatory Commission	
Ernst Zurflueh	Nuclear Regulatory Commission/Office of Nuclear Regulatory Research
Other Presenters and Participants	
Dave Amick	Science Applications International Corp.,, Augusta
Bob Gelinas	Science Applications International Corp.,, Augusta
Arch Johnston	Center for Earthquake Research and Information
Richard Lee	Savannah River Site, Westinghouse
Ron Marple	University of South Carolina
Jimmy Martin	Virginia Polytechnic Institute
Chuck Mueller	United State Geological Survey, Denver
Mark Petersen	California Department of Mines & Geology
Chris Powell	University of North Carolina
Dale Stephenson	Savannah River Site, Westinghouse
Alice Stievi	Savannah River Site, Westinghouse
Gordana Vlahovic	University of North Carolina

Table 4.2.6-1 List of Participants to the PSHA Source Characterization Trial Implementation Project Workshop III

Germantown, MD
January 15-17, 1997

Don Bernreuter Lawrence Livermore National Laboratory P.O. Box 808, L-203 Livermore, CA 94550	Jeff Kimball Department of Energy Facilities Eng. Division - DP-31 19901 Germantown Road Germantown, MD 20875
Gil Bollinger P.O. Box 806 - 39 Shady Lane Buffalo, WY 82834	Klaus Jacob LDEO of Columbia University Route 9W Palisades, NY 10964
Martin Chapman VPI - Dept. Geol Science 4044 Derring Hall, VPI Blacksburg, VA 24061	Cliff Munson U.S. NRC - Office of NRR Washington, DC 20555
Kevin Coppersmith Geomatrix 100 Pine Street, 10th Floor San Francisco, CA 94111	Jean Savy LLNL P.O. Box 808, L-203 Livermore, CA 94550
Allin Cornell CAC/Stanford 110 Coquito Avenue Portola Valley, CA 94025	Pradeep Talwani University of S. Carolina Geological Sciences Columbia, SC 29208
Bill Foxall Lawrence Livermore National Lab. P.O. Box 808 - L202 Livermore, CA 94550	E. Zurflueh U. S. NRC - Office of RES Mail Stop T-10L1 Washington, DC 20555
Bakr Ibrahim U.S. NRC - Office of NMSS Washington, DC 20555	

Table 4.2.6-2 Description of the Minimum Set Zones

EARTHQUAKE SOURCE ZONE MAPS
Explanatory Notes on Zone Maps

1. General

There are six maps showing the source zones significant to Vogtle and eight showing the source zones for Watts Bar. The maps shown in Figure 4.2.6-1a through m are intended to show the individual zone geometries and the spatial relationships among the zones. The maps are not intended to represent any particular source model scenarios (i.e. particular combinations of the zones); the scenarios are summarized in the logic trees shown in Figure 4.2.-2a through e.

2. Charleston

- Zone 1E is not shown. It *coexists* with 1A and comprises 2 areas, which are coincident with the NE and SW areas of 1B (Vogtle Map 5)

3. SC-GA Piedmont/Coastal Plain

- 3A and 3C are exclusive alternatives
- 3A-2 and 3A-2 represent fuzzy boundary of 3A. Possible combinations are:

    (3A-1)

    (3A-1) + (3A-2)

    (3A-1) + (3A-2) + (3A-3)

- 3B (Vogtle Map 3) can exist without 3A or 3C
- 3B forms the background to 3A and 3C (Vogtle Maps 1 and 2), so the following combinations are possible:

    3B

    3A, (3B-3A)

    3C, (3B-3C)

- Zone 7 forms the background to all Zone 3 alternatives and to Zone 6

Table 4.2.6-2 Description of the Minimum Set Zones *(cont'd)*

4. <u>ETSZ</u>

There are 5 basic alternative zone definitions for the ETSZ, 4A, 4B, 4C, 4D, and 4E (see Attachment 4), all of which have the same overall bounding geometry as Zone 4A, which is shown on the Watts Bar maps.

- 4A-2 and 4A-3 represent a fuzzy boundary. Possible combinations are:

  (4A-1) + (4A-2) + (4A-3) (Watts Bar Map 1)

  (4A-1) + (4A-2) (Watts Bar Map 2)

  (4A-1) (Watts Bar Map 3)

- Zone 4B is made up of two areas:

  the geometry of 4B-1 is identical to 4A-1

  the geometry of 4B-2 is identical to (4A-2) + (4A-3)

- possible combinations are:

  (4B-1)

  (4B-1) + (4B-2)

- The geometry of Zone 4C is identical to (4A-1) + (4A-2) + (4A-3), within which the sources are defined as eight discrete faults

- The geometry of Zone 4D is identical to (4A-1) + (4A-2) + (4A-3), within which the recurrence rate is inhomogeneous (rate spatial distribution determined by smoothing the seismicity map), rather than homogeneous as in each part of 4A, 4B, and 4E.

- The bounding geometry of Zone 4E is identical to (4A-1) + (4A-2) + (4A-3), but has a graded boundary defined by three cylindrical sources (Bender).

5. <u>Appalachian/Central US</u>

- Zone 5 forms the background to the ETSZ, and comprises three areas. The alternative combinations are:

  (5-1), (5-2), (5-3)

  (5-1) + (5-2), (5-3)

  (5-1), (5-2) + (5-3)

  (5-1) + (5-2) + (5-3)

- For all 4A alternative definitions for the ETSZ other than (4A-1) + (4A-2) + (4A-3) and for definition (4B-1), seismicity in the remaining Zone 4 areas [(4A-2) or (4A-2) + (4A-3), (4B-2)] is included in Zone 5 (e.g., Watts Bar Maps 2, 3, 7, 8)

- the Zone 5 alternatives can exists with or without a small, separate Giles County zone (not shown).

Table 4.3.1-1 Point Estimates Considered in the 1994 Trial Application

m_b=5.5

Period	5 km	20 km	70 km	200 km
1.0 Hz	-	x	x	x
2.5 Hz	-	x	-	-
10 Hz	-	x	x	-
25 Hz	-	x	-	-
PGA	-	-	x	-

m_b=7.0

Period	5 km	20 km	70 km	200 km
1.0 Hz	-	x	x	x
2.5 Hz	-	x	-	-
10 Hz	-	x	x	-
25 Hz	-	x	-	-
PGA	-	-	x	-

Table 4.3.2-1 List of Candidates for Ground Motion Experts Considered for the TIP Project

Name	Affiliation	Involvement in 1994 Study
Gail Atkinson	Carlton Univ.	Evaluator
Don Bernreuter	Lawrence Livermore National Laboratory	Evaluator
David Boore	US Geological Survey	TF Team
Ken Campbell	EQE	Evaluator
Art Frankel	US Geological Survey	None
Klaus Jacob	NCEER	None
Bill Joyner	US Geological Survey	Evaluator
Walt Silva	Pacific Engineering and Analysis	Evaluator
Paul Somerville	Woodward-Clyde Federal Services	Evaluator
Gabriel Toro	Risk Engineering	TF Team
Bob Youngs	Geomatrix Consultants	None

Table 4.3.3-1 Proponent Models

Atkinson and Boore	Point source stochastic
Campbell	Hybrid (empirical and point source Stochastic
Frankel	Point source stochastic
Horton	Finite source numerical
EPRI	Point source stochastic
Somerville	Finite source numerical

Table 4.3.3-2 Point Estimate Matrix

	DEPTH (KM)		
DISTANCE[1] (km)	5	10	20
0	x	x	x
10	x	x	x
20		x	x
70		x	
120		x	
200		x	

[1]Horizontal distance from surface expression of fault (up-dip extension).

Table 4.3.3-3 ENA Velocity Profile

LAYER	DEPTH TO TOP (km)	V_S (km/s)	V_P (km/s)	DENSITY (g/cm^3)
1	0	2.83	4.9	2.52
2	1	3.58	6.2	2.73
3	80	3.81	6.6	2.79
4	220	4.1	7.1	2.87
5	1000	4.68	8.1	3.38

Source: EPRI (1993)

Table 4.3.3-4 Q Model

High	1000 $f^{0.3}$
Median	670 $f^{0.33}$
Low	400 $f^{0.4}$

Table 4.3.3-5 132 Case Definitions for Point Estimates

(1) X-distance is the horizontal distance from the surface "trace" of the fault.

(2) HW refers to hanging wall location in reverse faulting, FW to footwall location in reverse faulting, and SS to strike-slip faulting.

(3) R_{Rupt} is rupture distance, the closest distance from the site to the fault rupture surface; R_{JB} is the Joyner-Boore distance, the closest distance to the surface projection of the rupture surface; R_{Seis} is seismogenic distance, the closest distance to the assumed seismogenic part of the rupture surface, here used as the part of the rupture surface that lies at least 3 km below the ground surface; R_{Hypo} is hypocentral distance.

132 case definitions for point estimates

CASE NO.	MAG	DEPTH (KM)	X-DISTANCE[1] (KM)	FAULTING STYLE[2]	R_{RUPT}[3] (KM)	R_{JB}[3] (KM)	R_{SEIS}[3] (KM)	R_{HYPO}[3] (KM)
1	5.0	5.0	0	FW	5.1	5.1	3.6	6.18
2	5.0	5.0	10	FW	14.1	14.1	13.6	14.51
3	6.0	5.0	0	FW	3.0	4.2	2.1	5.43
4	6.0	5.0	10	FW	12.3	13.3	12.1	13.12
5	7.0	5.0	0	FW	0.0	4.2	0.0	6.00
6	7.0	5.0	10	FW	10.0	13.3	10.0	11.66
7	7.5	5.0	0	FW	0.0	4.2	0.0	8.68
8	7.5	5.0	10	FW	10.0	13.3	10.0	13.24
9	5.0	10.0	0	FW	12.2	12.2	8.6	13.21
10	5.0	10.0	10	FW	20.5	20.5	18.6	21.14
11	5.0	10.0	20	FW	29.9	29.9	28.6	30.32
12	5.0	10.0	70	FW	79.1	79.1	78.6	79.26
13	5.0	10.0	120	FW	128.9	128.9	128.6	129.00
14	5.0	10.0	200	FW	208.8	208.8	208.6	208.90
15	6.0	10.0	0	FW	10.1	10.1	7.1	12.28
16	6.0	10.0	10	FW	18.6	18.6	17.1	19.83
17	6.0	10.0	20	FW	28.1	28.1	27.1	28.91
18	6.0	10.0	70	FW	77.5	77.5	77.1	77.77
19	6.0	10.0	120	FW	127.3	127.3	127.1	127.50
20	6.0	10.0	200	FW	207.3	207.3	207.1	207.40

132 case definitions for point estimates

CASE NO.	MAG	DEPTH (KM)	X-DISTANCE[1] (KM)	FAULTING STYLE[2]	R_{RUPT}[3] (KM)	R_{JB}[3] (KM)	R_{SEIS}[3] (KM)	R_{HYPO}[3] (KM)
21	7.0	10.0	0	FW	5.7	5.7	4.0	10.77
22	7.0	10.0	10	FW	14.6	14.6	14.0	17.20
23	7.0	10.0	20	FW	24.3	24.3	24.0	26.00
24	7.0	10.0	70	FW	74.1	74.1	74.0	74.6700
25	7.0	10.0	120	FW	124.1	124.1	124.0	124.40
26	7.0	10.0	200	FW	204.0	204.0	204.0	204.20
27	7.5	10.0	0	FW	1.9	4.2	1.3	10.09
28	7.5	10.0	10	FW	11.4	13.3	11.3	15.11
29	7.5	10.0	20	FW	21.4	23.2	21.3	23.55
30	7.5	10.0	70	FW	71.3	73.1	71.3	72.02
31	7.5	10.0	120	FW	121.3	123.0	121.3	121.70
32	7.5	10.0	200	FW	201.3	203.0	201.3	201.60
33	5.0	20.0	0	FW	26.3	26.3	18.6	27.33
34	5.0	20.0	10	FW	34.2	34.2	28.6	34.92
35	5.0	20.0	20	FW	42.9	42.9	38.6	43.50
36	6.0	20.0	0	FW	24.2	24.2	17.1	26.33
37	6.0	20.0	10	FW	32.1	32.1	27.1	33.70
38	6.0	20.0	20	FW	40.9	40.9	37.1	42.17
39	7.0	20.0	0	FW	19.8	19.8	14.0	24.41
40	7.0	20.0	10	FW	27.8	27.8	24.0	31.24
41	7.0	20.0	20	FW	36.8	36.8	34.0	39.44
42	7.5	20.0	0	FW	16.0	16.0	11.3	22.98
43	7.5	20.0	10	FW	24.1	24.1	21.3	29.23
44	7.5	20.0	20	FW	33.3	33.3	31.3	37.16
45	5.0	5.0	0	HW	5.1	5.1	3.6	6.18
46	5.0	5.0	10	HW	7.1	7.1	3.6	14.51
47	6.0	5.0	0	HW	3.0	4.2	2.1	5.43
48	6.0	5.0	10	HW	7.1	7.1	2.1	13.12

132 case definitions for point estimates

CASE NO	MAG	DEPTH (KM)	X-DISTANCE[1] (KM)	FAULTING STYLE[2]	R_{RUPT}[3] (KM)	R_{JB}[3] (KM)	R_{SEIS}[3] (KM)	R_{HYPO}[3] (KM)
49	7.0	5.0	0	HW	0.0	4.2	0.0	6.00
50	7.0	5.0	10	HW	7.1	7.1	0.0	11.66
51	7.5	5.0	0	HW	0.0	4.2	0.0	8.68
52	7.5	5.0	10	HW	7.1	7.1	0.0	13.24
53	5.0	10.0	0	HW	12.2	12.2	8.6	13.21
54	5.0	10.0	10	HW	8.7	8.7	0.0	21.14
55	5.0	10.0	20	HW	14.1	14.1	8.6	30.32
56	5.0	10.0	70	HW	59.7	59.7	58.6	79.26
57	5.0	10.0	120	HW	109.2	109.2	108.6	129.00
58	5.0	10.0	200	HW	189.0	189.0	188.6	208.90
59	6.0	10.0	0	HW	10.1	10.1	7.1	12.28
60	6.0	10.0	10	HW	7.7	7.7	0.0	19.83
61	6.0	10.0	20	HW	14.1	14.1	7.1	28.91
62	6.0	10.0	70	HW	58.6	58.6	57.1	77.77
63	6.0	10.0	120	HW	107.9	107.9	107.1	127.50
64	6.0	10.0	200	HW	187.6	187.6	187.1	207.40
65	7.0	10.0	0	HW	5.7	5.7	4.0	10.77
66	7.0	10.0	10	HW	7.1	7.1	0.0	17.20
67	7.0	10.0	20	HW	14.1	14.1	4.0	26.00
68	7.0	10.0	70	HW	56.3	56.3	54.0	74.67
69	7.0	10.0	120	HW	105.2	105.2	104.0	124.40
70	7.0	10.0	200	HW	184.7	184.7	184.0	204.20
71	7.5	10.0	0	HW	1.9	4.2	1.3	10.09
72	7.5	10.0	10	HW	7.1	7.1	0.0	15.11
73	7.5	10.0	20	HW	14.1	14.1	1.3	23.55
74	7.5	10.0	70	HW	54.6	54.6	51.3	72.02
75	7.5	10.0	120	HW	103.0	103.0	101.3	121.70
76	7.5	10.0	200	HW	182.3	182.3	181.3	201.60

132 case definitions for point estimates

CASE NO.	MAG	DEPTH (KM)	X-DISTANCE[1] (KM)	FAULTING STYLE[2]	R_{RUPT}[3] (KM)	R_{JB}[3] (KM)	R_{SEIS}[3] (KM)	R_{HYPO}[3] (KM)
77	5.0	20.0	0	HW	26.3	26.3	18.6	27.33
78	5.0	20.0	10	HW	20.5	20.5	8.6	34.92
79	5.0	20.0	20	HW	18.7	18.7	0.0	43.50
80	6.0	20.0	0	HW	24.2	24.2	17.1	26.33
81	6.0	20.0	10	HW	18.6	18.6	7.1	33.70
82	6.0	20.0	20	HW	17.4	17.4	0.0	42.17
83	7.0	20.0	0	HW	19.8	19.8	14.0	24.41
84	7.0	20.0	10	HW	14.6	14.6	4.0	31.24
85	7.0	20.0	20	HW	15.2	15.2	0.0	39.44
86	7.5	20.0	0	HW	16.0	16.0	11.3	22.98
87	7.5	20.0	10	HW	11.4	11.4	1.3	29.23
88	7.5	20.0	20	HW	14.3	14.3	0.0	37.16
89	5.0	5.0	0	SS	3.1	3.1	0.0	6.18
90	5.0	5.0	10	SS	10.5	10.5	10.0	14.51
91	6.0	5.0	0	SS	0.9	3.0	0.0	5.43
92	6.0	5.0	10	SS	10.0	10.4	10.0	13.12
93	7.0	5.0	0	SS	0.0	3.0	0.0	6.00
94	7.0	5.0	10	SS	10.0	10.4	10.0	11.66
95	7.5	5.0	0	SS	0.0	3.0	0.0	8.68
96	7.5	5.0	10	SS	10.0	10.4	10.0	13.24
97	5.0	10.0	0	SS	8.1	8.1	0.0	13.21
98	5.0	10.0	10	SS	12.8	12.8	10.0	21.14
99	5.0	10.0	20	SS	21.6	21.6	20.0	30.32
100	5.0	10.0	70	SS	70.5	70.5	70.0	79.26
101	5.0	10.0	120	SS	120.3	120.3	120.0	129.00
102	5.0	10.0	200	SS	200.2	200.2	200.0	208.90
103	6.0	10.0	0	SS	5.9	5.9	0.0	12.28
104	6.0	10.0	10	SS	11.6	11.6	10.0	19.83

132 case definitions for point estimates

CASE NO.	MAG	DEPTH (KM)	X-DISTANCE[1] (KM)	FAULTING STYLE[2]	R_{RUPT}[3] (KM)	R_{JB}[3] (KM)	R_{SEIS}[3] (KM)	R_{HYPO}[3] (KM)
105	6.0	10.0	20	SS	20.9	20.9	20.0	28.91
106	6.0	10.0	70	SS	70.3	70.3	70.0	77.77
107	6.0	10.0	120	SS	120.2	120.2	120.0	127.50
108	6.0	10.0	200	SS	200.1	200.1	200.0	207.40
109	7.0	10.0	0	SS	1.5	3.0	0.0	10.77
110	7.0	10.0	10	SS	10.1	10.4	10.0	17.20
111	7.0	10.0	20	SS	20.1	20.2	20.0	26.00
112	7.0	10.0	70	SS	70.0	70.1	70.0	74.67
113	7.0	10.0	120	SS	120.0	120.0	120.0	124.40
114	7.0	10.0	200	SS	200.0	200.0	200.0	204.20
115	7.5	10.0	0	SS	0.0	3.0	0.0	10.09
116	7.5	10.0	10	SS	10.0	10.4	10.0	15.11
117	7.5	10.0	20	SS	20.0	20.2	20.0	23.55
118	7.5	10.0	70	SS	70.0	70.1	70.0	72.02
119	7.5	10.0	120	SS	120.0	120.0	120.0	121.70
120	7.5	10.0	200	SS	200.0	200.0	200.0	201.60
121	5.0	20.0	0	SS	18.1	18.1	0.0	27.33
122	5.0	20.0	10	SS	20.6	20.6	10.0	34.92
123	5.0	20.0	20	SS	26.9	26.9	20.0	43.50
124	6.0	20.0	0	SS	15.9	15.9	0.0	26.33
125	6.0	20.0	10	SS	18.8	18.8	10.0	33.70
126	6.0	20.0	20	SS	25.6	25.6	20.0	42.17
127	7.0	20.0	0	SS	11.5	11.5	0.0	24.41
128	7.0	20.0	10	SS	15.3	15.3	10.0	31.24
129	7.0	20.0	20	SS	23.1	23.1	20.0	39.44
130	7.5	20.0	0	SS	7.7	7.7	0.0	22.98
131	7.5	20.0	10	SS	12.6	12.6	10.0	29.23
132	7.5	20.0	20	SS	21.4	21.4	20.0	37.16

Table 4.3.3-6 D. L. Bernreuter: General Model Weighting Scheme

PROPONENT MODEL	WEIGHT		
	M 5	M 6	M 7 and 7.5
Atkinson and Boore	0.3	0.3	0.25
Campbell	0.4	0.2	0.25
EPRI	0.3	0.2	0.25
Frankel	0.0	0.0	0.0
Horton	0.0	0.0	0.0
Somerville	0.0	0.2	0.25

No period, distance, or mechanism dependence. Weights pertain to μ estimates only; EPRI model σ values adopted for σ estimates.

Table 4.3.3-7 D. M. BOORE: Model Weighting Scheme

PROPONENT MODEL	WEIGHT (μ)	WEIGHT (σ)
Atkinson and Boore	0.5	0.333
Campbell	0.0	0.333
EPRI	0.3	0.334
Frankel	0.0	0.0
Horton	0.1	0.0
Somerville	0.1	0.0

No magnitude, distance, period, or mechanism dependence.

Table 4.3.3-8 K. W. CAMPBELL: General Model Weighting Scheme

PROPONENT MODEL	WEIGHT
Atkinson and Boore	0.17
Campbell	0.33
EPRI	0.08
Frankel	0.08
Horton	0.17
Somerville	0.17

No period or magnitude dependence. Campbell hybrid model is gradually downweighted at larger distances, see text for details. Weights pertain to μ estimates only. σ values are from the empirical western US attenuation relations considered in the hybrid model.

Table 4.3.3-9 K. JACOB: Model Weighting Scheme, μ Estimates (Unnormalized Values)

Strike-slip mechanism, m estimates:

PROPONENT MODEL	WEIGHTS		
	M 5	M 6	M 7 and 7.5
Atkinson and Boore	3	2	1
Campbell	2	2	2
EPRI	2	2	2
Frankel	2	2	1
Horton	3	3	3
Somerville	0	0	0

Reverse dip-slip mechanism, footwall:

PROPONENT MODEL	WEIGHTS		
	M 5	M 6	M 7 and 7.5
Atkinson and Boore	3	2	1
Campbell	2	2	2
EPRI	2	3	2
Frankel	2	2	1
Horton	0	0	0
Somerville	0	1	1

Reverse dip-slip mechanism, hanging wall:

PROPONENT MODEL	WEIGHTS		
	M 5	M 6	M 7 and 7.5
Atkinson and Boore	3	2	1
Campbell	2	2	2
EPRI	3	3	2
Frankel	2	2	3
Horton	2	2	3
Somerville	0	1	1

No period or distance dependence. Weights assigned correspond to 'high' (3), 'medium (2), 'low' (1) and not applicable (0). Weights shown are not normalized; normalized values are obtained by dividing each weight by the sum of the weights for all proponent models at that magnitude.

Table 4.3.3-9 K. JACOB: Model Weighting Scheme, μ Estimates (Unnormalized Values) *(cont'd)*

Strike-slip mechanism:

PROPONENT MODEL	WEIGHTS	
	M 5	M 6, 7, and 7.5
Atkinson and Boore	2	1
Campbell	2	3
EPRI	2	2
Frankel	3	3
Horton	1	1
Somerville	0	0

Reverse dip-slip mechanism, footwall:

PROPONENT MODEL	WEIGHTS	
	M 5	M 6, 7, and 7.5
Atkinson and Boore	2	2
Campbell	2	2
EPRI	2	2
Frankel	3	3
Horton	0	0
Somerville	0	1

Reverse dip-slip mechanism, hanging wall:

PROPONENT MODEL	WEIGHTS	
	M 5	M 6, 7, and 7.5
Atkinson and Boore	2	2
Campbell	2	2
EPRI	2	2
Frankel	3	3
Horton	1	1
Somerville	0	1

No period or distance dependence. Weights assigned correspond to 'high' (3), 'medium (2), 'low' (1) and not applicable (0). Weights shown are not normalized; normalized values are obtained by dividing each weight by the sum of the weights for all proponent models at that magnitude.

Table 4.3.3-10 P. G. SOMERVILLE: Model Weighting Scheme

Magnitude 5:

PROPONENT MODEL	WEIGHT
Atkinson and Boore	0.2
Campbell	0.4
EPRI	0.2
Frankel	0.2
Horton	0.0
Somerville	N/A

Magnitude 6, 7, 7.5:

PROPONENT MODEL	WEIGHT AT CLOSE DISTANCE	WEIGHT AT FAR DISTANCE
Atkinson and Boore	0.05	0.1
Campbell	0.4	0.4
EPRI	0.075	0.1
Frankel	0.075	0.1
Horton	0.0	0.0
Somerville	0.4	0.3

No period or mechanism dependence. Close distance defined as 10 km or less at M 6, 20 km or less at M 7 and 7.5. Far distance defined as 20 km or more at M 6, 70 km or more at M 7 and 7.5. Weights pertain to μ and σ estimates

Table 4.3.4-1A D. L. Bernreuter: Regression Coefficients Median Model

FREQUENCY (HZ)	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	SIGMA FIT
100	3.3522	0.2707	-1.4721	0.1816	0.138	0	0.0264	10.1	0.1089
25	4.9116	0.2707	-1.6716	0.1816	0.138	0.0085	-0.0114	11.8	0.1108
10	3.6617	0.2707	-1.3873	0.1816	0.138	-0.0085	0.0452	9.8	0.1165
2.5	2.444	0.2707	-1.1571	0.1816	0.138	-0.0742	0.0498	8.3	0.1248
1	1.4999	0.2707	-1.0754	0.1816	0.138	-0.1345	-0.0369	7.5	0.1341

Table 4.3.4-1B D. L. Bernreuter: Regression Coefficients Sigma Model

FREQUENCY (HZ)	b_1	b_2	b_4	SIGMA FIT
100	0.6853	-0.0294	7.2	0.0749
25	0.6838	-0.0428	7.2	0.0764
10	0.6701	-0.0302	7.2	0.0745
2.5	0.7224	-0.0247	7.2	0.0502
1	0.7923	-0.0178	7.2	0.0447

Table 4.3.4-1C D. L. Bernreuter: Regression Coefficients Sigma-Mu Model

FREQUENCY (HZ)	c_1	c_2	c_3	c_4	c_5	c_6	SIGMA FIT
100	0.3772	-0.0521	-0.0328	0.009	0.0556	6	0.2537
25	0.4019	-0.0472	-0.0735	0.0156	0.0881	6	0.2368
10	0.3435	-0.001	-0.0449	0.0098	0.0708	6	0.2641
2.5	0.314	-0.0292	0.0527	-0.0018	-0.0198	6	0.3005
1	0.508	-0.013	0.1171	-0.0167	-0.051	6	0.2324

Table 4.3.4-1D D. L. Bernreuter: Regression Coefficients Sigma-Sigma Model

FREQUENCY (HZ)	d_1	d_2	d_4	SIGMA FIT
100	0.213	0.0302	7.2	0.0677
25	0.1732	0.0135	7.2	0.0635
10	0.2119	0.0294	7.2	0.0679
2.5	0.164	0.0218	7.2	0.0426
1	0.1477	0.0167	7.2	0.0373

Table 4.3.4-2A D. M. Boore: Regression Coefficients Median Model

FREQUENCY (HZ)	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	SIGMA FIT
100	3.2922	0.371	-1.4556	0.1554	0.1385	0	0.0595	8.5	0.1388
25	4.7198	0.371	-1.5974	0.1554	0.1385	0.0054	0.0325	9.7	0.1362
10	3.5246	0.371	-1.3287	0.1554	0.1385	-0.0076	0.0593	8.2	0.1418
2.5	2.0581	0.371	-1.0892	0.1554	0.1385	-0.0693	0.0946	6.9	0.1536
1	0.9888	0.371	-1.0009	0.1554	0.1385	-0.1306	0.0489	6.4	0.1742

Table 4.3.4-2B D. M. Boore: regression Coefficients Sigma Model

FREQUENCY (HZ)	b_1	b_2	b_4	SIGMA FIT
100	0.6217	-0.0355	7.2	0.0374
25	0.6355	-0.0369	7.2	0.0352
10	0.6074	-0.0372	7.2	0.0363
2.5	0.6691	-0.0207	7	0.0324
1	0.7367	-0.0075	7	0.0363

Table 4.3.4-2C D. M. Boore: Regression Coefficients Sigma-Mu Model

FREQUENCY (HZ)	c_1	c_2	c_3	c_4	c_5	c_6	SIGMA FIT
100	0.3093	-0.0261	-0.0543	0.0066	0.0083	6	0.0798
25	0.3572	-0.0217	-0.0923	0.016	0.0184	6	0.0936
10	0.2436	-0.0067	-0.0403	0.008	0.0001	6	0.0759
2.5	0.17	-0.0171	0.0479	-0.0079	-0.0102	6	0.0898
1	0.2742	-0.0222	0.12	-0.023	-0.0388	6	0.1111

Table 4.3.4-2D D. M. Boore: Regression Coefficients Sigma-Sigma Model

FREQUENCY (HZ)	d_1	d_2	d_4	SIGMA FIT
100	0.0511	0.0006	7.2	0.0017
25	0.0504	0.0002	7.2	0.0005
10	0.0503	0.0002	7.2	0.0005
2.5	0.05	-0.0002	7.2	0.0005
1	0.0503	-0.0014	7.2	0.0035

Table 4.3.4-3A K. W. Campbell: Regression Coefficients Median Model

FREQUENCY (HZ)	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	SIGMA FIT
100	3.2806	0.3029	-1.4378	0.0496	0.1521	0	-0.0068	9	0.1364
25	4.6735	0.3029	-1.5793	0.0496	0.1521	0.0132	-0.0907	10.4	0.1582
10	3.4706	0.3029	-1.3119	0.0496	0.1521	-0.0083	-0.0122	8.6	0.1454
2.5	2.4492	0.3029	-1.1509	0.0496	0.1521	-0.0745	0.0609	7.7	0.1486
1	1.6744	0.3029	-1.102	0.0496	0.1521	-0.1347	-0.0243	7.3	0.1673

Table 4.3.4-3B K. W. Campbell: Regression Coefficients Sigma Model

FREQUENCY (HZ)	b_1	b_2	b_4	SIGMA FIT
100	0.568	-0.0232	7.2	0.0507
25	0.5798	-0.0214	7.2	0.056
10	0.5567	-0.0282	7.2	0.0433
2.5	0.6027	-0.0052	7.2	0.0514
1	0.666	0.0223	5.8	0.0557

Table 4.3.4-3C K. W. Campbell: Regression Coefficients Sigma-Mu Model

FREQUENCY (HZ)	c_1	c_2	c_3	c_4	c_5	c_6	SIGMA FIT
100	0.1719	-0.0056	-0.003	-0.0002	-0.0014	6	0.0178
25	0.2095	-0.0059	-0.0152	0.0009	0.0017	6	0.0359
10	0.1552	-0.0018	0.0057	-0.0013	-0.0013	6	0.0197
2.5	0.1657	-0.0046	0.0042	-0.0011	-0.0093	6	0.0268
1	0.1899	-0.0115	0.0254	-0.0056	-0.0201	6	0.0438

Table 4.3.4-3D K. W. Campbell: Regression Coefficients
Sigma-Sigma Model

FREQUENCY (HZ)	d_1	d_2	d_4	SIGMA FIT
100	0.0539	-0.0006	7	0.0079
25	0.0538	-0.0014	7	0.0102
10	0.0535	-0.0006	7	0.0068
2.5	0.0552	-0.0052	7	0.0106
1	0.0569	-0.0139	6.4	0.0146

Table 4.3.4-4A K. Jacob: Regression Coefficients Median Model

FREQUENCY (HZ)	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	SIGMA FIT
100	3.2113	0.3621	-1.4271	0.1079	0.1424	0	0.0048	8.6	0.1525
25	4.9629	0.3621	-1.6472	0.1079	0.1424	0.0089	-0.0973	11.2	0.181
10	3.6398	0.3621	-1.356	0.1079	0.1424	-0.0078	0.0042	9	0.1564
2.5	2.3168	0.3621	-1.1301	0.1079	0.1424	-0.0674	0.0841	7.5	0.1644
1	1.5657	0.3621	-1.0542	0.1079	0.1424	-0.1417	0.0073	6.9	0.1896

Table 4.3.4-4B K. Jacob: Regression Coefficients Sigma Model

FREQUENCY (HZ)	b_1	b_2	b_4	SIGMA FIT
100	0.6277	-0.012	7	0.051
25	0.6104	-0.0164	7.1	0.0591
10	0.6146	-0.0174	7	0.0455
2.5	0.6523	0.0013	5.8	0.0457
1	0.7137	0.0115	7.2	0.0516

Table 4.3.4-4C K. Jacob: Regression Coefficients Sigma-Mu Model

FREQUENCY (HZ)	c_1	c_2	c_3	c_4	c_5	c_6	SIGMA FIT
100	0.4374	-0.0182	-0.0911	0.0113	-0.0043	6	0.1296
25	0.5841	-0.021	-0.1308	0.0207	-0.033	6	0.1775
10	0.3658	0.0144	-0.0594	0.0094	-0.023	6	0.1293
2.5	0.3034	-0.0198	0.0016	0.0004	-0.045	6	0.1413
1	0.4183	-0.0235	0.0428	-0.0077	-0.0365	6	0.1473

Table 4.3.4-4D K. Jacob: Regression Coefficients Sigma-Sigma Model

FREQUENCY (HZ)	d_1	d_2	d_4	SIGMA FIT
100	0.1444	-0.0023	7	0.0597
25	0.1198	-0.0168	7	0.0835
10	0.1452	0.0156	5.8	0.0565
2.5	0.133	-0.0303	7	0.0664
1	0.1331	-0.0427	7.2	0.0808

Table 4.3.4.5A P. G. Somerville: Regression Coefficients Median Model

FREQUENCY (HZ)	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	SIGMA FIT
100	3.2482	0.159	-1.4498	0.1317	0.1596	0	-0.0078	10.1	0.1217
25	4.9854	0.159	-1.698	0.1317	0.1596	0.0128	-0.077	12.8	0.1484
10	3.6428	0.159	-1.3915	0.1317	0.1596	-0.0092	0.0096	10.1	0.1173
2.5	2.512	0.159	-1.1677	0.1317	0.1596	-0.075	0.0333	8.3	0.1395
1	1.6282	0.159	-1.0794	0.1317	0.1596	-0.1406	-0.0539	7.1	0.1508

Table 4.3.4.5B P. G. Somerville: Regression Coefficients Sigma Model

FREQUENCY (HZ)	b_1	b_2	b_4	SIGMA FIT
100	0.5959	-0.0282	7	0.0409
25	0.6005	-0.03	7	0.046
10	0.5843	-0.0304	7	0.0358
2.5	0.6287	-0.0165	7	0.0342
1	0.7012	-0.0091	6.4	0.0337

Table 4.3.4.5C P. G. Somerville: Regression Coefficients Sigma-Mu Model

FREQUENCY (HZ)	c_1	c_2	c_3	c_4	c_5	c_6	SIGMA FIT
100	0.1873	-0.0109	-0.014	0.0019	0.0044	6	0.0351
25	0.2151	-0.0086	-0.0324	0.0063	0.0084	6	0.0581
10	0.1687	-0.0022	-0.0059	0.0009	0.0027	6	0.0253
2.5	0.1612	-0.0038	0.0021	0	-0.0067	6	0.0329
1	0.2247	-0.0135	0.0106	-0.0013	-0.041	6	0.063

Table 4.3.4.5D P. G. Somerville: Regression Coefficients
Sigma-Sigma Model

FREQUENCY (HZ)	d_1	d_2	d_4	SIGMA FIT
100	0.0562	-0.0021	5.8	0.0133
25	0.0593	-0.0027	6.5	0.0188
10	0.0564	0.0008	7.2	0.0125
2.5	0.0562	-0.0069	7	0.0159
1	0.0581	-0.0079	7	0.0212

Table 4.3.4-6A. Expert Composite: Regression Coefficients Median Model

FREQUENCY (HZ)	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	SIGMA FIT
100	3.2672	0.2944	-1.4464	0.1265	0.1458	0	0.0153	9.2	0.1182
25	4.8347	0.2944	-1.6354	0.1265	0.1458	0.0097	-0.0487	11.1	0.129
10	3.5804	0.2944	-1.3535	0.1265	0.1458	-0.0082	0.0213	9.1	0.1223
2.5	2.349	0.2944	-1.1375	0.1265	0.1458	-0.0721	0.0646	7.7	0.132
1	1.4643	0.2944	-1.0608	0.1265	0.1458	-0.1363	-0.0117	7	0.1454

Table 4.3.4-6B Expert Composite: Regression Coefficients Sigma Model

FREQUENCY (HZ)	b_1	b_2	b_4	SIGMA FIT
100	0.619	-0.0251	7.2	0.0378
25	0.6177	-0.0273	7.2	0.042
10	0.6058	-0.028	7.2	0.0336
2.5	0.6557	-0.0137	7	0.0283
1	0.7223	-0.0026	7	0.0286

Table 4.3.4-6C Expert Composite: Regression Coefficients Sigma-Mu Model

FREQUENCY (HZ)	c_1	c_2	c_3	c_4	c_5	c_6	SIGMA FIT
100	0.3097	-0.0208	-0.0485	0.0064	0.0207	6	0.1036
25	0.3882	-0.0162	-0.0846	0.0137	0.03	6	0.1236
10	0.2702	0.0016	-0.0375	0.0065	0.0148	6	0.1028
2.5	0.226	-0.0176	0.0291	-0.0037	-0.0246	6	0.1183
1	0.3599	-0.0148	0.0728	-0.0133	-0.0476	6	0.1152

Table 4.3.4-6D Expert Composite: Regression Coefficients Sigma-Sigma Model

FREQUENCY (HZ)	d_1	d_2	d_4	SIGMA FIT
100	0.115	0.0055	7.2	0.0296
25	0.0919	-0.0084	7	0.0326
10	0.1143	0.0086	7.2	0.0297
2.5	0.102	-0.0095	7	0.0223
1	0.1008	-0.0153	7.2	0.0236

Table 4.4-1 Probability Distributions of the Upper Magnitude Cutoff M_u for Bollinger

EVA: **Gilbert BOLLINGER**

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps.
Date of the elicitation: 8-Jan-97

ELICITATION OF UPPER MAGNITUDE CUTOFFS: M_U

Names of Zones in the composite set of zonation maps	Magnitude Cutoff M_U				Comments
	Lower bound	*Mode*	*Upper bound*	Distribution shape	
3A	5.00	5.50	6.00	Uniform	Barely above background
3B-3A	4.50	5.00	5.50	Uniform	
3C	5.00	5.50	6.00	Uniform	
3B-3C	5.00	5.50	6.00	Uniform	
Charleston					
1A-(Characteristic)	7.00	7.30	7.60	Triangle	
1B-(3-blobs)	7.00	7.30	7.60	Triangle	Center blob has properties of 1A
1C-(ZRA)	7.00	7.30	7 60	Triangle	
1D-(Long--SW-NE)	7.00	7.30	7.60	Triangle	Same as 1B but different geometry
1E(2side.blobs+1A)	5.50	6.00	6.50	Triangle	Non characteristic part of 1A
Bckgnd to Charlstn					(side blobs of the 3-blob scenario)
6-Central-Virginia	6.00	6.30	6 60	Triangle	
7(Coast.Plain-CVSC)	4.50	5.00	5.50	Uniform	
8-Offshore	4.50	5.00	5.50	Uniform	
ETSZ					
4A-1	6.00	6.50	7.30	U taper	Based on 3 different methods
(4A-1)+(4A-2)	6.00	6.50	7.30	U taper	estimates: (1) Max Hist + Δ,
(4A-1)+(4A-2)+(4A-3)	6.00	6.50	7.30	U taper	(2) 1000 yr reccur. extrapolation, and
4B-1	5.50	6.50	7.30	U taper	(3) estimate from fault length equat.
4B-2	6.00	6.00	6 80	U taper	4B-1=4A-1, 4B-2=(4A-2)+(4A-3)
4-C-(8-faults)	6.50	7.00	7.50	Triangle	8 faults system, see white paper
4-D-(varying-rates)				Triangle	
4-E-(rate-cylinders)	6.00	7.00	8.00	Triangle	same geometry as 4A, 10% PE
Backgrnd to ETSZ					
(5-1)	5.00	6 00	6 80	U taper	
(5-2)	5.00	6.00	6.80	U taper	
(5-1)+(5-2)	5.00	6.00	6.80	U taper	
(5-3)	5 00	5 00	5 50	Uniform	
(5-1)+(5-2)+(5-3)	4.50	6.30	7.00	U taper	

Table 4.4-2 Probability Distributions of the Upper Magnitude Cutoff M_u for Chapman

EVA: **Martin CHAPMAN**

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps.
Date of the elicitation: 19-Dec-96

ELICITATION OF UPPER MAGNITUDE CUTOFFS: M_U

Names of Zones in the composite set of zonation maps	Magnitude Cutoff M_U				Comments
	Lower bound	*Mode*	*Upper bound*	Distribution shape	
3A	6.00	6.50	7.00	Uniform	
3B-3A	6.00	6.50	7.00	Uniform	Complement to 3A
3C	6 00	6 50	7.00	Uniform	
3B-3C	6.00	6.50	7.00	Uniform	Complement to 3C
Charleston					
1A-(Characteristic)	6 90	7.20	7.50	Triangle	Lower & Upper based on A. Johnston
1B-(3-blobs)	6.50	7.20	7.50	U taper R	Center blob has properties of 1A
1C-(ZRA)	6.90	7.20	7.50	Triangle	Lower & Upper based on A. Johnston
1D-(Long--SW-NE)	6.50	7.20	7.50	U taper R	Same as 1B but different geometry
1E(2side.blobs+1A)					Non characteristic part of 1A
Bckgnd to Charlstn					
6-Central-Virginia	6.00	6.50	7.00	Uniform	Magn. vs. length considerations
7(Coast.Plain-CVSZ)	6 00	6.50	7.00	Uniform	Magn. vs length considerations
8-Offshore	6.00	7.00	7.50	Uniform	Same as 6 & 7, NOT Characteristic
ETSZ					
4A-1	6.50	7.00	7.50	Uniform	Based on uncertainty on the max.
(4A-1)+(4A-2)	6.50	7.00	7.50	Uniform	length of the possible segments
(4A-1)+(4A-2)+(4A-3)	6.50	7.00	7.50	Uniform	
4B-1	6.50	7.00	7.50	Uniform	4B is exclusive of 4A
4B-2	6.00	7.00	7.50	Uniform	
4C-(8faults)					
4D-(varying-rates)					
4E-(rate-cylinders)					
Backgrnd to ETSZ					
(5-1)	6.00	7.00	7.50	Uniform	
(5-2)	6.00	7.00	7.50	Uniform	
(5-1)+(5-2)	6.00	7.00	7.50	Uniform	
(5-3)	6.00	7.00	7.50	Uniform	
(5-4)					

Table 4.4-3 Probability Distributions of the Upper Magnitude Cutoff M_u for Coppersmith

EVA: **Kevin COPPERSMITH**

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps.
Date of the elicitation: 8-Jan-97

ELICITATION OF UPPER MAGNITUDE CUTOFFS: M_u

Names of Zones in the composite set of zonation maps	Magnitude Cutoff M_u				Comments
	Lower bound	*Mode*	*Upper bound*	Distribution shape	
3A	5.60	6.40	7.20	Triangle	See the SCR EPRI Study:
3B-3A	5.60	6.40	7.20	Triangle	Extended crust: 5 6, 6 4, 7.2
3C	5.90	6.30	6.70	Triangle	Non-extended crust: 5 9, 6.3, 6.7
3B-3C	5.60	6 40	7.20	Triangle	
Charleston					
1A-(Characteristic)	6.80	7.30	7.70	Triangle	Also account for any type of
1B-(3-blobs)	6.80	7.30	7.70	Triangle	scenario. Handles the geological
1C-(ZRA)	6.80	7.30	7.70	Triangle	aspect
1D-(Long--SW-NE)	6.80	7.30	7.70	Triangle	
1E(2side.blobs+1A)	6.80	7.30	7.70	Triangle	Same Mu for both blobs
Bckgnd to Charlstn					
6-Central-Virginia					
7(Coast.Plain-CVSZ)	5.60	6.40	7.20	Triangle	Extended crust
8-Offshore					
ETSZ					
4A-1	5.90	6.30	7.20	Triangle	5.9 from SCR, 7.2 from Chapman's
(4A-1)+(4A-2)	5.90	6.30	7.20	Triangle	long fault scenario.
(4A-1)+(4A-2)+(4A-3)	5.90	6.30	7.20	Triangle	
4B-1	5.90	6.30	7.20	Triangle	
4B-2	5.90	6.30	7.20	Triangle	
4-C-(8-faults)	5.90	6.30	7.20	Triangle	8 faults system, see white paper
4-D-(varying-rates)	5.90	6 30	7.20	Triangle	
4-E-(rate-cylinders)	5.90	6.30	7.20	Triangle	same geometry as 4A, 10% PE
Backgrnd to ETSZ					
(5-1)	5.90	6.30	6.70	Triangle	Non-extended crust, same as 3C
(5-2)	5.90	6.30	6.70	Triangle	
(5-1) + (5-2)	5.90	6.30	6.70	Triangle	
(5-3)	5.90	6.30	6 70	Triangle	
(5-1)+(5-2)+(5-3)	5.90	6.30	6.70	Triangle	

Table 4.4-4 Probability Distributions of the Upper Magnitude Cutoff M_u for Jacob

EVA: **Klaus JACOB**

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps.
Date of the elicitation: 19-Dec-96

ELICITATION OF UPPER MAGNITUDE CUTOFFS: M_U

Names of Zones in the composite set of zonation maps	Magnitude Cutoff M_U				Comments
	Lower bound	*Mode*	*Upper bound*	Distribution shape	
3A	6.50	7.00	7.50	Triangle	Excludes Charleston
3B-3A	6.00	6.50	7.00	Triangle	Complementary to 3A
3C	6.00	6.50	7.00	Triangle	Influenced w/seismicity, consistent
3B-3C	6.50	7.00	7.50	Triangle	with Virginia seismic zone
Charleston					
1A-(Characteristic)	7.00	7.50	7.80	Triangle	Jonston lower bound is 6.9
1B-(3-blobs)	7.00	7.50	7.80	Triangle	Does not exist
1C-(ZRA)	7.00	7.50	7.80	Triangle	
1D-(Long--SW-NE)	6.20	7.00	7.20	Triangle	Elongated with midle same as 1A
1E(2side.blobs+1A)	6.20	7.00	7.20	Triangle	Mu here, only for the side blobs
Bckgnd to Charlstn					
6-Central-Virginia	6.00	6.50	7.00		
7(Coast.Plain-CVSZ)	6.00	6.50	7.00		
8-Offshore	6.80	7.25	7.60		Only a characteristic earthquake
ETSZ					
4A-1	5.50	6.50	7.50	Triangle	
(4A-1)+(4A-2)	5.50	6.50	7.50	Triangle	Lower bound driven by seismicity +.5
(4A-1)+(4A-2)+(4A-3)	5.50	6.50	7.50	Triangle	than historical.
4B-1	5.50	6.50	7.50	Triangle	Upper bound driven by Chapman's
4B-2	5.50	6.50	7.50	Triangle	long fault scenario.
4-C-(8-faults)	5.50	6.50	7.50	Triangle	
4-D-(varying-rates)	5.50	6.50	7.50	Triangle	
4-E-(rates-cylinders)	5.50	6.50	7.50	Triangle	
Backgrnd to ETSZ					
(5-1)	6.00	6.50	7.00	Triangle	
(5-2)	6.00	6.50	7.00	Triangle	
(5-1)+(5-2)	6.00	6.50	7.00	Triangle	
(5-3)	6.00	6.50	7.00	Triangle	
(5-1)+(5-2)+(5-3)	6.00	6.50	7.00	Triangle	

Table 4.4-5 Probability Distributions of the Upper Magnitude Cutoff M_u for Talwani

EVA: **Pradeep TALWANI**

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps.
Date of the elicitation: 18-Dec-96

ELICITATION OF UPPER MAGNITUDE CUTOFFS: M_u

Names of Zones in the composite set of zonation maps	Magnitude Cutoff M_u				Comments
	Lower bound	*Mode*	*Upper bound*	Distribution shape	
3A	5.00	5.50	5.70	Triangle	Excludes Charleston
3B-3A	5.00	5.50	5.70	Triangle	Complementary to 3A
3C	5.00	5.50	5.70	Triangle	Runs along with Piedmont faults
3B-3C	4.80	5.00	5.50	Triangle	with Virginia seismic zone
Charleston					
1A-(Characteristic)	7.00	7.30	7.50	Triangle	
1B-(3-blobs)	7.00	7.30	7.50	Triangle	Delineation based on liquefaction
1C-(ZRA)	7.00	7.30	7 50	Triangle	
1D-(Long–SW-NE)	7.00	7.30	7.50	Triangle	Elongated with midle same as 1A
1E(2side.blobs+1A)	5.50	6.00	6.20	Triangle	
Bckgnd to Charlstn					
6-Central-Virginia	5 00	5.50	5 70		Same as 3C
7(Coast.Plain-CVSZ)	4.00	4.50	5.00		
8-Offshore					No input. Probability of existence=0
ETSZ					
4A-1	5.00	6.00	7.00	Triangle	Difficult to generate more than a
(4A-1)+(4A-2)	5.00	6.00	7.00	Triangle	m=6 because of the limited length of
(4A-1)+(4A-2)+(4A-3)	5.00	6.00	7.00	Triangle	possible fault scenarios. Mostly
4B-1	5.00	6.00	7.00	Triangle	based on historical seismicity, not
4B-2	5.00	6.00	7.00	Triangle	much weight of long N-S fault.
4-C-(8-faults)	5.00	6.00	7.00	Triangle	
4-D-(varying-rates)	5 00	6.00	7.00	Triangle	
4-E-(rate-cylinders)	5.00	6.00	7.00	Triangle	
Backgrnd to ETSZ					
(5-1)	4.50	5.50	5.70	Triangle	Without Giles County, which is
(5-2)	4.50	5.50	5.70	Triangle	localized and is treated separately.
(5-1)+(5-2)	4.50	5.50	5.70	Triangle	The 1916 N Alabama earthquake is
(5-3)	4.50	5.50	5.70	Triangle	a quarry blast (Bollinger, Stover)
(5-1)+(5-2)+(5-3)	4.50	5.50	5.70	Triangle	

Table 4.4-6 Probability Distributions of the Seismicity Rates f(4) for Bollinger

EVA Gilbert BOLLINGER

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps
Date of the elicitation· 8-Jan 97

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE 4 0

Names of Zones in the composite set of zonation maps	Frequency rate per year for M_b>=4 0				Zone Area (km²)	f(4)/(km²) for M_b>=4 0			Return Periods (years)			Comments
	Lower bound	*Mode*	*Upper bound*	Distribution shape		*Lower bound*	*Mode*	*Upper bound*	*Lower bound*	*Mode*	*Upper bound*	
3A	0 02	0 0398	0 0667	Triangle	85307	2 344E-05	4 666E-05	7 819E-05	15 0	25 1	50 0	3A1 with Charleston & Bowman removed
3B-3A	0 0098	0 0195	0 0385	Triangle	89362	1 097E-05	2 182E-05	4 308E-05	26 0	51 3	102 0	JGR paper, use 95% confidence bounds, 3A1 removed
3C-Alternative-to-3A	0 05	0 08	0 15	Triangle	51988	9 618E-05	0 0001539	0 0002885	6 7	12 5	20 0	
3B-3C	0 0164	0 0195	0 0244	Triangle	130167	1 26E-05	1 498E-05	1 875E-05	41 0	51 3	61 0	3B with part of 3C in 3B, Bowman & Charleston 1A removed
Charleston												
1A(localized1886)	0 0122	0 0247	0 0526	Taper-Unif	1924	0 0006341	0 0012838	0 0027339	19 0	40 5	82 0	Used LLNL regression fit provided
1B(3blobs)	0 0196	0 0398	0 0847	Taper Unif	3098	0 0006341	0 0012838	0 0027339	11 8	25 1	50 9	
1C(ZRA)	0 0507	0 1026	0 2185	Taper-Unif	7992	0 0006341	0 0012838	0 0027339	4 6	9 7	19 7	
1D(3extended blobs)	0 057	0 1155	0 2459	Taper-Unif	8996	0 0006341	0 0012838	0 0027339	4 1	8 7	17 5	
1E(2side blobs+1A)	0 0126	0 0256	0 0545	Taper-Unif	1993	0 0006341	0 0012838	0 0027339	18 4	39 1	79 1	
Bckgnd to-Charlstn												
6-Central-Virginia	0 0204	0 0331	0 0667	Taper-Unif,	24926	8 184E-05	0 0001328	0 0002676	15 0	30 2	49 0	
7(Coast Plain-CVSZ)	0 0053	0 0105	0 0208	Taper-Unif	298749	1 774E-06	3 515E-06	6 962E-06	48 1	95 2	188 7	CVSZ removed
8 Offshore	0 0013	0 0026	0 0051	Taper-Unif	72932	1 774E-06	3 515E-06	6 962E-06	196 9	390 1	772 9	
ETSZ												
4A-1	0 0537	0 085	0 1612	Taper-Unif	15746	0 0003411	0 0005397	0 0010237	6 2	11 8	18 6	
(4A-1)+(4A 2)	0 0681	0 1078	0 2045	Taper-Unif	19973	0 0003411	0 0005397	0 0010237	4 9	9 3	14 7	
(4A-1)+(4A 2)+(4A-3)	0 0833	0 1318	0 25	Taper-Unif	24422	0 0003411	0 0005397	0 0010237	4 0	7 6	12 0	
4B-1	0 075	0 15	0 3	Taper-Unif	15746	0 0004763	0 0009526	0 0019052	3 3	6 7	13 3	
4B 2	0 0035	0 0073	0 0139	Taper-Unif	8876	4 008E-05	8 373E-05	0 0001603	71 9	137 7	287 6	
4C-(8-faults)				Taper-Unif					#DIV/0!	#DIV/0!	#DIV/0!	
4D (varying) rates					24422	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
4E-(3 cyl rate-zones)												
first cylinder-(4-1)	0 0655	0 1036	0 1965	Taper-Unif	15746	0 0004159	0 0006581	0 0012482	5 1	9 7	15 3	
second cyl (4-2)	0 0132	0 0209	0 0396	Taper-Unif.	4227	0 0003119	0 0004935	0 0009362	25 3	47 9	75 8	
third-cylind -(4-3)	0 0046	0 0073	0 0139	Taper-Unif	4449	0 000104	0 0001645	0 0003121	72 0	136 6	216 2	
Bckgnd-to-ETSZ												
(5-1)	0 0317	0 0662	0 1267	Uniform	79058	4 008E-05	8 373E-05	0 0001603	7 9	15 1	31 6	Giles County & 4A(1+2+3) removed
(5-2)	0 0683	0 1427	0 2733	Uniform	170435	4 008E 05	8 373E-05	0 0001603	3 7	7 0	14 6	
(5-1)+(5-2)	0 1	0 2089	0 4	Uniform	249493	4 008E-05	8 373E-05	0 0001603	2 5	4 8	10 0	
(5-3)				Uniform	81393	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
(5-1)+(5-2)+(5-3)				Uniform	340000	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
Large Bowman-9A	0 0054	0 0107	0 0213	Uniform	922	0 0005857	0 0011605	0 0023102	46 9	93 5	185 2	

multiplicative factor for the size of unit area (in km ²) = 100
Thus the rates in columns 7, 8 and 9 are normalized for 100 km²

Table 4.4-7 Probability Distributions of the Seismicity Rates f(4) for Chapman

EVA. Martin CHAPMAN

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps
Date of the elicitation: 19 Dec-96

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE 4.0

Names of Zones in the composite set of zonation maps	Frequency rate per year for M_L>=4.0 Lower bound	Mode	Upper bound	Distribution shape	Zone Area (km^2)	f(4)/(km^2) for M_L>=4.0 Lower bound	Mode	Upper bound	Return Periods (years) Lower bound	Mode	Upper bound	Comments
3A	0.037	0.073	0.146	Triangle	85307	4.337E-05	8.6573E-05	0.00017115	6.8	13.7	27.0	
3B Comp to-3A	0.0175	0.035	0.07	Triangle	89362	1.958E-05	3.9187E-05	7.8333E-05	14.3	28.6	57.1	
3C-Alternative to-3A	0.037	0.073	0.147	Triangle	51988	7.117E-05	0.00014042	0.00027506	7.0	13.7	27.0	
(3A+3B) 3C	0.0175	0.035	0.07	Triangle	130167	1.344E-05	2.6889E-05	5.3777E-05	14.3	28.6	57.1	
Charleston												
1A(localized1886)	0.027	0.053	0.106	Triangle	1924	0.0014033	0.00275468	0.00550936	9.4	18.9	37.0	LLNL estimates, factor 2 both ways
1B(3blobs)	0.027	0.053	0.106	Triangle	3098	0.0008715	0.00171078	0.00342156	9.4	18.9	37.0	Same total numbers as 1A, but distributed over greater area
1C(ZRA)	0.027	0.053	0.106	Triangle	7992	0.0003378	0.00066316	0.00132633	9.4	18.9	37.0	
1D(3extended blobs)	0.027	0.053	0.106	Triangle	8995	0.0003001	0.00058915	0.0011783	9.4	18.9	37.0	
1E(2side blobs+1A)	0.006	0.0117	0.0235	Triangle	1993	0.0003001	0.00058915	0.0011783	42.6	85.2	167.2	
Bckgnd-to-Charlstn												
6-Central-Virginia	0.022	0.044	0.088	Triangle	24926	8.826E-05	0.00017652	0.088	11.4	22.7	45.5	
7 Coastal plain	0.015	0.03	0.06	Triangle	298749	5.021E-06	1.0042E-05	2.0084E-05	16.7	33.3	66.7	
8 Offshore	0.0037	0.0073	0.0146	Triangle	72932	5.021E-06	1.0042E-05	2.0084E-05	68.3	136.5	273.1	
ETSZ												
(4-1)————A	0.051	0.102	0.204	Triangle	15746	0.0003239	0.00064778	0.00129557	4.9	9.8	19.6	
(4.1)+(4.2)———A	0.0558	0.1115	0.2231	Triangle	19973	0.0002793	0.0005585	0.001117	4.5	9.0	17.9	
(4.1)+(4.2)+(4.3)—A	0.0608	0.1216	0.2432	Triangle	24427	0.000249	0.00049781	0.00099562	4.1	8.2	16.4	Basic estimate. Others in module 4 are proportional to areas
(4.1)————B	0.051	0.102	0.204	Triangle	15746	0.0003239	0.00064778	0.00129557	4.9	9.8	19.6	
(4-2)+(4-3)———B	0.0098	0.0196	0.0392	Triangle	8676	0.000113	0.00022591	0.00045182	25.5	51.0	102.0	
4C-(8-faults)	0.0608	0.1216	0.2432	Triangle	100	0.0608	0.1216	0.2432	4.1	8.2	16.4	
4D-(varying)-rates				Triangle	24427	0	0	0				Rates are estimated on a (10km x 10km) grid basis
4E-(3 cyl rate zones)												
-first-cyl-(4-1)	0.0478	0.0956	0.1912	Triangle	15746	0.0003036	0.00060713	0.00121427	5.2	10.5	20.9	
-second-cyl (4.2)	0.0096	0.0192	0.0385	Triangle	4227	0.0002277	0.00045535	0.0009107	26.0	52.0	103.9	
-third-cylnd (4.3)	0.0034	0.0068	0.0135	Triangle	4449	7.589E-05	0.00015178	0.00030357	74.0	148.1	296.2	
[illegible]												

Table 4.4-8 Probability Distributions of the Seismicity Rates f(4) for Coppersmith

EVA: Kevin COPPERSMITH

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps.

Date of the elicitation: 8-Jan-97

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE 4.0

Frequency rate per year for M_0>=4.0 Lower bound	Mode	Upper	Distribution shape	Zone Area (km^2)	f(4)/(km^2) for M_0>=4 0 Lower bound	Mode	Upper bound	Return Periods (years) Lower bound	Mode	Upper bound	Comments
0.04	0 1	0 2	Triangle	85307	4 68895E-05	0 000117224	0.000234447	5.0	10 0	25 0	
0.015	0 04	0 06	Triangle	89362	1 67857E-05	4.47618E-05	6 71426E-05	16.7	25 0	66 7	
0.05	0 09	0 15	Triangle	51988	9.6176E-05	0 000173117	0.000288528	6 7	11.1	20.0	
			Triangle	130167	0	0	0				
0.035	0 06	0 1	Triangle	1924	0 001819127	0.003118503	0 005197505	10 0	16.7	28 6	
0.035	0 06	0.1	Triangle	3098	0 001129761	0.001936733	0.003227889	10 0	16.7	28.6	
0.035	0.06	0 1	Triangle	7992	0 000437938	0.000750751	0.001261251	10.0	16.7	28 6	
			Triangle	8996	0	0	0				
			Triangle	1993	0	0	0				
0.022	0 044	0 088	Triangle	24926	8 82613E-05	0.000176523	0 088	11.4	22 7	45 5	Based on LLNL calculations
0.015	0 03	0 06	Triangle	298749	5 02094E-06	[illegible].00419E-05	2 00837E-05	16.7	33.3	66.7	Based on LLNL calculations
0.0027	0 0053	0 016	Triangle	72932	3 70208E-06	[illegible].26704E-06	2.19382E-05	62.5	188.7	370.4	Based on LLNL calculations
0.07	0 15	0 2	Triangle	15746	0 000444557	0.000952623	0 001270164	5 0	6 7	14.3	Represent the entire seismicity
0.07	0 15	0 2	Triangle	19973	0 000350473	0.000751014	0.001001352	5 0	6 7	14.3	of the ETSZ, regardless of boundary
0.07	0.15	0 2	Triangle	24422	0 000286627	0.0006142	0 000818934	5 0	6 7	14.3	location
0 045132	0 096712	0 [illegible]289493	Triangle	15746	0 000286627	0.0006142	0.000818934	7.8	10 3	22 2	Apportion by areas, total of 4B-1
0.024868	0 053288	0 [illegible]710507	Triangle	8676	0 000286627	0.0006142	0 000818934	14.1	18 8	40 2	and 4B-2 equals 4a(1+2+3)
			Triangle								
			Triangle	24422	0	0	0				
0 065033	0 1[illegible]7927	0 [illegible]572359	Triangle	15746	0 000349502	0 000748933	0.000998577	6 4	8 5	18 2	
0 01108	0 0[illegible]3743	0 0[illegible]16574	Triangle	4227	0 000262126	0 0005617	0 000748933	31 6	42.1	90 3	
0 003887	0 [illegible]0833	0 0[illegible]11067	Triangle	4449	8 73755E-05	0 000187233	0.000249644	90 0	120 0	257 2	
			Triangle	[illegible]9058	0	0	0				
			Triangle	[illegible]0435	0	0	0				
			Triangle	2[illegible]9493	0	0	0				
			Triangle	[illegible]1393	0	0	0				
0.25	0.5	[illegible]	Triangle	340000	7.35294E-05	0 000147059	0 000205882	1.4	2.0	4 0	

size of unit area (in km^2) = 100

7, 8 and 9 are normalized for 100 km^2

Table 4.4-9 Probability Distributions of the Seismicity Rates f(4) for Jacob

EVA. Klaus JACOB

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps
Date of the elicitation 19-Dec-96

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE 4 0

Names of Zones in the composite set of zonation maps	Frequency rate per year for M_b>=4 0 Lower bound	Mode	Upper bound	Distribution shape	Zone Area (km²)	f(4)/(km²) for M_b>=4 0 Lower bound	Mode	Upper bound	Return Periods (years) Lower bound	Mode	Upper bound	Comments
3A-1	0 05	0 1	0 2	Triangle	85307	5 861E-05	0 00011722	0 0002344	5 0	10 0	20 0	
3B-3A	0 05	0 08	0 15	Triangle	89362	5 595E-05	8 9524E-05	0 0001679	6 7	12 5	20 0	
3C-Alternative-to-3A	0 045	0 083	0 15	Triangle	51988	8 656E-05	0 00015965	0 0002885	6 7	12 0	22 2	
3B-3C	0 02	0 05	0 08	Triangle	130167	1 536E-05	3 8412E-05	6 146E-05	12 5	20 0	50 0	
Charleston												
1A(localized1886)	0 05	0 07	0 1	Triangle	1924	0 0025988	0 00363825	0 0051975	10 0	14 3	20 0	
1B(3blobs)	0 05	0 07	0 1	Triangle	3098	0 0016139	0 00225952	0 0032279	10 0	14 3	20 0	
1C(ZRA)	0 05	0 07	0 1	Triangle	7992	0 0006256	0 00087588	0 0012513	10 0	14 3	20 0	
1D(3extended blobs)	0 05	0 07	0 1	Triangle	8996	0 0005558	0 00077812	0 0011116	10 0	14 3	20 0	
1E(2side-blobs+1A)	0 05	0 07	0 1	Triangle	1993	0 0025088	0 00351229	0 0050176	10 0	14 3	20 0	Two side blobs, non characteristic part
Bckgnd-to-Charlstn												
6-Central-Virginia	0 03	0 08	0 12	Triangle	24926	0 0001204	0 00032095	0 12	8 3	12 5	33 3	
7(Coast Plain-CVSZ)	0 01	0 025	0 05	Triangle	298749	3 347E-06	8 3682E-06	1 674E-05	20 0	40 0	100 0	
8 Offshore				Triangle	72932	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
ETSZ												
4A-1	0 0387	0 0967	0 1612	Triangle	15746	0.0002457	0 0006142	0 0010237	6 2	10 3	25 8	
(4A-1)+(4A-2)	0 0491	0 1227	0 2045	Triangle	19973	0 0002457	0 0006142	0 0010237	4 9	8 2	20 4	
(4A-1)+(4A-2)+(4A-3)	0 06	0 15	0 25	Triangle	24422	0 0002457	0 0006142	0 0010237	4 0	6 7	16 7	
4B-1	0 0387	0 0967	0 1612	Triangle	15746	0 0002457	0 0006142	0 0010237	6 2	10 3	25 8	
4B-2	0 0213	0 0533	0 0888	Triangle	8676	0 0002457	0 0006142	0 0010237	11 3	18 8	46 9	Seismicity distributed uniformly among the 8 faults
4C-(8-faults)	0 06	0 15	0 25	Triangle	100	0 06	0 15	0 25	4 0	6 7	16 7	
4D-(varying)-rates				Triangle	24422	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
4E-(3 cyl rate-zones)												
-first-cylinder-(4-1)	0 0472	0 1179	0 1965	Triangle	15746	0 0002996	0 00074893	0 0012482	5 1	8 5	21 2	
--second cyl -(4-2)	0 0095	0 0237	0 0396	Triangle	4227	0 0002247	0 0005617	0 0009362	25 3	42 1	105 3	
--third-cylind -(4-3)	0 0033	0 0083	0 0139	Triangle	4449	7.489E-05	0 00018723	0 0003121	72 0	120 0	300 1	
Bckgnd-to-ETSZ												
(5-1)				Triangle	79058	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
(5-2)				Triangle	170435	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
(5-1)+(5-2)				Triangle	249493	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
(5-3)				Triangle	81393	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
(5-1)+(5-2)+(5-3)				Triangle	340000	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	

multiplicative factor for the size of unit area (in km ²) = 100
Thus the rates in columns 7, 8 and 9 are normalized for 100 km²

Table 4.4-10 Probability Distributions of the Seismicity Rates f(4) for Talwani

EVA Pradeep TALWANI

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps
Date of the elicitation 26-Jan-97

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE 4.0

Names of Zones in the composite set of zonation maps	Frequency rate per year for M_b>=4.0				Zone Area (km²)	f(4)/(km²) for M_b>=4.0			Return Periods (years)			Comments
	Lower bound	Mode	Upper bound	Distribution shape		Lower bound	Mode	Upper bound	Lower bound	Mode	Upper bound	
3A	0.07	0.0813	0.0955	Triangle	85307	8.206E-05	9.528E-05	0.00011195	10.5	12.3	14.3	
3B-3A	0.0182	0.0257	0.0955	Triangle	89362	2.037E-05	2.876E-05	0.00010687	10.5	38.9	54.9	
3C-Alternative-to-3A	0.03	0.0407	0.0832	Triangle	51988	5.771E-05	7.829E-05	0.00016004	12.0	24.6	33.3	
3B-3C	0.025	0.0309	0.0955	Triangle	130167	1.921E-05	2.374E-05	7.3367E-05	10.5	32.4	40.0	
Charleston												
1A(localized1886)	0.0372	0.0407	0.0646	Triangle	1924	0.0019309	0.0021175	0.00335759	15.5	24.5	26.9	
1B(3blobs)				Triangle	3098	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
1C(ZRA)				Triangle	7992	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
1D(3extended-blobs)				Triangle	8996	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
1E(2side-blobs+1A)				Triangle	1993	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
Bckgnd-to-Charlstn												
6-Central-Virginia	0.0316	0.0525	0.0589	Triangle	24926	0.0001269	0.0002105	0.00023622	17.0	19.1	31.6	Based on LLNL calculations
7(Coast Plain CVSZ)	0.01	0.0148	0.0251	Triangle	298749	3.347E-06	4.951E-06	8.4084E-06	39.8	67.6	100.0	Based on LLNL calculations
8 Offshore				Triangle	72932	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Based on LLNL calculations
ETSZ												
4A-1				Triangle	15746	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Represent the entire seismicity
(4A 1)+(4A 2)				Triangle	19973	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	of the ETSZ, regardless of boundary
(4A-1)+(4A 2)+(4A 3)	0.07	0.0866	0.1412	Triangle	24422	0.0002866	0.0003546	0.00057817	7.1	11.5	14.3	location
4B 1				Triangle	15746	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Apportion by areas, total of 4B-1
4B-2				Triangle	8676	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	and 4B 2 equals 4a(1+2+3)
4C-(8 faults)				Triangle	-				#DIV/0!	#DIV/0!	#DIV/0!	
4D (varying)-rates				Triangle	24422	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	
4E-(3 cyl rate-zones)												
--first cylinder-(4-1)	0.055	0.0681	0.111	Triangle	15746	0.0003495	0.0004324	0.000705	9.0	14.7	18.2	
--second-cyl -(4-2)	0.0111	0.0137	0.0224	Triangle	4227	0.0002621	0.0003243	0.00052875	44.7	73.0	90.3	
--third-cylind (4-3)	0.0039	0.0048	0.0078	Triangle	4449	8.738E-05	0.0001081	0.00017625	127.5	207.9	257.2	
Bckgnd-to-ETSZ												
(5-1)	0.0778	0.1177	0.1518	Triangle	79058	9.84E-05	0.0001489	0.00019199	6.6	8.5	12.9	
(5 2)	0.1677	0.2538	0.3272	Triangle	170435	9.84E-05	0.0001489	0.00019199	3.1	3.9	6.0	
(5 1)+(5-2)	0.2455	0.3715	0.479	Triangle	249493	9.84E-05	0.0001489	0.00019199	2.1	2.7	4.1	
(5 3)	0.0811	0.1227	0.1582	Triangle	82393	9.84E-05	0.0001489	0.00019199	6.3	8.2	12.3	
(5-1)+(5-2)+(5-3)	0.3346	0.5063	0.6528	Triangle	340000	9.84E-05	0.0001489	0.00019199	1.5	2.0	3.0	

multiplicative factor for the size of unit area (in km²) = 100
Thus the rates in columns 7, 8 and 9 are normalized for 100 km²

Table 4.4-11 Probability Distributions of the Seismicity Rates $f(m_l)$ for Bollinger

EVA. Gilbert BOLLINGER

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps

Date of the elicitation. 8 Jan 97

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE M_i

Names of Zones in the composite set of zonation maps	M_i	Frequency rate per year for m >=M_i Lower bound	Mode	Upper bound	Distribution shape	Zone Area (km²)	f(4)/(km²) for m>=M_i Lower bound	Mode	Upper bound	Return Periods (years) Lower bound	Mode	Upper bound	Comments
3A(1+2)	5 00	2 500E 03	4 900E 03	9 600E 03	Triangle	85307	2 931E 06	5 744E 06	1.125E 05	104 2	204 1	400 0	
3B 3A	5 00	1 700E 03	3 300E 03	5 000E-03	Triangle	89362	1 902E 06	3 693E 06	5 595E 06	200 0	303 0	588 2	
3C-Alternative-to-3A	6 00	1 000E 04	3 000E 04	1 100E-03	Triangle	51988	1 924E 07	5 771E 07	2 116E 06	909 1	3333 3	10000 0	
3B 3C	4 50	4 357E 04	8 278E 04	1 699E-03	Triangle	130167	3 347E 07	6 360E 07	1 305E 06	588 5	1208 0	2295 1	
Charleston													
1A(localized1886)	6 00	1 000E 04	4 000E 04	1 100E 03	U taper	1924	5 198E 06	2 079E-05	5 717E 05	909 1	2500 0	10000 0	
Charleston-Charact	7 30	2 000E 04	1 000E 03	1 667E 03	U taper	1924	3 848E 03	1 924E-02	3 207E 02			-	
1B(3blobs)	6 00	1 000E 04	4 000E 04	1 100E 03	U taper	3098	3 228E 06	1 291E 05	3 551E 05	909 1	2500 0	10000 0	
1C(ZRA)	6.00	1.000E 04	4.000E 04	1.100E 03	U taper	7992	1.251E 06	5.005E-06	1.376E 05	909 1	2500.0	10000.0	
1D(3extended blobs)	6 00	1 000E 04	4 000E 04	1 100E 03	U taper	8996	1 112E 06	4 446E 06	1 223E 05	909 1	2500 0	10000 0	
1E(2side blobs+1A)	6 00	1 000E 04	4 000E 04	1 100E 03	U taper	1993	5 018E 06	2 007E 05	5 519E 05	909 1	2500 0	10000 0	
Bckgnd-to-Charlstn													
6-Central-Virginia	5 80	1 600E-03	3 000E-03	4 170E 02	Taper U	24926	6 419E 06	1 204E 05	4 170E 02	24 0	333 3	625 0	
7(Coast.Plain CVSZ)	4 50	1 000E-03	1 900E 03	3 900E 03	Triangle	298749	3 347E 07	6 360E 07	1 305E 06	256 4	526 3	1000 0	
8 Offshore	4 50	2 441E 04	4 638E 04	9 521E 04	Triangle	72932	3 347E 07	6 360E-07	1 305E 06	1050 3	2155 9	4096 3	
ETSZ													
4A 1	6 00	1 032E-03	1 354E 03	1 934E-03	Uniform	15746	6 651E 06	8 599E 06	1 228E 05	517 0	738 6	969 4	
(4A-1)+(4A 2)	6 00	1 309E 03	1 717E 03	2 453E-03	Uniform	19973	6 551E 06	8 599E 06	1 228E 05	407 6	582 3	764 2	
(4A-1)+(4A 2)+(4A 3)	6 00	1 600E 03	2 100E-03	3 000E-03	Uniform	24422	6 551E 06	8 599E 06	1 228E 05	333 3	476 2	625 0	
4B 1	6 00	2 750E 04	1 100E 03	4 400E 03	Uniform	15746	1 746E-06	6 986E 06	2 794E 05	227 3	909 1	3636 4	
4B 2	6 00	1 515E-04	6 061E-04	2 400E-03	Uniform	8676	1 746E 06	6 986E 06	2 766E 05	4 17E+02	1 65E+03	6 60E+03	
4C-(8 faults)													
4D-(varying) rates						24422	0 000E+00	0 000E+00	0 000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
4E-(3.cyl rate zones)													
first cylinder-(4 1)	6.00	1.258E 03	1.651E 03	2.359E 03	Triangle	15746	7.989E 06	1.049E 05	1.498E 05	424.0	605.7	795.0	
second-cyl (4 2)	6 00	2 533E 04	3 324E 04	4 749E 04	Triangle	4227	5 991E 06	7 864E 06	1 123E 05	2105 9	3008 4	3948 5	
third-cylind.-(4 3)	6 00	8 885E 05	1 166E 04	1 666E 04	Triangle	4449	1 997E 06	2 621E-06	3 745E 06	6002 4	8574 9	11254 5	
Bckgnd-to-ETSZ													
(5-1)	5 50	1 933E-03	2 408E-03	4 818E 03	Uniform	79058	2 445E 06	3 046E 06	6 092E 06	207 6	415 2	517 3	
(5-2)	5 50	4 167E 03	5 192E 03	1 038E 02	Uniform	170435	2 445E 06	3 046E 06	6 092E-06	96 3	192 6	240 0	
(5-1)+(5-2)	5 50	6 100E-03	7 600E 03	1 520E-02	Uniform	249493	2 445E 06	3 046E 06	6 092E 06	65 8	131 6	163 9	
(5-3)	5.50				Uniform	81393	0.000E+00	0.000E+00	0.000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
(5-1)+(5-2)+(5-3)	5 50				Uniform	340000	0 000E+00	0 000E+00	0 000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
Large Bowman 9A	5 50	1 300E 03	2 700E-03	5 400E-03	Uniform	922	1 410E 04	2 928E 04	5 857E 04	185 2	370 4	769 2	

multiplicative factor for the size of unit area (in km²) = 100

Rates in columns 7, 8 and 9 are normalized for 100 km²

Table 4.4-12 Probability Distributions of the Seismicity Rates $f(m_1)$ for Chapman

EVA Martin CHAPMAN

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps

Date of the elicitation 19 Dec 96

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE M_1

Names of Zones in the composite set of zonation maps	M_1	Frequency rate per year for m>=M₁ Lower bound	Mode	Upper bound	Distribution shape	Zone Area (km²)	f(4)/(km²) for m>=M₁ Lower bound	Mode	Upper bound	Return Periods (years) Lower bound	Mode	Upper bound	Comments
3A	5.90	3.000E-04	1.000E-03	3.000E-03	Triangle	85307	3.517E-07	1.172E-06	3.517E-06	333.3	1000.0	3333.3	
3B-3A	6.00	2.670E-05	1.060E-04	4.250E-04	Triangle	89362	2.988E-08	1.186E-07	4.756E-07	2352.9	9434.0	37453.2	
3C Alternative to-3A	6.00	5.500E-05	2.200E-04	8.800E-04	Triangle	51988	1.058E-07	4.232E-07	1.693E-06	1136.4	4545.5	18181.8	
3B-3C	6.00	2.670E-05	1.060E-04	4.250E-04	Triangle	130167	2.051E-08	8.143E-08	3.265E-07	2352.9	9434.0	37453.2	
Charleston													
1A(localized1886)	6.50	1.450E-04	2.900E-04	5.800E-04	Triangle	1924	7.536E-06	1.507E-05	3.015E-05	1724.1	3448.3	6896.6	
Charleston Charact	7.20	5.000E-04	1.000E-03	1.198E-03	Uniform	1924	9.620E-03	1.924E-02	2.305E-02				
1B(3blobs)					Triangle	3098	0.000E+00	0.000E+00	0.000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
1C(ZRA)	6.50	5.000E-04	1.000E-03	1.198E-03	Uniform	7992	6.256E-06	1.251E-05	1.499E-05	834.7	1000.0	2000.0	
1D(3extended blobs)					Triangle	8996	#VALUE!	0.000E+00	0.000E+00	#DIV/0!	#DIV/0!	#VALUE!	
1E(2side blobs+1A)					Triangle	1993	0.000E+00	0.000E+00	0.000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
Bckgnd to-Charlstn													
6 Central Virginia	6.00	6.000E-04	2.400E-03	9.500E-03	Triangle	24926	2.407E-06	9.629E-06	9.500E-03	105.3	416.7	1666.7	
7(Coast Plain-CVSZ)	6.00	1.000E-04	3.000E-04	1.400E-03	Triangle	298749	3.347E-08	1.004E-07	4.686E-07	714.3	3333.3	10000.0	
8 Offshore	6.00	1.800E-05	7.324E-05	2.470E-04	Triangle	72932	2.468E-08	1.004E-07	3.387E-07	4048.6	13654.2	55555.6	
ETSZ													
4A-1	6.00	1.853E-04	7.413E-04	2.965E-03	Triangle	15746	1.177E-06	4.708E-06	1.883E-05	337.3	1349.0	5396.7	
(4A-1)+(4A-2)	6.00	1.717E-04	5.275E-04	2.126E-03	Triangle	19973	8.599E-07	2.641E-06	1.065E-05	470.3	1895.7	5822.6	
(4A-1)+(4A-2)+(4A-3)	6.00	2.100E-04	6.450E-04	2.600E-03	Triangle	24422	8.599E-07	2.641E-06	1.065E-05	384.6	1550.4	4761.9	
4B-1	6.00	2.750E-04	1.100E-03	4.400E-03	Triangle	15746	1.746E-06	6.986E-06	2.794E-05	227.3	909.1	3636.4	
4B-2	6.00	3.560E-05	1.422E-04	5.690E-04	Triangle	8676	4.103E-07	1.639E-06	6.558E-06	1.76E+03	7.03E+03	2.81E+04	
4C-(6-faults)					Triangle					#DIV/0!	#DIV/0!	#DIV/0!	
4D-(varying)-rates					Triangle	24422	0.000E+00	0.000E+00	0.000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
4E-(3.cyl.rate-zones)													
first cylinder-(4-1)	6.00	1.651E-04	5.071E-04	2.044E-03	Triangle	15746	1.049E-06	3.220E-06	1.298E-05	489.2	1972.1	6057.0	
second-cyl.-(4-2)	6.00	3.324E-05	1.021E-04	4.115E-04	Triangle	4227	7.864E-07	2.415E-06	9.736E-06	2429.9	9794.8	30084.0	
third-cylnd.-(4-3)	6.00	1.166E-05	3.582E-05	1.444E-04	Triangle	4449	2.621E-07	8.051E-07	3.245E-06	6925.8	27918.1	85748.5	
Bckgnd-to-ETSZ													
(5-1)	6.00	6.000E-04	2.500E-03	1.010E-02	Triangle	79058	7.589E-07	3.162E-06	1.278E-05	9.90E+01	4.00E+02	1.67E+03	
(5-2)	6.00	3.100E-03	1.250E-02	5.000E-02	Triangle	170435	1.819E-06	7.334E-06	2.934E-05	2.00E+01	8.00E+01	3.23E+02	
(5-1)+(5-2)	6.00	6.500E-03	2.620E-02	1.050E-01	Triangle	249493	2.605E-06	1.050E-05	4.209E-05	9.52E+00	3.82E+01	1.54E+02	
(5-3)	6.00	1.880E-04	7.500E-04	3.000E-03	Triangle	81393	2.310E-07	9.215E-07	3.686E-06	333.3	1333.3	5319.1	
(5-1)+(5-2)+(5-3)	6.00				Triangle	340000	0.000E+00	0.000E+00	0.000E+00	#DIV/0!	#DIV/0!	#DIV/0!	

multiplicative factor for the size of unit area (in km²) = 100

Rates in columns 7, 8 and 9 are normalized for 100 km²

Table 4.4-13 Probability Distributions of the Seismicity Rates $f(m_1)$ for Coppersmith

EVA. Kevin COPPERSMITH

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps
Date of the elicitation. 8-Jan-97

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE M_1

Names of Zones in the composite set of zonation maps	M_1	Frequency rate per year for m >= M_1				Zone	f(4)/(km²) for m >= M_1			Return Periods (years)			Comments
		Lower bound	Mode	Upper bound	Distribution shape	Area (km²)	Lower bound	Mode	Upper bound	Lower bound	Mode	Upper bound	
3A	6 00	1 500E-04	4 000E-04	1 000E-03	Triangle	85307	1 758E-07	4 689E-07	1 172E 06	1000 0	2500 0	6666 7	
3B 3A	5 50	2 000E-04	5 000E-04	1 500E 03	Triangle	89362	2 238E-07	5 595E-07	1 679E-06	666 7	2000 0	5000 0	
3C Alternative-to-3A	5 50	3 000E-04	9 000E-04	2 500E-03	Triangle	51988	5 771E-07	1 731E-06	4 809E-06	400 0	1111 1	3333 3	
3B-3C	5 50	2 000E-04	5 000E-04	1 500E-03	Triangle	130167	1 536E-07	3 841E-07	1.152E-06	666 7	2000 0	5000 0	
Charleston													
1A(localized 1886)	6 50	1 000E-04	3 500E-04	2 000E-03	Triangle	1924	5 198E 06	1.819E-05	1 040E-04	500 0	2857.1	10000 0	
Charleston-Charact.	7 30	4 000E-04	1 000E 03	3 330E-03	Uniform	1924	7 696E-03	1 924E-02	6 407E-02				
1B(3blobs)					Triangle	3098	0 000E+00	0 000E+00	0 000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
1C(ZRA)	6 50	1 000E-04	3 500E-04	2 000E-03	Uniform	7992	1 251E-06	4 379E-06	2 503E-05	500.0	2857 1	10000 0	
1D(3extended-blobs)					Triangle	8996	#VALUE!	0 000E+00	0 000E+00	#DIV/0!	#DIV/0!	#VALUE!	
1E(2side blobs+1A)					Triangle	1993	0 000E+00	0 000E+00	0 000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
Bckgnd-to-Charlstn													
6-Central-Virginia					Triangle	24926	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
7(Coast.Plain-CVSZ)					Triangle	298749	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
8-Offshore					Triangle	72932	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
ETSZ													
4A-1	6 00	9 671E-05	2 579E-04	6 447E-04	Triangle	15746	6 142E-07	1.638E-06	4 095E-06	1551 0	3877 5	10340 0	
(4A-1)+(4A-2)	6 00	1 227E-04	3 271E-04	8 178E-04	Triangle	19973	6 142E-07	1 638E-06	4 095E-06	1222 8	3056 9	8151 7	
(4A-1)+(4A 2)+(4A-3)	6 00	1 500E-04	4 000E-04	1 000E-03	Triangle	24422	6 142E-07	1 638E-06	4 095E-06	1000 0	2500 0	6666 7	
4B-1	6 00	9 671E-05	2 579E-04	6 447E-04	Triangle	15746	6 142E-07	1 638E-06	4.095E 06	1551 0	3877 5	10340 0	
4B-2	6 00	5 329E-05	1 421E 04	3.553E-04	Triangle	8676	6 142E 07	1 638E-06	4 095E-06	2 81E+03	7 04E+03	1 88E+04	
4C-(8-faults)					Triangle					#DIV/0!	#DIV/0!	#DIV/0!	
4D-(varying)-rates					Triangle	24422	0 000E+00	0 000E+00	0 000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
4E-(3.cyl.rate-zones)													
first cylinder-(4-1)	6 00	1.179E-04	3.145E-04	7.862E-04	Triangle	15746	7.489E-07	1 997E-06	4 993E-06	1272 0	3179 9	8479 8	
second-cyl.-(4-2)	6 00	2 374E-05	6 331E-05	1 583E-04	Triangle	4227	5 617E-07	1.498E-06	3 745E-06	6317 6	15794 1	42117 6	
third-cylind -(4-3)	6 00	8 330E-06	2 221E-05	5 553E-05	Triangle	4449	1 872E-07	4 993E-07	1 248E-06	18007 2	45018 0	120048 0	

Table 4.4-14 Probability Distributions of the Seismicity Rates f(m1) for Jacob

EVA Klaus JACOB

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps

Date of the elicitation 19 Dec-96

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE M1

Names of Zones in the composite set of zonation maps	M1	Frequency rate per year for m>=M1: Lower bound	Mode	Upper bound	Distribution shape	Zone Area (km²)	f(4)/(km²) for m>=M1: Lower bound	Mode	Upper bound	Return Periods (years): Lower bound	Mode	Upper bound	Comments
3A	6 50	5 000E-05	1 600E-04	1.000E-03	Triangle	85307	5 861E-08	1 876E-07	1.172E-06	1000 0	6250 0	20000 0	
3B 3A	6 00	8 000E-05	1 500E-04	8 000E-04	Triangle	89362	8 952E-08	1 679E-07	8 952E-07	1250 0	6666 7	12500 0	
3C-Alternative-to-3A	6 00	1 000E-04	3 000E-04	1 000E-03	Triangle	51988	1.924E-07	5.771E-07	1.924E-06	1000 0	3333 3	10000 0	
3B 3C	6 00	1.000E-04	9 000E-04	2 000E-03	Triangle	130167	7 682E 08	6 914E-07	1.536E 06	500 0	1111 1	10000 0	
Charleston													
1A(localized1886)	6 00	5 000E-04	2 000E 03	3 300E-03	Triangle	1924	2 599E-05	1 040E-04	1 715E-04	303 0	500 0	2000 0	
Charleston-Charact	7.50	7.100E-04	1 600E-03	3 000E-03	Uniform	1924	1.366E-02	3.078E-02	5.772E-02	333.3	625 0	1408 5	
1B(3blobs)					Triangle	3098	#VALUE!	#VALUE!	0 000E+00	#DIV/0!	#VALUE!	#VALUE!	
1C(ZRA)	7 50	5 000E 04	2 000E-03	3 300E-03	Uniform	7992	6 256E-06	2 503E-05	4,129E-05	303 0	500 0	2000 0	
1D(3extended blobs)	6 00	7,100E-04	1 600E-03	3 000E-03	Triangle	8996	7.892E-06	1.779E-05	3.335E-05	333.3	625.0	1408.5	
1E(2side-blobs+1A)	6 00	7 100E-04	1 600E-03	3 000E-03	Triangle	1993	3 562E-05	8 028E-05	1 505E-04	333 3	625 0	1408 5	
Bckgnd-to-Charlstn													
6-Central Virginia	6 00	2 000E-04	1 300E-03	4 000E-03	Triangle	24926	8 024E-07	5 215E-06	4 000E-03	250 0	769.2	5000 0	
7(Coast Plain-CVSZ)	6 00	1 500E-04	4 500E-04	1.200E 03	Triangle	298749	5.021E-08	1 506E 07	4 017E-07	833 3	2222 2	6666 7	
8 Offshore						72932	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
ETSZ													
4A-1	6 00	1 900E-04	1,300E-03	3 200E-03	Triangle	15746	1.207E-06	8 256E-06	2.032E-05	312.5	769.2	5263.2	
(4A 1)+(4A-2)	6 00	2 400E-04	1 600E-03	4,100E-03	Triangle	19973	1.202E-06	8 011E-06	2 053E-05	243 9	625 0	4166 7	
(4A-1)+(4A 2)+(4A 3)	6.00	3.000E 04	2.000E-03	5 000E-03	Triangle	24422	1 228E-06	8 189E-06	2 047E-05	200 0	500.0	3333.3	
4B 1	6 00	1,900E-04	1,300E-03	3 200E-03	Triangle	15746	1.207E 06	8 256E-06	2 032E-05	312 5	769.2	5263.2	
4B-2	6.00	1.070E-04	7.100E-04	1.780E-03	Triangle	8676	1.233E-06	8 183E-06	2.052E-05	5 62E+02	1.41E+03	9.35E+03	
4C-(8-faults)					Triangle					#DIV/0!	#DIV/0!	#DIV/0!	
4D-(varying)-rates					Triangle	24422	0.000E+00	0 000E+00	0 000E+00	#DIV/0!	#DIV/0!	#DIV/0!	
4E (3.cyl.rate zones)													
first cylinder-(4-1)	6 00	2.365E-04	1.577E 03	3.942E-03	Triangle	15746	1 502E-06	1 001E-05	2.503E-05	253 7	634 2	4228 2	
second-cyl.-(4-2)	6.00	4.762E-05	3.175E-04	7.936E-04	Triangle	4227	1.127E-06	7.510E-06	1.878E-05	1260.0	3150.1	21000.4	
third-cylind.-(4 3)	6 00	1.671E-05	1.114E 04	2.784E 04	Triangle	4449	3.755E-07	2.503E-06	6 258E-06	3591.5	8978.6	59857 6	
Bckgnd-to ETSZ													
(5-1)	6 00	3.200E-02	6.500E-02	2.000E-02	Triangle	79058	4 048E-05	8.222E-05	2.530E-05	5.00E+01	1.54E+01	3.13E+01	
(5-2)	6 00	4.500E-03	9.600E-03	2.700E 02	Triangle	170435	2.640E-06	5 633E-06	1.584E 05	3 70E+01	1.04E+02	2.22E+02	
(5-1)+(5-2)	6 00	8 100E-03	1 600E-02	4 800E-02	Triangle	249493	3.247E-06	6.413E 06	1.924E-05	2.08E+01	6 25E+01	1.23E+02	
(5-3)	6.00	1.900E-03	3 800E-03	1.150E-02	Triangle	82393	2.306E-06	4.612E-06	1.396E 05	87.0	263.2	526 3	
(5-1)+(5-2)+(5-3)	6 00	1 000E-02	2 000E-02	6 000E-02	Triangle	340000	2 941E-06	5 882E-06	1 765E-05	16 7	50 0	100 0	

multiplicative factor for the size of unit area (in km²) = 100

Rates in columns 7, 8 and 9 are normalized for 100 km²

Table 4.4-15 Probability Distributions of the Seismicity Rates f(m1) for Talwani

EVA Pradeep TALWANI

Elicitation of preliminary estimates for the seismicity rates and upper magnitude cutoffs for the zones in the composite seismic sources maps
Date of the elicitation 20 Jan 97

ELICITATION OF FREQUENCY RATES PER YEAR AT MAGNITUDE M_1

Names of Zones in the composite set of zonation maps	M_1	Frequency rate per year for m>=M_1				Zone Area (km²)	f(4)/(km²) for m>=M_1			Return Periods (years)			Comments
		Lower bound	Mode	Upper bound	Distribution shape		Lower bound	Mode	Upper bound	Lower bound	Mode	Upper bound	
3A	5 00	6 46E 03	6 92E-03	1 51E 02	Triangle	77241	8 36343E-06	8 95897E 06	1 9601E 05	66 1	144 5	154 6	
3B 3A	5 00	1 41E 03	3 16E 03	1 51E-02	Triangle	100274	1 40615E-06	3 15137E-06	1 50986E 05	66 1	316 5	709 2	
3C-Alternative to 3A	5 00	2 50E 03	3 09E 03	1 29E 02	Triangle	52780	4 73664E 06	5 85449E 06	2 44032E 05	77 6	323 6	400 0	
3B 3C	4 50	9 23E 03	9 77E 03	3 43E 02	Triangle	132203	6 98169E-06	7 39015E 06	2 59298E 05	29 2	102 4	108 3	
Charleston													
1A(localized1886)	6 80	1 00E 04	1 23E 04	2 00E-03	Triangle	1924	5 19751E-06	6 39293E 06	0 00010395	500 0	8130 1	10000 0	
Charleston-Charact	7 30		2 00E 03		Uniform	1924	#VALUE!	0 03848	#VALUE!				
1B(3blobs)					Triangle	4985	#VALUE!	#VALUE!	0	#DIV/0!	#VALUE!	#VALUE!	
1C(ZRA)					Uniform	11920	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
1D(3extended blobs)					Triangle	15266	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
1E(2side blobs+1A)					Triangle	3060	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
Bckgnd to-Charlstn													
6-Central-Virginia	5 00	0 00589	7 59E 03	0 01	Triangle	24926	2 36299E 05	3 04501E-05	0 01	100 0	131 8	169 8	
7(Coast Plain-CVSZ)	4 00	1 00E 02	1 48E-02	0 02512	Triangle	323676	3 08952E 06	4 5694E 06	7 76087E-06	39 8	67 6	100 0	
8 Offshore						57200							
ETSZ													
4A 1	5 50	5 68E 04	8 00E 04	4 07E 03	Triangle	15746	3 60785E 06	5 07801E 06	2 58405E 05	245 8	1250 7	1760 3	
(4A 1)+(4A 2)	5 50	7 21E 04	1 01E 03	5 16E 03	Triangle	19973	3 60785E-06	5 07801E-06	2 58405E-05	193 8	986 0	1387 7	
(4A-1)+(4A 2)+(4A 3)	5 50	8 81E 04	1 24E 03	6 31E-03	Triangle	24419	3 60785E-06	5 07801E 06	2 58405E 05	158 5	806 5	1135 1	
4B-1	5 50	5 68E 04	8 00E 04	4 07E-03	Triangle	15746	3 60785E-06	5 07801E-06	2 58405E-05	245 8	1250 7	1760 3	
4B 2	5 50	3 13E 04	4 41E 04	2 24E-03	Triangle	8676	3 60785E 06	5 07801E-06	2 58405E-05	4 46E+02	2 27E+03	3 19E+03	
4C-(8-faults)					Triangle								
4D-(varying)-rates					Triangle	15746	0	0	0				
4E-(3.cyl.rate-zones)													
first cylinder (4 1)	5 50	0 00069265	0 000974899	0 00496098	Triangle	15746	4 3989E-06	6 19141E-06	3 15063E-05	201 6	1025 7	1443 7	
second-cyl -(4 2)	5 50	0 000139456	0 000196283	0 000998826	Triangle	4227	3 29917E-06	4 64356E 06	2 36297E-05	1001 2	5094 7	7170 7	
third-cylind -(4 3)	5 50	4 89267E 05	6 8864E 05	0 000350429	Triangle	4449	1 09972E-06	1 54785E 06	7 87657E 06	2853 6	14521 4	20438 7	
Bckgnd to-ETSZ													
(5-1)	5 00	1 49E 02	1 87E 02	1 96E-02	Triangle	110000	1 35154E-05	1 70152E-05	1 78192E-05	5 10E+01	5 34E+01	6 73E+01	
(5-2)	5 00	2 08E 02	2 62E-02	2 74E 02	Triangle	154000	1 35154E-05	1.70152E 05	1 78192E 05	3 64E+01	3 82E+01	4 80E+01	
(5-1)+(5-2)	5 00	3 72E 02	4 68E 02	4 90E-02	Triangle	274872	1 35154E-05	1 70152E-05	1 78192E-05	2 04E+01	2 14E+01	2 69E+01	
(5-3)	5 00	0 008784998	0 011059875	0 011582482	Triangle	65000	1 35154E-05	1 70152E-05	1 78192E 05	86 3	90 4	113 8	
(5-1)+(5-2)+(5-3)	5 00	0 045952298	0 057851655	0 060585291	Triangle	340000	1 35154E-05	1 70152E-05	1 78192E-05	16 5	17 3	21 8	

multiplicative factor for the size of unit area (in km ²) = 100
Rates in columns 7, 8 and 9 are normalized for 100 km²

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