Implementation of the SSHAC Guidelines for Level 3 and 4 PSHAs—Experience Gained from Actual Applications

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Introduction

In April 1997, after four years of deliberations, the Senior Seismic Hazard Analysis Committee released its report "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts" through the U.S. Nuclear Regulatory Commission as NUREG/CR–6372, hereafter SSHAC (1997). Known informally ever since as the "SSHAC Guidelines," SSHAC (1997) addresses why and how multiple expert opinions–and the intrinsic uncertainties that attend them–should be used in Probabilistic Seismic Hazard Analyses (PSHA) for critical facilities such as commercial nuclear power plants.

Ten years later, in September 2007, the U.S. Geological Survey (USGS) entered into a 13-month agreement with the U.S. Nuclear Regulatory Commission (NRC) titled "Practical Procedures for Implementation of the SSHAC Guidelines and for Updating PSHAs." The NRC was interested in understanding and documenting lessons learned from recent PSHAs conducted at the higher SSHAC Levels (3 and 4) and in gaining input from the seismic community for updating PSHAs as new information became available. This study increased in importance in anticipation of new applications for nuclear power facilities at both existing and new sites. The intent of this project was not to replace the SSHAC Guidelines but to supplement them with the experience gained from putting the SSHAC Guidelines to work in practical applications. During the course of this project, we also learned that updating PSHAs for existing nuclear power facilities involves very different issues from the implementation of the SSHAC Guidelines for new facilities. As such, we report our findings and recommendations from this study in two separate documents, this being the first.

The SSHAC Guidelines were written without regard to whether the PSHAs to which they would be applied were site-specific or regional in scope. Most of the experience gained to date from high-level SSHAC studies has been for site-specific cases, although three ongoing (as of this writing) studies are regional in scope. Updating existing PSHAs will depend more critically on the differences between site-specific and regional studies, and we will also address these differences in more detail in the companion report.

Most of what we report here and in the second report on updating PSHAs emanates from three workshops held by the USGS at their Menlo Park facility: "Lessons Learned from SSHAC Level 3 and 4 PSHAs" on January 30-31, 2008; "Updates to Existing PSHAs" on May 6-7, 2008; and "Draft Recommendations, SSHAC Implementation Guidance" on June 4-5, 2009. These workshops were attended by approximately 40 scientists and engineers familiar with hazard studies for nuclear facilities. This company included four of the authors of SSHAC (1997) and four other experts whose contributions to this document are mentioned in the Acknowledgments section; numerous scientists and engineers who in one role or another have participated in one or more high-level SSHAC PSHAs summarized later in this report; and representatives of the nuclear industry, the consulting world, the regulatory community, and academia with a keen interest and expertise in hazard analysis. This report is a community-based set of recommendations to NRC for improved practical procedures for implementation of the SSHAC Guidelines.

In an early publication specifically addressing the SSHAC Guidelines, Hanks (1997) noted that the SSHAC Guidelines were likely to evolve for some time to come, and this remains true today. While the broad philosophical and theoretical dimensions of the SSHAC Guidelines will not change, much has been learned during the past decade from various applications of the SSHAC Guidelines to real PSHAs in terms of how they are implemented. We anticipate that, in their practical applications, the SSHAC Guidelines will continue to evolve as more experience is gained from future SSHAC applications. Indeed, to the extent that every PSHA has its own particular wrinkles to iron out, some flexibility must be maintained in interpreting SSHAC (1997) and what we recommend here. For the same reason, it will surely be helpful for present and future projects to take stock of their own experience in implementing the SSHAC Guidelines.

The next section, The SSHAC Guidelines, recounts the reason for SSHAC (1997) and a brief summary of it, emphasizing what we consider to be the essential element of the SSHAC Guidelines, the SSHAC process of expert interaction. We then briefly describe the types of participants in the PSHAs conducted according to SSHAC (1997), how they function on the four different levels of SSHAC, and a brief description of high-level SSHAC PSHAs completed to date. The bulk of this report resides in the subsequent section, which presents our recommendations based on what we have learned from these completed studies and issues that arose while these studies were being conducted. We conclude with a glossary of terminology and appendices containing information about the workshops conducted as part of this project.

The SSHAC Guidelines are a complex tapestry woven from many different threads, occasionally imperfectly. Dealing with both the individual threads and the fabric as a whole in the sequential form of a written report presents significant challenges and, ultimately, arbitrary decisions as to which thread comes first, the most common commentary we received in the 17 reviews of the draft of this report. As is the case for the SSHAC Guidelines readers of this report must exercise some patience in working through it.

The SSHAC Guidelines

The SSHAC Guidelines are mostly concerned with the theory and practice of conducting probabilistic seismic hazard analyses for critical facilities for which significant economic, legal, political, and/or regulatory matters exist. Probabilistic Seismic Hazard Analysis (PSHA) is a methodology that calculates the likelihood that some measure of earthquake ground motion will be exceeded at some site during some specified time interval in the future. There are two essential inputs to PSHA. The first input is seismic-source characterization (SSC) information, which describes earthquake occurrence in the area of interest—where earthquakes occur, how often they occur, and how big they are when they do occur. The second input is ground-motion characterization (GMC) information, which describes the excitation and propagation of earthquake ground motion for all the earthquakes that may affect the site as a function of earthquake magnitude, distance, and frequency content of the radiated field.

These two basic building blocks of PSHA have been known and appreciated since Allin Cornell first articulated the PSHA methodology 40 years ago (Cornell, 1968). The principal concern of SSHAC (1997) is the *uncertainty* in these inputs to PSHA–and thus with the uncertainty in the final results of the PSHA. Indeed, the SSHAC Guidelines are emphatic on this matter; just one page into the Executive Summary, its readers are informed that "The most important and fundamental fact that must be understood about a PSHA is that the objective of estimating annual frequencies of exceedance of earthquake-caused ground motions can be attained only with significant uncertainty." It is this fundamental concern with uncertainties that generalizes the SSHAC Guidelines beyond PSHA to all manner of hazard analysis; even at an early date the SSHAC Guidelines provided the framework for the

Probabilistic Volcanic Hazard Analysis (PVHA) for the radioactive-waste repository at Yucca Mountain.

More specifically, the SSHAC Guidelines are concerned with how to capture, quantify, and communicate both the implicit and explicit uncertainties expressed by multiple experts. Such uncertainties arise even when the assembled experts are dealing with the same question, such as: What is the median peak ground acceleration (PGA) that will occur at a distance *R* of 10 km for a magnitude (M) 6.5 earthquake? At first glance, it would seem that such a simple, straightforward question would have one and only one, quantifiable answer, but this is not the case in the real world of experts having different ways (models) to answer the same question.

These differing answers to the same question, of which the one above is about as simple as they come in PSHA studies, constitute a generally unappreciated source of (epistemic) uncertainty and raise a number of questions as to how to obtain information from an individual expert and how to aggregate the information obtained from all the assembled experts. SSHAC (1997) relates how this problem arose through the differing PSHA results obtained by the Electric Power Research Institute (EPRI, 1989) and Lawrence Livermore National Laboratory (Bernreuter and others, 1989) for the same nuclear facilities in the eastern United States (EUS). According to SSHAC (1997), the differing PSHA results stemmed from the different ways that EPRI (1989) and Bernreuter and others (1989) elicited and aggregated the differing interpretations, judgments, and models of their experts, in situations where **the experts themselves are a major source of uncertainty**.

In response to these matters, SSHAC (1997) proposed a process for obtaining and aggregating expert interpretations, judgments, and models that is quite different from those used in conventional elicitation/aggregation procedures (see references in Appendix J of the SSHAC Guidelines). This process begins with diverse inputs, such as differing models and interpretations obtained from multiple experts, which are then evaluated through an interactive process overseen by a technical integrator (TI) or technical facilitator/integrator (TFI). This process results in a model representing not only the experts from whom it was derived but, ideally, also the larger informed technical community (ITC) that the experts in principle represent. The SSHAC process of expert interaction formulated by SSHAC (1997)–and demanded by it for Level 4–forms the heart of the SSHAC Guidelines and is what sets it apart from conventional expert elicitation, which emphasizes the independence, **not the interaction**, of the experts in the course of their deliberations.

The goal of all this interaction is "to represent the center, body, and range of technical interpretations that the larger informed technical community would have if they were to conduct the study." (Loosely speaking, the "center" is the median of a set of models that purport to do the same thing, the "range" reflects the credible model space with associated uncertainties about this median, and the "body" is the shape of the distribution of these models about the median.) The SSHAC Guidelines, however, offer no metric with which to judge whether this goal has been–or even can be–achieved; neither have the 12 years of experience of implementing the SSHAC Guidelines in actual PSHAs shed much light on such a quantitative–or even an agreed-upon metric. We return to these important topics in a later section to discuss them in more detail.

The SSHAC Level 4 expert interaction, however, comes at a considerable price. Significant demands are placed on both the SSC and GMC experts, who are asked to be both model proponents and evaluators and also to be experts on material that they may not be expert in, PSHA calculations for example. They need to know what really matters in the PSHA calculations that are built upon their expertise–and what does not matter. Experts who are expert in their own research and models can be surprisingly ignorant of other experts' models. Moreover, it takes a lot of supplementary expertise to deal with all these experts, TIs, TFIs, and participatory peer-review panels that also interact with the experts.

What, then, is the essence of SSHAC? Is it the SSHAC process of expert interaction? Or is it the unproven goal of representing the center, body, and range of the informed technical community with a small number of experts? Or is it SSHAC Level 4, the most fertile ground for achieving the greatest interaction and the most likely representation of the informed technical community? The SSHAC Guidelines are all of these things and more.

Indeed, the SSHAC process is also defined by operational procedures with which the overall goals discussed above are realized, and we discuss these matters in the next two sections. Then, we briefly review those PSHA projects that have been conducted in the Level 3 or 4 frameworks, the levels at which extensive expert interaction occurs. These case studies are the basis for improving the practical implementation for the SSHAC Guidelines.

SSHAC Participants

There are nine (at least) different types of SSHAC participants, indicated schematically in figure 1. They may be engaged on four different playing fields, the four different SSHAC Levels described in the next section. Who is playing, and in what role, and especially at what intensity of effort depends on the SSHAC Level. The descriptions of participants below are brief synopses of their definitions in SSHAC (1997), provided here as a convenience to the reader; for brevity, "SG, p. xx" denotes the page of SSHAC (1997) where the more complete definitions may be found. At the end of this section, we also discuss *normative experts* (which may or may not be part of a Level-3/4 study) and distinguish between the *technical community* (TC) and the *informed technical community* (ITC), as defined in the SSHAC Guidelines.

The *project sponsor* provides the financial support for the project, hires the study team (including the project leader), and "owns" the study's results in the sense of property ownership (SG, p. 22).

The *project leader* "is the entity that takes managerial and technical responsibility for organizing and executing the project, oversees all other project participants, and makes decisions regarding the level of study of particular issues" (SG, p. 22).

Technical experts provide the basic SSC and GMC input to the PSHA calculations, and there are three types of technical experts, described below:

- *Resource experts* provide information and special knowledge, often a database of specific interest to SSC or GMC issues. They are called upon as needed by the TI/TFI, generally early in the project (SG, p. 25).
- *Proponent experts* advocate the use of one or more models that provide the SSC or GMC information required in the PSHA. Proponent experts can be expected to advocate the use of a single model developed by that same expert (SG, p. 24).
- *Evaluator experts* evaluate the models developed by the other experts, assimilating the best aspects of all the models, and derive their own distributions that represent the center, body, and range of the "informed technical community" (SG, p. 24-25).

All three types of the experts defined above are drawn from the SSC or GMC *technical community*, the cadre of scientists and engineers known for their experience with and knowledge of SSC or GMC issues. A single expert almost never provides both GMC and SSC input.

Integrators, at first glance, appear to be referees overseeing the technical action, but they have full responsibility for the experts knowing what they need to know, such that the expert interaction process captures the center, body, and range of the informed technical community, also referred to as the community distribution (SG, p. 22).

An integrator can be either a *technical integrator* (TI) or *technical facilitator/integrator* (TFI). The TI and the TFI can be a single individual or a team. The TI is responsible for representing the views (the community distribution) of the ITC, based on the open literature and/or through discussions with experts. The TFI is used in SSHAC Level 4 studies and is responsible for aggregating the community distribution from the panel of evaluator experts. Important tasks of the TFI are to lead discussions and interactions among the evaluator experts in joint sessions, to conduct interviews with individual evaluator experts, and to draw on resource and proponent experts as required. TI/TFIs are the most important entities in the SSHAC framework, and their roles are described at length in SSHAC (1997): for the TI on SG, p. 26-29, and for the TFI on SG, p. 29-49.

Peer reviewers review both the soundness of the technical input and the final hazard results and, for SSHAC Levels 3 and 4, the procedural aspects of the expert interaction. Peer review at Levels 3 and 4 is formalized with Participatory Peer Review Panels (PPRP) that provide commentary throughout the course of the project. Review panels may also be constituted by either the project sponsor(s) or the pertinent regulator(s).

Hazard analysts are the PSHA cognoscenti who actually perform the PSHA calculations. They benefit from observing the study as it progresses and can provide important feedback and answer questions about how the community distributions will be used in computing the PSHA. They are also important sources for identifying the things that matter in PSHA calculations–and also the things that do not matter.

Observers may represent the project sponsor, the pertinent regulatory body, or may simply have an interest in how the SSHAC process works. They may or may not be present, depending on project-sponsor and/or regulatory concerns.

Normative experts have sound theoretical understanding of and practical experience with model building in probabilistic frameworks and the development of the logic trees required for the hazard calculations. Depending on the background and experience of the TI/TFI, separate normative experts may or may not be part of a Level 3 or 4 study.

The *informed technical community* (ITC, also *informed scientific community*) is defined by SSHAC (1997) in the following way:

> *Regardless of the level of study, the goal in the various approaches is the same: to provide a representation of the informed scientific community's view of the important components and issues and, finally, the seismic hazard. ("Informed" in this sense assumes, hypothetically perhaps, that the community of experts [technical community, as defined above] was provided with the same data and level of interaction as that of the evaluators).* (SG, p. 26).

The informed technical community (ITC), then, is distinguished from the technical community (TC), as defined earlier in this section, by the additional features of access to the project-specific database and the SSHAC process of interaction in the course of the project.

The Four SSHAC Study Levels

SSHAC (1997) recognizes that PSHAs are conducted for a wide range of public and private facilities and that most PSHAs will be conducted with limited resources. Thus, SSHAC (1997) identifies four different PSHA study levels, based primarily on the level of complexity of the study and the resources dedicated to it by the project sponsor. Level 1 is the simplest and least resource intensive, and Level 4 is the most complex and resource intensive. Even casual readers of the SSHAC Guidelines will note that a disproportionate amount of SSHAC (1997) is devoted to the theory and practice of Level 4, and the reason for this is plain. Level 4, with its emphasis on the process of expert interaction, will capture and quantify the uncertainty in seismic hazard analysis to the fullest extent.

The four SSHAC study levels are operationally defined by what happens at each level, and, for completeness, the minimum components of the four SSHAC Levels are presented below; they are described in more detail in SG, p. 25-26, with a useful summary table on SG, p. 23. Our primary interest in this document, however, remains improved practical implementation of the SSHAC Guidelines at Levels 3 and 4.

SSHAC Level 1

The principal participant in a Level 1 study is the Technical Integrator (TI), who reviews and evaluates the literature, datasets, and models related to the technical issues (fig. 2). The TI then quantifies uncertainties and expresses his/her view of the ITC and documents all models, parameters, and their technical basis. The TI is usually a single hazard analyst, but the TI need not be restricted to a single person.

A preliminary report describing the hazard results is written using this information and is peer reviewed, typically at a late stage, to determine if the views of the ITC have been captured and the documentation is complete. Examples of Level 1 studies include PSHAs for conventional facilities, screening studies to evaluate multiple sites, and sensitivity studies to evaluate new information.

SSHAC Level 2

A Level 2 study includes all aspects of Level 1, plus the following attributes (fig. 3). The TI team contacts members of the ITC regarding applicable databases (published, unpublished, or restricted access) and directly communicates with proponents of alternative viewpoints in order to understand the alternatives and the technical bases behind them. Topical meetings are employed to resolve questions about key topics; however, no workshops are required in a Level 2 study. The hazard analyst is part of the TI team and provides feedback on hazard significance to the other members of the TI team.

Peer review in a Level 2 study includes a review of the process followed to develop the technical content, as well as the hazard results calculated from the technical inputs. This review may be either participatory or late-stage, depending on the technical issues involved. Examples of Level 2 studies include PSHAs conducted for the toll bridges in the San Francisco Bay area for Caltrans (Geomatrix Consultants, 1993).

SSHAC Level 3

The key change from Level 2 to Level 3 is that the proponents and resource experts are brought together with the TI team in a series of workshops to discuss the strengths and weaknesses of the various methods, models, and databases pertinent to the hazard at the site. The TI team questions the resource and proponent experts to obtain a full understanding of the applicability of the alternative models and methods. The expert interaction for a Level 3 study is shown in figure 4. The learning achieved during the workshops impacts the evaluations and community distribution developed by the TI team. The idea is that if a different TI team had been selected, the new team would learn from the workshops in similar ways and develop a similar estimate of the community distribution as obtained by the first TI team. As with SSHAC Levels1 and 2 projects, feedback in terms of hazard implications occurs within the TI team. Revision to the models in light of feedback occurs readily because the TI team is the only entity carrying out the evaluations.

In a Level 3 PSHA, the peer review is usually participatory. The PPRP reviews the technical decisions made by the TI team in developing the community model. Since there is only one TI team, the PPRP focus is on the technical results, with less emphasis on the process other than to ensure that adequate discussion occurred during the workshops and that all of the credible methods, models, and data were discussed at the workshops.

Level 3 documentation includes a discussion of all models, parameters, and their technical basis; the final hazard results with sensitivity analyses to understand the important contributors to the hazard and the associated uncertainties; the methodology used; and an explanation of how the final results are thought to capture the views of the ITC.

Examples of Level 3 studies include the EPRI EUS ground motion update (EPRI, 2004) and the ongoing CEUS SSC (EPRI, 2008) and BC Hydro (McCann, written comm., 2008) analyses. Although, the Diablo Canyon PSHA (PG&E, 1988) was conducted before the SSHAC Guidelines were developed, the Diablo Canyon PSHA possessed the attributes of a Level 3 study, including expert interaction, multiple workshops, field trips, and extensive peer review. The process used to develop the National Seismic Hazard Maps (Petersen and others, 2008) also shares many of the attributes of a Level 3 study, including workshops, a single TI team, and feedback, although the National Seismic Hazard Map Program does not attempt to capture the center, body, and range of the ITC.

SSHAC Level 4

As in Level 3, workshops are essential for enabling expert interaction. The resource and proponent experts play the same role at Level 4 as they do in Level 3. The key difference between Level 3 and Level 4 studies is that a Level 4 study uses multiple evaluators or evaluator teams rather than just a single TI team. (Individual evaluators are typical for GMC deliberations, small evaluator teams for SSC; in the prose below, we refer to both as evaluators for brevity.) The multiple evaluators perform the same technical integration as the TI team, but they are limited to a single technical topic (for example, SSC or GMC) and do not include the hazard analyst. Each evaluator is presented with the significant hazard implications (feedback) of his/her model and has the opportunity to change it.

In a Level 4 study, a new participant, the TFI, is added, one for GMC and one for SSC. Each TFI serves as facilitator at the workshops, ensuring that key technical issues are fully addressed and that all evaluators are equally informed about the available methods, models, and data. The TFI also is responsible for working with the evaluators individually to help them formulate their models of the community distribution in terms of the structure of the logic tree, significant uncertainties, and estimating weights for branches. This is done in one or more interview sessions between the TFI and each evaluator team. Finally, the TFI is responsible for integrating the estimates of the community distribution from the individual evaluators into a single community distribution. The expert interaction for a Level 4 study is shown in figure 5.

While the TFI has the option to use different weights for the different evaluator teams, the goal is equal weights. As long as the evaluators have equal access to information and have fully participated in the workshops, equal weights are expected.

The purpose of using multiple evaluators is to obtain a more robust estimate of the community distribution. If a single TI team is used, such as in Level 3, there remains the question: did this TI team capture the center, body, and range of the ITC? By using multiple evaluators at Level 4, we get multiple estimates of the community distribution. With more estimates, we do not necessarily have a better expression of the aggregate community distribution, but we have greater confidence that the community distribution is captured.

A Level 4 review consists of both technical review and process review. The technical review is primarily conducted among the evaluator experts and the TFI in the course of their interaction and development of the community distribution. The PPRP is primarily concerned with whether the *process* of interaction and development of the community distribution is inclusive and complete, although the PPRP is free to address any matter that arises in a Level 4 analysis.

Documentation in Level 4 includes all information of a Level 3 study plus summaries written individually by each evaluator expert to express his/her interpretations, technical bases, and estimates of uncertainty; the summaries form the basis for understanding each expert's models and the thought processes behind them.

Further Thoughts on SSHAC Levels 3 and 4

The fundamental differences between SSHAC Levels 3 and 4 are driven by the assurance that the sponsor wants or needs to reasonably expect that the project will meet extant regulatory and/or public demands. The higher level of assurance provided by Level 4 comes with significant additional costs attending the greater number of people involved and the increased duration of the project. As we have noted previously, Level 4 brings more experts into the fold and more intense interaction among them, a TFI in place of a TI, increased responsibilities for the PPRP, and greater documentation. Level 4 also brings more distributed "ownership" of the final results, a matter we will discuss in more detail in the Ownership Issues section.

Description of Previous Studies

This document relies on the experience gained during the past 14 years to develop recommendations for improving the process of implementing a SSHAC process. This section presents brief summaries of completed Level 3 and Level 4 projects, emphasizing their regulatory context, purpose, participants, and durations. Detailed descriptions of these studies are beyond the scope of this report; readers of this report, however, should be aware of these earlier projects. This section also illustrates that the PSHA methodology is applicable to other probabilistic natural-hazard analyses (P*x*HA); in fact, it has been applied to the volcanic hazards (PVHA) affecting the designated radioactive-waste repository at Yucca Mountain. The lessons learned from these studies in terms of improved implementation of the SSHAC Guidelines are included throughout this document. Described first are four Level 4 projects: (1) PSHA for Yucca Mountain, (2) PEGASOS PSHA, (3) PVHA for Yucca Mountain, (4) PVHA-U for Yucca Mountain. This material is followed by descriptions of two Level 3 projects: (1) EPRI EUS ground motions and (2) the CEUS SSC project.

1998 Yucca Mountain PSHA

A SSHAC Level 4 PSHA was conducted during a four-year period for the Yucca Mountain Project (CRWMS M&O, 1998) for use in seismic design of preclosure facilities (prior to the closure and sealing of the repository) and evaluations of the performance of the repository system following closure. The SSC panel consisted of six multidisciplinary teams of three experts each, and the GMC panel consisted of seven experts acting individually. The Level 4 process was chosen in light of NRC regulatory guidance developed specifically for the high-level waste program (Kotra and others, 1996). Kotra and others (1996) identify a number of conditions that warrants the use of experts, including "empirical data [that] are not reasonably obtainable; uncertainties [that] are large and significant to a demonstration of compliance; and [that] more than one conceptual model can explain and be consistent with the available data." The U.S. Department of Energy (DOE) concluded that these criteria applied to the seismic hazard at Yucca Mountain and developed a work plan that satisfied the guidance of Kotra and others (1996), as well as the SSHAC Guidelines, which, at the time, were still in the process of being developed.

Geologic and seismologic studies of the Yucca Mountain region had been conducted during the preceding 15 years, and the data developed from these studies provided a fundamental resource for the SSC experts. Field trips were held with the SSC experts to provide them with opportunities to observe the field relationships on which interpretations of the paleoseismic behavior of faults were based. The study included multiple workshops designed to facilitate the interactions among the experts and to assist them in their evaluations. Because the study was concluded just after SSHAC (1997) was published, much was learned about practical implementation of Level 4 studies.

GMC at Yucca Mountain included evaluations of empirical ground motions recorded worldwide and at Yucca Mountain, region-specific numerical simulations for the Yucca Mountain sources and crustal structure, and ground motions from nuclear explosions at the adjacent Nevada Test Site.

2004 PEGASOS

A SSHAC Level 4 PSHA known as PEGASOS was conducted during a four-year period for four existing nuclear power facilities in Switzerland (Abrahamson and others, 2002; NAGRA, 2004; Coppersmith and others, 2008). The Swiss Nuclear Safety Inspectorate (HSK) required that the PSHA be conducted by the Swiss nuclear plant owners at SSHAC Level 4. The technical evaluations were made by a SSC expert panel, a GMC expert panel, and for the first time a site-response characterization (SRC) expert panel. The SSC panel consisted of four multidisciplinary teams of three experts each, the GMC panel consisted of five experts acting individually, and the SRC panel consisted of four experts acting individually. The Swiss regulator concluded that there was significant uncertainty in the site amplification, including nonlinear site amplification as well as two- and three-dimensionality effects, which should be included in the PSHA.

The PEGASOS project represented the first application of the SSHAC Guidelines outside of the United States. The evaluator experts were all from European countries, but the TFIs were selected from the U.S. because there was no equivalent experience in Europe. The TFIs, all of whom had worked on the Yucca Mountain PSHA just described, asked for better documentation from the evaluator experts, which led to much improved expert evaluator summaries.

In response to the extremely large ground motions that arose when the 1998 Yucca Mountain PSHA was extended to hazard levels of 10^{-8}/year, PEGASOS also employed maximum rock ground motions in its GMC and maximum soil ground motions in its SRC. Extreme ground motions at Yucca Mountain are presently being considered in the five-year Extreme Ground Motion program (Hanks and others, 2006) funded by the DOE. Considerable progress is being made on the application of physical limits to ground motion, fragile geologic structures, and various event frequencies to seismic hazard analysis at low hazard levels (10^{-6}/yr to 10^{-8}/yr). Limits to earthquake ground motion have been presented in the Yucca Mountain Safety Analysis Report (DOE, 2008). Extreme ground-motion issues and their applications in PSHA are likely to evolve for some time to come.

1996 Yucca Mountain PVHA and 2008 Update

A PVHA was carried out for Yucca Mountain (CRWMS M&O, 1996; Kerr, 1996; Coppersmith and others, 2009) during a three-year period. The study was conducted using a SSHAC Level 4 process. The motivation for using the SSHAC process of expert interaction was the same as that for the Yucca Mountain PSHA, namely the existing regulatory guidance for the high-level waste program (Kotra and others, 1996). Ten experts were selected from a pool of 70 candidates; 15 years of geologic and volcanic data-collection activities were available to them. The experts participated in workshops and two field trips. The results of the hazard assessment provided inputs to the total system-performance assessment for the repository system for the 10,000-year compliance period. This first PVHA was completed in 1996.

In the late 1990s, new aeromagnetic data were collected in the Yucca Mountain region, which suggested the possibility of previously unrecognized volcanic centers lying beneath the alluvial deposits of Crater Flats west of Yucca Mountain. DOE and NRC agreed to undertake a program of data collection (including high-resolution aeromagnetics, drilling, and age determinations) and to update the PVHA in light of the new data. The PVHA Update (Sandia National Laboratories, 2008) was carried out during a four-year period (one year of the study period was a down-year during which drilling was carried out), and the study was conducted using a SSHAC Level 4 process. Eight experts were present on the panel, and a number of workshops and a field trip were held to ensure expert interactions. Rather than merely updating the assessments made in the original PVHA study, the experts provided completely new evaluations in light of all pertinent data gathered during the decade following the original study. The TFI team, which consisted of the same people involved in the original study, took advantage of the lessons learned in the earlier Level 4 studies.

2004 EPRI GMC

A SSHAC Level 3 GMC study for eastern North America was conducted by EPRI (2004) during a four-year period and was the first application of the Level 3 process. The goal was updating applicable ground-motion models in light of significant new information; SSC issues were not addressed. EPRI selected Level 3 for this project because the ground-motion models impact all of the nuclear power sites in the EUS. Level 2 was not considered adequate, and EPRI chose to avoid the high costs of a Level 4 study.

This project used a three-member TI team; proponent experts attended workshops to review current ground-motion data and models. This study experienced some difficulties in implementing what is required for a Level 3 study. In addition to providing feedback to the TI team, feedback was provided to the proponents, and multiple workshops were held to present the TI ground-motion models to the proponents for their review. As a result, this project began to move to an indeterminate position between Levels 3 and 4, suggesting the need to better define the requirements for a Level 3 study.

2009 CEUS SSC Project (in progress)

The CEUS SSC Project—jointly sponsored by NRC, EPRI, and DOE—is aimed at developing a comprehensive seismic-source model for the entire CEUS (EPRI, 2008). This Level 3 study began in

September 2008, will conclude in September 2010, and will supersede the 1986 EPRI-SOG seismic source model. The goal of the CEUS SSC Project is to develop a stable and long-lived CEUS SSC that includes (1) full assessment and incorporation of uncertainties, (2) the range of diverse technical interpretation, (3) consideration of an up-to-date database, (4) proper and appropriate documentation, and (5) peer review. The CEUS SSC project team is consists of program and project management, a TI team, TI staff, a PPRP, specialty contractors, sponsors, and agency experts.

The CEUS SSC prospectus calls for three major tasks to be completed before three workshops. The pre-workshop tasks are (1) develop the project plan defining the Level 3 approach, team personnel and functions, work plan, and schedule; (2) develop a CEUS geological, geophysical, and seismological database in geographic information system (GIS) format; and (3) update the CEUS earthquake catalog that merges and reconciles several regional catalogs and develops uniform moment magnitudes.

The workshops will (1) identify hazard-significant SSC issues and identify and discuss important databases; (2) present, discuss, and debate alternative interpretations of significant SSC issues with proponents of alternative models; and (3) present the preliminary SSC model and discuss hazard feedback and sensitivity analyses. Following the second workshop, a preliminary SSC model will be developed, which will be the basis for hazard and sensitivity calculations to be discussed at the third workshop. Following the third workshop, the SSC model will be finalized with all uncertainties, and the CEUS SSC project report will be developed for review. A number of working meetings of the TI team, which consists of about fifteen seismologists, geologists, and hazard analysts, will be held throughout the project to develop the SSC model. A PPRP is responsible for oversight of both the technical and process aspects of the project.

Issues, Lessons Learned, and Recommendations

The matters presented in this section are ordered not according to their importance but simply as they are likely to arise in executing SSHAC Level 3 and 4 PSHAs. Much of what we recount in this section summarizes what may be found in the SSHAC Guidelines, including the suggestions and recommendations of SSHAC (1997). Recommendations drawn from the experience gained from the actual implementations are presented below in **boldface**.

Selection of SSHAC Study Level

First and foremost, the appropriate SSHAC Level depends on the time available for the proposed project and the resources that the sponsor will commit to it. SSHAC (1997) also identifies as "decision factors" (regulatory concerns, resources available, and public perceptions) and the "issue degree" (the amount and nature of uncertainty, controversy, and complexity) as additional determinants of the study level (SG, p. 23). As the SSHAC level increases, the project costs increase, as well as the number of participants involved and the demands upon them. The credibility of the final product also increases with SSHAC level. An issue related to the selection of the SSHAC Level is the treatment of GMC and SSC at different SSHAC levels during the course of the same project. While the SSHAC Guidelines allows for this possibility (SG, p. 24), this has not occurred in practice. Likewise, it is difficult to envision how different issues within SSC and/or GMC, for example, would be addressed with different SSHAC Levels.

> **While we recognize that the choice of SSHAC level belongs to the project sponsor who will be paying for it, we recommend that this decision be made in conjunction with the regulator, so that the sponsor has a reasonable expectation that the final results will meet regulatory requirements.**

Selection of Participants

In an earlier section, we briefly identified the SSHAC participants. Of these, the TI/TFI, the evaluator experts, the proponent experts, and the members of the PPRP are the most important to the successful implementation of Level 3 and 4 studies, and we detail their selection criteria below.

TI/TFI

The selection of the TI/TFI is made by the Project Leader, with the following considerations in mind as articulated by SSHAC (1997). The TI/TFI must (1) have a working technical knowledge of the topics relevant to the project in order to focus discussions on the significant issues; (2) qualify as a technical peer of the evaluator and proponent experts; (3) adhere to the fundamental goal of capturing the center, body, and range of the ITC; (4) choose proponent experts who span the credible model/interpretation space, thereby representing at least the range of the ITC; (5) ensure that the evaluator experts are well versed in the basic tenets of probability theory, understand the significance of aleatory and epistemic uncertainty in hazard analysis, and are aware of the various biases that affect the decisions they make and the models they espouse (SG p. 44-45); (6) be sure that the evaluator experts understand that the process of expert interaction does not seek a single, best model but a community distribution that represents all of the experts and the center and body of the ITC they represent; and (7) ensure that the outcome of this interaction is the collective wisdom of all the experts, not the result of a single, overbearing personality, whether it is that of an expert or their own.

Evaluator Experts

Evaluator experts are selected by the TI/TFI from a pool of potential candidates formed early in the project (SG p. 42-44). Selection criteria for nomination to this pool include such attributes as professional reputation, willingness to forsake the role of a proponent, willingness to commit the necessary time and effort for the project, ability to interact with expert peers as an evaluator of alternative hypotheses, and strong communication skills (SG, p. 42). As stated in SSHAC (1997) "It is important to ensure that the final group represents a broad spectrum of scientific expertise, technical points of view, and organizational representation… In the TFI process, evaluation ability and experience is especially important for the experts as informed evaluators." (SG, p. 43). A broad spectrum of expertise is useful, but because the expert evaluators are each required to represent the larger informed technical community and not a narrow proponent view, there is no need in the selection process to anticipate how the range of expert views will span the spectrum of the community's views. That is, the expert panel's individual (as proponents) views coming into the project will be set aside as they assume the role of evaluators. Thus, the problem of expert-evaluator selection should not be viewed as a "sampling problem" in which the selector must ensure that an adequate number of experts, range of viewpoints, and number of experts per viewpoint accurately represents the community distribution.

Proponent Experts

Proponent experts should be selected by the TI/TFI to span the credible model space for GMC issues, for example. By "credible models" we mean models that have been published, well cited, and used by other researchers in the field of interest. Rarely, a high-level PSHA project must consider a promising model that has only recently been available and is not yet vetted by the community, as well as a model that is highly controversial but, nevertheless, too visible to ignore. The role of proponent experts is to present and advocate a single model, generally the product of that particular proponent expert.

PPRP Members

SSHAC (1997) is well aware of the importance of thorough, complete, and independent peer review: "peer review has a long history of application in quality assurance for scientific endeavors including seismic hazard analysis" (SG, p. 48), and the nature and function of PPRP at Levels 3 and 4 are discussed at length in a later section of this report. While experts will be chosen for their expertise in SSC or GMC matters, PPRP members ideally should have considerable knowledge of all of the relevant SSC, GMC, and hazard-analysis issues, so to identify an SSC issue that might affect GMC models, for example, that in turn might affect the final hazard results. PPRP members should also have some experience with, and appreciation of, the theory and practice of the SSHAC Guidelines.

The increasing interest in PSHA in general, and especially PSHA executed within the SSHAC framework, has led to the existence of well-qualified, potential PPRP members in a variety of professional environments, including academia, the consulting world, private industry, federal research laboratories, and regulatory agencies. PPRP members should understand that their only business as a PPRP member, much like a member of a jury in civil or criminal proceedings, is evaluating what they see and hear in the course of the project. Whatever their current professional affiliation may be, PPRP members must act as independent experts expressing their own views, not their employer's, on the technical and procedural content of the project.

Experts of the Future

Currently, there is a very small group of PSHA experts that are qualified and available to act in the TI or TFI roles, and this pool should be expanded. In particular, the demographics of PSHA experts need to be changed to include younger scientists and engineers. Large PSHA projects, such as Level 3 and 4 studies, provide excellent learning opportunities for young professionals.

As part of Level 3 and 4 PSHA studies, young scientists and engineers should be invited to attend the workshops as observers to allow them to learn about PSHA, the implementation of the SSHAC Guidelines, and to interact and communicate with sponsors and regulators. Young scientists and engineers from outside of the U.S. should be part of this pool of talent.

In addition to expanding the pool of TIs, TFIs, and evaluator experts as discussed above, a less well-appreciated problem is that the "much larger" technical community

is not so large as it is often thought to be. It is just in the nature of things that the "first team" of 3 or 5 or 7 experts, whether resource, proponent, or evaluator, will be better qualified than the second team. While there are several dozen scientists and engineers in this country who are well versed in GMC issues, for example, it is also true that only five or six of them stand apart as the acknowledged leaders of this field. Unsurprisingly, they show up again and again for one high-level PSHA after another and have done so for 20 years or more. The new experts involved in PEGASOS and the recently initiated South Africa Level 3 PSHA are welcome developments.

The vast majority of SSC and GMC experts work for private consulting companies or for federal agencies and do not pass on their experience to younger scientists and engineers. Funding of university departments by Federal entities such as NRC and DOE would help ensure the continual flow of SSC, GMC, and PSHA expertise.

Finding the Center, Body, and Range of the Informed Technical Community (ITC)

The material in this section is central to the successful implementation of SSHAC Level 3 and 4 studies, and most of what we recount here is taken directly from the SSHAC Guidelines. Coming to grips with what the ITC is–and is not–has been a real challenge for us, just has it has been for many of the participants in SSHAC Level 3 and 4 projects, and this is the subject of the section just below.

The ITC

The informed technical community (ITC) is a hypothetical construct of the SSHAC Guidelines, the practical implications of which were never articulated by SSHAC (1997). As we have noted earlier, the ITC is distinguished from the technical community (TC) by the additional features of access to the database especially constructed for the PSHA study at hand and the SSHAC process of expert interaction in the course of this project.

The ITC seems, at first glance, to be a general concept, but the distinctions above also impart project-specific characteristics to it. At the beginning of the project, the ITC does not exist in any functional or tangible way. At the end of the project, the several evaluator experts, together with the TFI (at Level 4) and the TI (team) that serves as the evaluator expert(s) (at Level 3), are real, identifiable members of the ITC. They have been charged to represent the center, body, and range of the larger number of ITC members who exist only hypothetically (because they have not had access to the project-specific database and been part of the project-specific expert interaction). In principle, this has occurred in the course of the project; in fact, it may or may not have occurred. It is simply not possible to verify that the center, body, and range of the full ITC have been successfully captured without repeating the entire process of expert interaction with a different group of experts and perhaps different TI/TFIs as well. As a matter of practical reality, this has not occurred.

These problems with words, definitions, and the meaning of ITC notwithstanding, we remain convinced that SSHAC Level 3 and 4 studies entertain and include the most comprehensive SSC and GMC inputs and thus obtain the best possible hazard results. Our experience has persuaded us that the community distributions at Levels 3 and 4 are robust representations of the ITC at the time the studies are undertaken. Nevertheless, all that can be "proved" to a peer panel or regulatory body is that a structured, documented process has been followed that encourages and requires deliberate consideration of the viewpoints of the larger TC.

Understanding the ITC and representing it in the form of the community distribution has been a continuing problem for SSHAC Level 3 and 4 participants; hypothetical concepts are always hard to express in words. The ideas above were written when the draft of this

report was being revised; they were neither discussed at the workshops nor vetted by workshop participants. We recommend continued discussion and refinement of the ideas above at ongoing and future Level 3 and 4 studies, with documentation of these discussions.

The SSHAC Process of Expert Interaction

The goal of the SSHAC Guidelines at any level of analysis is to represent the center, body, and range of the ITC; the SSHAC process of expert interaction is the means to that end. Given this goal, it is plain that consensus among the evaluator experts is not required nor even sought. Nevertheless, common estimates of the center, body, and range of the ITC arising from multiple experts in the course of the expert interaction provide credence–but not proof–that the goal has been reached at the time of the project. It is most important that the evaluator experts–and all of the participants in SSHAC Level 3 and 4 projects–understand that they are not random samples of the ITC; they have been called to represent the center, body, and range of the ITC by fashioning the community distribution for it through the SSHAC process of expert interaction.

The first step in this process is for the evaluator experts to assimilate and thoroughly understand the database assembled for the study at hand. All of the experts then share common ground through this common, study-specific database. The second step involves hearing all of the proponent models. The TI/TFI must ensure that the evaluator experts are presented with the full complement of methods and models that span the credible model space for whatever issue is at hand. Occasionally, the TI/TFI must make allowance for controversial, but highly visible methods and/or models that have little credence in the TC.

Then begins the two-stage evaluation process described in SSHAC (1997, p. 40-41). In Stage I, the experts act as independent, informed evaluators who attempt to represent the ITC based on their own evaluation of the available information. In Stage II the experts act as integrators who now attempt to represent the ITC based on the interactions with the other evaluator experts and feedback from their

Stage I assessments. Experience from Level 4 studies shows that this process occurs not as two separate assessments, but rather as an evolution in thinking that comes from the interaction and feedback process.

The preliminary models of Stage I are subjected to feedback, discussions and interactions with their peers, and sensitivity analyses. The evaluators review and challenge each other in a workshop forum and explicitly consider how their evaluations provide a reasonable representation of the community distribution. The evaluators, now acting as integrators, then revise and refine their models to represent the center, body, and range of the ITC. This final refinement, which takes advantage of the learning and insights from the entire process, would represent the Stage II evaluation of the SSHAC Guidelines. This evolution in the evaluations of multiple evaluators is shown diagrammatically in figure 6.

The basic expectation here is that the evaluator experts will enlarge their initial assessments of the community distribution as they learn more and more about the views held by the other evaluator experts. This will not always be the case, of course, but to the extent it is the case, a certain robustness of the community distribution is achieved as the individual distributions move from those shown on the left-hand side of figure 6 to the right-hand side.

What the Evaluator Experts Need to Know

Evaluator experts are chosen by the TI/TFI from the TC for their special expertise in SSC or GMC matters. Many will have published widely in their field(s) of study, and all will be known at least nationally, and often internationally, for their contributions and accomplishments. Being an expert in earthquake ground-motion estimation, however, does not mean that this same expert is well versed in what really matters in PSHA calculations, for example. Neither does it mean that this expert has the social facilities to interact with co-experts. Indeed, quite a few experts in one field or another of the earth sciences have made their reputations on the basis that "I am right, and you are wrong" and have the theoretical and observational evidence to prove it. Such experts will do well as proponent experts, but will often fail as evaluator experts.

It should come as no surprise at all, at least in the SSHAC framework, that most experts are quite inexpert in one or more of the several matters important to SSHAC at Levels 3 and 4. These matters include

- The SSHAC process of expert interaction,
- The basic elements of PSHA, what really matters in PSHA and what does not, and various nuances in PSHA (some of which the TC is still learning about),
- Epistemic and aleatory uncertainty and the important differences between them, and
- The theory and practice of logic trees, alternative models, and composite models.

We will not repeat here all the things experts need to know about the matters above; most of them are covered in SSHAC (1997) and/or in the extensive literature that has been written for the high-level SSHAC PSHAs that we have discussed previously. All of what the experts need to know, ideally, should be covered in the workshops that play such an important role at Levels 3 and 4.

Workshop Topics at Levels 3 and 4

The identification of six types of workshop topics in this section does not imply that six separate meetings are required; often, multiple topics can be covered in a single meeting. On the other hand, more than one workshop may be required for some topics, depending on the technical issues at hand. Selection of all participants must be accomplished prior to the first workshop.

Organizational Matters, Important Issues, and Data Needs (Levels 3 and 4)

This first workshop should cover the following items

- Introduction to the goals and context of the project,
- Review of the ground rules for all workshops,
- Identification of the key issues that must be addressed by the experts, and
- Review of available data, methods and models for use in the evaluations.

The first workshop should result in a list of requests for data and analyses that the evaluator experts consider important for their evaluations. Typically, SSC workshops are focused more on regional data (for example, earthquake catalogs and fault slip-rates), whereas GMC workshops are focused more on regional models and site-specific ground-motion amplification data. Resource experts play an important role in this workshop to present available data sets.

What the Evaluator Experts Need to Know (Level 4)

We have discussed these needs in the previous section. It would be in this workshop that normative experts may be called on by the TI/TFI to help with the presentation and explanation of the material to be covered.

Methods and Models (Levels 3 and 4)

The purpose of this workshop is to evaluate alternative methods and models, together with their advantages and disadvantages. This workshop also serves to prepare the evaluator experts for developing their preliminary logic trees.

Preliminary Assessments and Initial Feedback (Level 4)

At this workshop, the evaluator experts present their preliminary models and assessments and receive feedback from their colleagues on the evaluator-expert panel (fig. 5). This workshop should feature open collegial debate of the preliminary assessments; it is expected that revisions and/or clarifications will result from this interaction. Feedback is presented to the evaluators in terms of the different models of the different evaluator teams and how they fit the data. This type of peer feedback is different from the hazard-sensitivity feedback that occurs later. In Level 3, this initial feedback is conducted within the TI team and is not part of a formal workshop.

Hazard-Sensitivity Feedback (Level 4)

This workshop provides feedback to the evaluator experts regarding the sensitivity of the seismic hazard to various aspects of their models, focusing on aspects of models and methods that have a significant impact on the hazard. In Level 3, this hazard feedback is conducted within the TI team and is not part of a formal workshop.

Results

The end-of-project meeting is an optional get-together for all members of the project, with the purpose of reviewing the final hazard results. This meeting can also be used to present results to the interested public at a time when all the technical evaluations and documentation are complete. The principal beneficiaries of the workshop will be the sponsors and observers, who will have an opportunity to discuss the final results with all the experts.

Discussion of Workshop Topics and Related Issues

The workshop topics discussed above relate in multiple ways to other concerns that are of significance to more than one workshop topic. These concerns are interface issues, feedback requirements, participation of observers, expert autonomy, and SSHAC process versus expert elicitation, which are discussed in turn in the text that follows.

Interface Issues

Interface issues involve both how SSC results may impact GMC deliberations and how GMC deliberations may impact SSC results. For example, regions or sites with differing rates of seismicity will require different ground-motion probabilities to obtain the same hazard level, or probability of exeedance. A region of high seismicity rate requires reaching for lower-probability (higher amplitude) ground motions and, conversely, a region of low seismicity requires reaching for higher probability (lower amplitude) ground motions.

The SSC and GMC aspects of a PSHA are commonly conducted separately and in parallel, and the project schedule should allow for periodic communication and interactions between the groups carrying out their respective assessments. The PEGASOS project provided a case history in which the aspects of the SSC assessments were not communicated to the GMC aspect until late in the project, thus leading to additional scope for the GMC and delay in the assessments. Therefore, it is important that the interfaces between the project components be given attention early and throughout the project. The points in the project where communication is needed follow, including examples of the types of information that can be shared.

- During identification of key issues and databases—GMC can indicate the desired magnitude scales and distance definitions to be used; SSC can indicate the regional tectonic environment (for example, stable continental, compressional).
- During construction of preliminary assessments—SSC can indicate types of seismic sources (faults, zones), styles of faulting, likely Mmax ranges; GMC can indicate their ability to model various rupture geometries and characteristics.
- Following feedback—Both SSC and GMC can confirm the most important technical issues and assessments.

Periodic communications and interactions between SSC and GMC evaluators are important and should occur throughout the course of a project.

Feedback Requirements

Obtaining the SSC and GMC assessments are complex processes. Providing feedback early in these processes can assist in directing the effort toward those components that are most significant to the hazard results. The SSHAC Guidelines call for providing feedback to the experts following the development of the preliminary models and prior to finalization. Experience on a number of projects has provided additional insights and specificity in the timing and content of feedback.

Prior to the involvement of experts, the TFI team can use available information (for example, previous hazard studies, experience) to construct a preliminary model and to conduct pilot hazard studies and sensitivity analyses. The results can be used to focus the subsequent data compilation activities and to illuminate the most important issues for the experts. In the case of the Yucca Mountain PVHA-Update project new data-collection activities were initiated, but available resources only rarely allow for this. Many GMC experts do not have an intuitive feel for SSC issues important to seismic hazard, and *vice versa*. Early discussion will help identify those issues.

Once preliminary assessments have been made, feedback should include global (across evaluator teams) assessments of the importance of various issues and local (for each expert) assessments of importance for Level 4 studies. For Level 3 studies, the Feedback workshop is the opportunity for the TI team to provide feedback for the preliminary model from proponent experts. Feedback should include summaries of the assessments and their technical bases, sensitivity analyses showing the relative importance of the various assessments to mean hazard, and uncertainty analyses showing the relative contributions of various assessments to the total hazard uncertainty.

Examples of feedback for SSC include plots of the predicted spatial distribution of recurrence rates (rate density), comparison of predicted and observed rates, comparison of maximum magnitude distributions for key seismic sources, contributions of various SSC issues to mean hazard results, and contributions to total hazard uncertainty from various SSC issues.

Examples of feedback for GMC includes plots of the median ground-motion models (versus distance and magnitude) and applicable recorded or simulated ground motions, plots of the standard deviation of the ground motion, plots of ground-motion scaling as a function of the site condition, and relative contribution to the hazard uncertainty from the GMC logic-tree branches.

Experience has shown that feedback can provide important information and insights early, during, and late in the evaluation process. As described above, pilot studies, expert-specific feedback, and a variety of sensitivity analyses as described for SSC and GMC can be carried out to provide insight to the experts (Level 4) and the TI team (Level 3).

Participation of Observers

The SSHAC process uses workshops to facilitate interaction of the expert evaluators. To preserve expert autonomy in reaching their positions, the SSHAC Guidelines did not permit observers to participate in workshop discussions, other than resource experts called by the TFI/TI. These protocols also maximize time for interaction among the evaluators by avoiding extended conversations among observers. Observers include the regulators, owners, peer reviewers, resource experts (except when they are presenting), and other interested experts in attendance.

In the Yucca Mountain and PEGASOS projects, the TFI met with regulators and peer reviewers at the end of each day to hear any comments that they had on either the process or technical issues. If process issues were raised, the TFI took corrective action in the subsequent workshops. If technical issues were raised, the TFI brought these issues up for discussion with the evaluators, thereby shielding the evaluators from undue influence or pressure from the observers. Many workshop observers were not satisfied with this restriction on their participation.

At the end of each day or topic of a workshop, time should be scheduled to allow observers to voice their comments and concerns directly to the assembled participants.

Expert Autonomy

Maintaining autonomy of the evaluator expert during the SSHAC process of expert interaction would seem to present some problems, at least in principle. An overbearing TI/TFI might condition the attitude and response of one or more experts. Early discussions of what are the most important issues can, in principle, bias or "anchor" one or more experts to a limited range of the important matters at hand. The PPRP communicates with the Project Leader and the TI/TFI to protect the experts' autonomy, although they will hear the PPRP concerns through the TI/TFI. The participation of observers is likewise limited. Experience gained from the Level 3 and 4 studies to date, however, reveals that experts are not persuaded by, or to, a single point of view, unless there is very good reason to be.

> **Because what might have happened in principle has not occurred in practice, Level 3 and 4 experts have little need of protection from the real or imagined intentions of review panels and observers. Time set aside at the end of the day for review panel and observer commentary, as recommended above, may indeed be beneficial, especially if it induces greater observer involvement.**

SSHAC Process versus Expert Elicitation

In conventional expert elicitation, the experts are asked narrowly defined questions about specific uncertain quantities within their area of expertise, and they provide their judgments in the form of probability estimates or distributions. In this approach, experts are treated as independent point estimators of an uncertain quantity, and the elicitation "problem" is viewed primarily in terms of determining how to ask the right questions, as clearly as possible, of the most knowledgeable experts. The expert elicitation tools and approaches reflect the general philosophy that probabilities are something that exist in the experts' minds, and the job of the elicitor is to extract, or elicit, those probabilities.

The SSHAC process of expert interaction, in contrast, is a structured process for identifying and quantifying uncertainties using the assessments of multiple experts. Proponent and evaluator experts are asked to participate in an interactive process of ongoing data evaluation, learning, model building, and, ultimately, quantification of uncertainty. Experts are explicitly tasked with developing the community distribution that represents the center, body and range of the ITC. Interactions among experts during this process, up to and including discussion of preliminary assessments of specific uncertain quantities, are strongly encouraged and, in most cases, are built into the structure of the project.

> **Because the SSHAC process of expert interaction is very different from the conventional expert elicitation, the term "expert elicitation" does not describe the SSHAC process of expert interaction and should not be used in reference to this process.**

Peer Review

Participatory Peer Review Panel (PPRP)

Peer review is an integral part of the scientific method and is a critical part of the technical analysis within the SSHAC framework. For SSHAC Levels 3 and 4, the project review has several different dimensions. The SSHAC Guidelines demands both reviews of the process from which the technical results emanate, as well as the technical results themselves. The technical review includes all SSC, GMC, and hazard issues. This process/technical review is assigned to the project PPRP. In addition to the project/sponsor review, the appropriate regulatory body may wish to have its own review team. The sponsor and regulator should decide this matter at the time that the SSHAC Level is decided.

SSHAC (1997) also discusses at length the distinction between participatory and late-stage peer review (SG, p. 48-50). Experience has shown that a PPRP is most effective for Level 3 and 4 studies, particularly because of the opportunities to observe the process at workshops. The SSHAC Guidelines anticipate that the peer-review process for a Level 4 study should focus on the process aspects, with the technical aspects considered, but with a lesser emphasis. This is because of the direct participation of technical experts in Level 4 studies, thus providing a higher level of assurance that a full range of technical views are considered. Level 3 studies, in contrast, rely on a TI team to identify, engage, and interact with members of the technical community. Hence, the report recommends that the PPRP for Level 3 studies focus on both technical and process issues.

The word “participatory” has attracted some concern from those who interpret it to mean that PPRP actually “participates” in the deliberations of the experts. This is not the case. Rather, “participatory peer review” in the context of the SSHAC Guidelines are used in contrast to “late-stage peer review” and means that the PPRP is present at and listens to workshop deliberations as they develop during the course of the project. The PPRP review is **continual**, perhaps a better adjective than “participatory,” throughout the project, from beginning to completion of the final report. The essence of a continual review is that advice and concerns can be conveyed while there is still time to address them.

To maintain expert autonomy, PPRP communicates its deliberations and concerns–if any–through the TI/TFI, which then takes them up with the experts. For reasons mentioned earlier, expert autonomy is of less concern, and we believe now that the PPRP commentary should be distributed to the project leadership (for example, the TI/TFI, project leader, project sponsor, and regulator) as a whole. This presumes, however, that the sponsor has sufficient in-house expertise to understand the review panel’s commentary, the content of the final report, and its results.

> **The PPRP for Level 3 and 4 projects should observe and provide commentary following key work activities such as project planning, all workshops, and development of the draft project report. Providing this feedback to the project leadership in a timely manner will allow for “mid-course corrections” throughout the study.**
>
> **The PPRP, both individually and collectively, must be entirely free to comment on any issue concerning technical content and project application of the SSHAC process.**

Other Review Panels

With the rising interest in SSHAC Level 3 and 4 studies, there has been increasing demand from pertinent regulatory bodies, interested government agencies, and others to be involved in these studies, through one review panel or another, specifically the PPRP. The PPRP is the only legitimate review panel recognized by the SSHAC Guidelines; there is only one PPRP for a SSHAC Level 3 or 4 study, and its sole and unique obligation is to provide on-going commentary to TI/TFI as the project develops. All other "review panels" should be considered as observers, unless the project leadership agrees in advance to a different role/format for them.

Evaluator Models, Logic Trees, and More Models

Evaluator models are the product of the expert interaction that occurs in SSHAC Level 3 and 4 PSHAs. For Level 3, a single evaluator model is constructed by the TI team; multiple evaluator models emanate from the SSHAC Level 4 process. At either Level 3 or 4, each evaluator model is intended to represent the community distribution held implicitly by the ITC. The TFI integrates the multiple Level 4 evaluator models into a single estimate of the community distribution.

Logic Trees

Logic trees are the numerical interface between the evaluator models and the hazard calculations. The logic tree for a single evaluator model structures, in principle, all of the epistemic uncertainty that attends the evaluator model it represents through sets of discrete alternative choices, each weighted for its relative merit and/or its likelihood of occurrence. There is a separate logic tree for each evaluator model. In Level 4, the separate logic tree allows tracking of the effects of each evaluator model on the final hazard results. Operationally, "integration" of multiple evaluator models by the TFI in Level 4 is accomplished by expressing all of these models as their logic trees with equal weights (which is regarded as a goal, not a requirement, by the SSHAC Guidelines).

Branches of the SSC and GMC logic trees, in general, will express epistemic uncertainty through viable alternative choices in both the models and the parameters for these models. An SSC example of alternative models is discrete tectonic source zones in contrast to spatial smoothing of known earthquakes (for example, uniform source zones or zoneless models). An SSC example of a branch containing a model parameter is the slip-rate on a fault.

For the Yucca Mountain PSHA, the GMC logic trees were constructed for point estimates of ground motion, in response to questions of the form: "What is the median PGA caused by an **M** = 6.5 normal-faulting earthquake having a 60° dip at a site 4 km from the fault trace on the hanging wall?" The answers to questions of this sort allow for meaningful distribution functions to be constructed and sampled in the logic tree; in this case, the weights on the logic trees can be considered as probabilities. An enormous number of similar questions need to be posed and answered, however, to develop a complete GMC logic tree in this format.

The PEGASOS project dealt directly with alternative ground-motion models, asking the experts to weight them on the basis of their relative scientific merit. This approach is much easier to implement and more transparent to others, but at the price that relative weights on models are more subjective than specific distribution functions. The PEGASOS GMC TFI considered the advantage of transparency more important than the issue of weights representing relative merit, not probabilities.

Logic trees are much more manageable when they represent the underlying models and associated weights compared to logic trees featuring vast arrays of point estimates of ground-motion values and earthquake-rate estimates.

The fundamental precept of the SSHAC Guidelines are the representation of "the center, body, and range of technical interpretations" that the larger ITC would have if they were to conduct the study.

As we have noted earlier, the essential goal is a defensible accounting of uncertainty, which is, at least in principle, neither to be underestimated nor overestimated. Similarly, the goal is that logic trees express all of the viable alternative models, the range of parameters required for them, and the uncertainties that attend both. All these sources of uncertainty, however, can lead to very complex logic trees, making the final hazard calculations difficult to implement by reviewers or anyone not part of the project, thus resulting in a serious lack of transparency for the results.

Moreover, as the complexity of the logic trees grows, the number of possible combinations of their different branches becomes enormous, on the order of 10^{20} in past studies. In the past, the requirement has been to fully sample the logic tree, now a huge computational challenge. There are several ways to deal with this problem.

First, Monte Carlo methods can be used to sample the logic trees, significantly reducing the computational load. Monte Carlo methods have not been used in PSHA for nuclear projects because of studies in the 1980s that showed the Monte Carlo methods were not converging in a stable manner, but we recommend that Monte Carlo methods be reconsidered.

A second approach to swinging through very complex logic trees is to recognize that there is much "dead wood" within them (branches that have little or no impact on the final hazard calculations). Hazard-insensitive branches can be "trimmed" from the logic tree, provided such trimming is done with input and concurrence from the TI/TFI, experts, and hazard analysts.

A third approach to reducing the number of branches in a logic tree is to develop a composite model, which is achieved by sampling the full logic tree and then reformulating the results into a new, simpler logic tree that maintains the center, body, and range of the full logic tree. In this way, a new logic tree is developed that represents the more complicated logic tree developed by the experts. This approach was used for ground motions in the PEGASOS project.

Finally, the fourth way of dealing with the complexity of the logic trees, especially in Level 4 studies, is to construct simplified hazard models. As we have seen above, much of the complexity of the logic trees does not have a significant impact on the final hazard results. For both Yucca Mountain and PEGASOS, simplified versions of the hazard model have been developed that capture the main aspects of the epistemic uncertainty (for example, mean, median, and 90th percentiles). By using these simplified hazard models, calculation times were reduced by about a factor of 100.

Setting aside Monte Carlo methods as a computational expedient, we should emphasize that trimming the logic trees and the construction of composite models and/or simplified models should also be viewed as operational expedients; they are no substitute for what the TI Team (Level 3) and TFI plus evaluator experts (Level 4) develop in the course of their deliberations. There is value in these approaches in terms of adding simplicity and transparency, but these approaches also have downsides.

Trimming logic trees, for example, may be time-consuming and may add to the time and cost of Level 3 and 4 projects. Moreover, there is some inconsistency in this approach, on the one hand stretching the experts to include all uncertainties, and on the other hand asking them, near the end of the project, to eliminate much of what they have constructed. A disadvantage of composite models is that they lose the ability to track the influence of a single logic-tree branch on the final hazard since the original branches developed by the experts have been replaced. We also believe that any composite model is intrinsically nonunique. Trying to represent the inner workings of a system from its results is akin to problems in potential-field theory, divining the (nonunique) density structure of the earth from surface measurements of the gravitational field, for example.

The simplified hazard models mentioned above were developed years after the projects were completed, born of the need to have less complicated and less time-consuming general-utility calculations. A drawback of developing a simplified model outside of the SSHAC process is that it is neither developed nor reviewed by the evaluators—would the evaluators agree that the simplified model captures the key features of the full logic tree?

Despite these drawbacks, we believe that SSHAC Level 3 and 4 projects should continue to experiment with trimming logic trees and developing composite/simplified models, to the extent available resources and the schedule allow. While constructing simplified models, for example, will add to the duration and cost of Level 3 and 4 studies, our experience in developing them suggests that these costs would be only nominal, especially in view of the benefits achieved through simplicity and increased transparency. Developing simplified models as part the SSHAC process would provide these models credibility, as well as helping the evaluators to trim the logic tree of branches that are not significant in terms of hazard.

Documentation Requirements

Responding to the deficiencies in the documentation of earlier studies, SSHAC (1997) devotes an entire chapter to documentation requirements (Chapter 7), including documenting SSC and GMC inputs, the process methodology, seismic-hazard results, and sensitivity analyses. The need for comprehensive documentation continues to be important, especially for studies conducted within the regulatory arena. In these environments, the reviewers are looking for assurance that the process followed and the evaluations given have completely accounted for all significant uncertainties. The project documentation provides the only lasting evidence that can justify this assurance.

As part of the Yucca Mountain PVHA-Update project, consideration was given to some aspects of the documentation requirements given in the NRC regulatory guidance for the high-level waste program (Kotra and others, 1996). In that NRC regulatory guidance, expert elicitation steps are identified, including eliciting expert judgments and documenting the technical bases for the assessments. The guidance notes that the first elicitations of the experts should be completely documented, and that any revisions in the expert assessments that might result from feedback or interactions with fellow experts should also be documented. The point is made that the reasons for any revisions should be "scrupulously documented." The DOE took exception to this guidance in the implementation of the PVHA-Update using a SSHAC Level 4 process. By its nature, a SSHAC process entails the interaction, learning, and feedback among experts; the evaluator experts are expected to freely change their minds and revise their assessments throughout the process. The final expert evaluations contained within their final Evaluation Summaries are the only documentation required. Indeed, a requirement that the evaluator experts document their early assessments and explain any changes to those assessments could lead to anchoring the experts and to discouraging learning during the process.

> **Project documentation is the essential assurance that the process followed and the evaluations given have completely accounted for all significant uncertainties held by the ITC. Although the final expert evaluations must be completely documented, documentation of the interim assessments made by the evaluators during the course of the project is unnecessary, time-consuming, and potentially counterproductive.**

Intellectual Ownership Issues

Who owns what at the end of a costly and complicated Level 3 or 4 project? As a matter of property, the project belongs to the sponsor who paid for it. From an intellectual point of view, things get a bit more complicated. If, for example, some potential sponsor has great confidence in an individual, experienced TI (team), that sponsor may opt for Level 3 precisely because the intellectual ownership of the final results and all of its components resides with the TI alone. By contrast, in Level 4, intellectual ownership of the community distribution and the final results belongs to the TFI, but ownership of each individual evaluator estimate of the community distribution belongs to the individual evaluator that constructed that estimate. Wide community involvement in the process is a desirable goal in the SSHAC framework, but distributed ownership of the final results and all of its components need not be, especially for the sponsor.

In any event, who owns what in a SSHAC Level 3 study seems to be a continuously evolving issue. The on-going (as of this writing) SSHAC Level 3 BC Hydro project has decided: “In a variation of the SSHAC Guidelines defining the responsibility for the SSC evaluation, the evaluation and the intellectual ownership of the SSC is shared by the TI and the SSC evaluation staff" (McCann, written comm., 2008). The CEUS SSC project is being conducted in the same fashion, such that the technical ownership of the results lies with the larger TI team and not just the TI lead.

Ownership issues are best left to the sponsor, regulator, and the TI/TFI. The intellectual ownership of the technical evaluations in Level 3 projects can be expanded to include a TI team, should that be a desirable goal.

Reducing Time and Costs for SSHAC Level 4

The PSHA, PVHA, and PVHA-Update for Yucca Mountain and PEGASOS projects have shown that Level 4 projects can take three to four years to complete. Both the long time interval from beginning to end and the higher costs of these studies pose significant problems for sponsors. Level 4 studies to date have been characterized by short, intense bursts of activity separated by long periods of inactivity (in which much can be forgotten, especially in the case of first-time experts). Workshops can be scheduled more closely in time, which should not lead to a lesser product, so long as all of the essential features of SSHAC Level 4 are maintained.

SSHAC Level 4 projects can be shortened in the following ways:

- **Establish the complete project schedule before the project begins, with shorter time intervals between the workshops.**
- **Obtain commitments from all participants, especially the evaluator experts for whom the commitment of time is the greatest, to this schedule—these experts must be part of the process that sets this schedule.**
- **Perform all necessary preliminary work before the formal Levels 3 and 4 processes begin, including compiling appropriate databases and existing hazard calculations; development of preliminary hazard models, if necessary; and completing whatever scientific analyses are considered critical to the project.**

Acknowledgments

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References Cited

Abrahamson, N.A., Birkhauser P., Koller, M., Mayer-Rosa, D. Smit, P., Sprecher, C., Tinic, S. and Graf, R., 2002, PEGASOS–A comprehensive probabilistic seismic hazard assessment for nuclear power plants in Switzerland: 12th European Conference on Earthquake Engineering, London, Paper No. 633.

Bernreuter, D.L., Savy, J.B., Mensing, R.W., and Chen, J.C., 1989, Seismic hazard characterization of 69 nuclear plant sites east of the Rocky Mountains, Vols. 1-8: Washington, D.C., U.S. Nuclear Regulatory Commission, Lawrence Livermore National Laboratory, NUREG/CR–5250, UCID–2151.

Coppersmith, K.J., Youngs, R.R., and Sprecher, C., in press, Methodology and main results of seismic source characterization for the PEGASOS Project, Switzerland: Swiss Journal of Geosciences.

Coppersmith, K.J., Perman, R.C., Jenni, K.E., and Youngs, R.R., in press, Lessons learned—The use of formal expert assessment in probabilistic seismic and volcanic hazard analysis, *chap. 20 of* Connor, C., and Connor, L., eds., Volcanism, tectonism, and siting of nuclear facilities: Cambridge University Press.

Cornell, C.A., 1968, Engineering Seismic Risk Analysis: Bulletin of the Seismological Society of America, v. 58, no. 5, p. 1583-1606.

CRWMS M&O, 1996, Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada: Las Vegas, Nevada BA0000000-01717-2200-00082 REV 0.

CRWMS M&O, 1998, Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada, Vols. 1-3: Las Vegas, Nevada, Milestone SP32IM3.

DOE [U.S. Department of Energy], Yucca Mountain Safety Analysis Report, DOE/RW-0573, Revised.

EPRI [Electric Power Research Institute], 1989, Probabilistic seismic hazard evaluations at nuclear power sites in the central and eastern United States—Resolution of the Charleston earthquake issue: Palo Alto, Calif., EPRI Special Report NP-6395-D, Research Project P101-53.

EPRI, 2004, CEUS Ground Motion Project: Palo Alto, Calif., EPRI Final Report 1009684.

EPRI, 2008, Project Plan: Central and Eastern United States Seismic Source Characterization for Nuclear Facilities: Palo Alto, Calif., Technical Update 1016756.

Geomatrix Consultants, 1993, Seismic ground motion study for San Mateo-Hayward Bridge, San Mateo and Alameda Counties, California: Contract No. 59N772, CALTRANS Project No 2016G.

Hanks, T.C., 1997, Imperfect science: Uncertainty, diversity, and experts: Eos, v. 78, p. 369-377.

Hanks, T.C., Abrahamson, N.A., Board, M., Boore, D.M., Brune, J.N., and Cornell C.A., 2006, Report of the Workshop on Extreme Ground Motions at Yucca Mountain, August 23-25, 2004: U.S. Geological Survey Open-File Report 2006-1277.

Kerr, R. A., 1996, Risk Assessment—A new way to ask the experts: Rating radioactive waste risks: Science, v. 274, no. 5289, p. 913-914 (DOI: 10.1126/science.274.5289.913).

Kisslinger, C., Aki, K., Arabasz, W.J., Benson, D.K., Ebel, J.E., Hanks, T.C., Langer, J.S., Rasmussen, N.C., Reiter, L., and Veneziano, D., 1997, Review of recommendations for probabilistic seismic hazard analysis—Guidance on uncertainty and use of experts: Washington, D.C., National Academy of Sciences, National Academy Press, (This report is also the appendix of SSHAC, 1997).

Kotra, J.P., Lee, M.P., Eisenberg, N.A., and DeWispelare, A.R., 1996, Branch technical position on the use of expert elicitation in the High-Level Radioactive Waste Program: Washington, D.C., U.S. Nuclear Regulatory Commission, NUREG-1563.

McCann, M., 2008, BC Hydro PSHA project, seismic source characterization guidance: Revision 0 draft (unpublished report).

NAGRA, 2004, Probabilistic Seismic Hazard Analysis for Swiss Nuclear Power Plant Sites (PEGASOS Project): Report to Swissnuclear prepared by Nationale Genossenschaft für die Lagerung radioaktiver Abfälle, Wettingen, 358 p.

U.S. NRC [U.S. Nuclear Regulatory Commission], 1993, Revised Livermore seismic hazard estimates for 69 nuclear power plant sites east of the Rocky Mountains: Washington, D.C., U.S. Nuclear Regulatory Commission Report, NUREG–1488.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Y., Boyd, O.S., Perkins, D.M., Luco, N., Field, E.H., Wills, C.J., and Rukstales, K.S., 2008, Documentation for the 2008 update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2008–1128, 61 p.

PG&E [Pacific Gas and Electric Company], 1988, Final report of the Diablo Canyon Long Term Seismic Program: U.S. Nuclear Regulatory Commission Docket Nos. 50-275 and 50-323.

SNL [Sandia National Laboratories], 2008, Probabilistic volcanic hazard analysis update (PVHA-U) for Yucca Mountain, Nevada: Las Vegas, Nevada, TDR-MGR-PO-000001 REV 01.

SSHAC [Senior Seismic Hazard Analysis Committee, R.J. Budnitz, Chairman, G. Apostolakis, D.M. Boore, L.S. Cluff, K.J. Coppersmith, C.A. Cornell, and P.A. Morris], 1997, Recommendations for probabilistic seismic hazard analysis—Guidance on uncertainty and use of experts: Washington, D.C., U.S. Nuclear Regulatory Commission Report, NUREG/CR-6372.

Acronyms

CEUS: Central and Eastern United States

DOE: U.S. Department of Energy

EPRI: Electric Power Research Institute

EUS: Eastern United States

GMC: Ground Motion Characterization

HSK: Swiss Nuclear Safety Inspectorate

ITC: Informed Technical Community

LLNL: Lawrence Livermore National Laboratory

NPP: Nuclear Power Plant(s)

NRC: U.S. Nuclear Regulatory Commission

PPRP: Participatory Peer review Panel

PSHA: Probabilistic Seismic Hazard Analysis

SRC: Site Response Characterization

SSC: Seismic Source Characterization

SSHAC: Senior Seismic Hazard Analysis Committee

TC: Technical Community

TFI: Technical Facilitator/Integrator

TI: Technical Integrator

USGS: U.S. Geological Survey

Glossary

Aleatory Uncertainty/Variability: The random variability in a set of observations that would or should otherwise be the same; aleatory uncertainty is knowable but not reducible.

Anchoring: A form of cognitive bias that involves the human tendency to rely on a single data set or a particular model.

Cognitive Bias: Cognitive bias is the tendency of people to arrive at decisions that clearly differ from rational-choice theory; it is thought to be common to all human beings. Cognitive biases arise from one's experience, education, data sets, models, and mentors. Thus, cognitive bias is the individual, microcultural cloud in which each expert (and each of the rest of us) lives and makes decisions.

Community Distribution: The quantitative representation of the informed technical community.

Epistemic Uncertainty: The uncertainty that arises from the different outcomes

of viable alternative models, interpretations, and/or assumptions operating on the same data. Epistemic uncertainty is reducible and is reduced as knowledge increases

Evaluator Expert: A technical expert who provides his/her representation of the community distribution by examining the available data and assessing the technical basis for proponent models; the expert then is expected to represent the community distribution of the ITC in light of the other evaluators distributions.

Expert Elicitation: A technique of conventional decision analysis in which experts are asked narrowly-defined questions about specific uncertain quantities within their area of expertise.

Informed Technical (Scientific) Community: A hypothetical construct of the SSHAC Guidelines that embodies the community distribution sought by the SSHAC process at any Study Level.

Normative Expert: An expert with sound theoretical and conceptual understanding of probability, logic trees, and model building in probabilistic frameworks.

Proponent Expert: A technical expert who advocates a particular hypothesis or technical position and has developed and evaluated a particular hypothesis to explain the data (SG, p. 24).

Resource Expert: A technical expert who has either site-specific knowledge or expertise with a particular methodology or procedure useful to the evaluator experts in developing the community distribution.

SSHAC Process of Expert Interaction: The SSHAC methodology for capturing the views of the informed technical community (the community distribution) by explicitly quantifying uncertainties.

Technical Facilitator/Integrator (TFI): A SSHAC Level 4 individual or team who compiles the community distributions constructed by each evaluator team into a single community distribution representing the views of the informed technical community (SG, p. 29).

Technical Integrator (TI): A SSHAC Level 3 individual or team responsible for capturing the views of the informed technical community in the form of a community distribution (SG, p. 30).

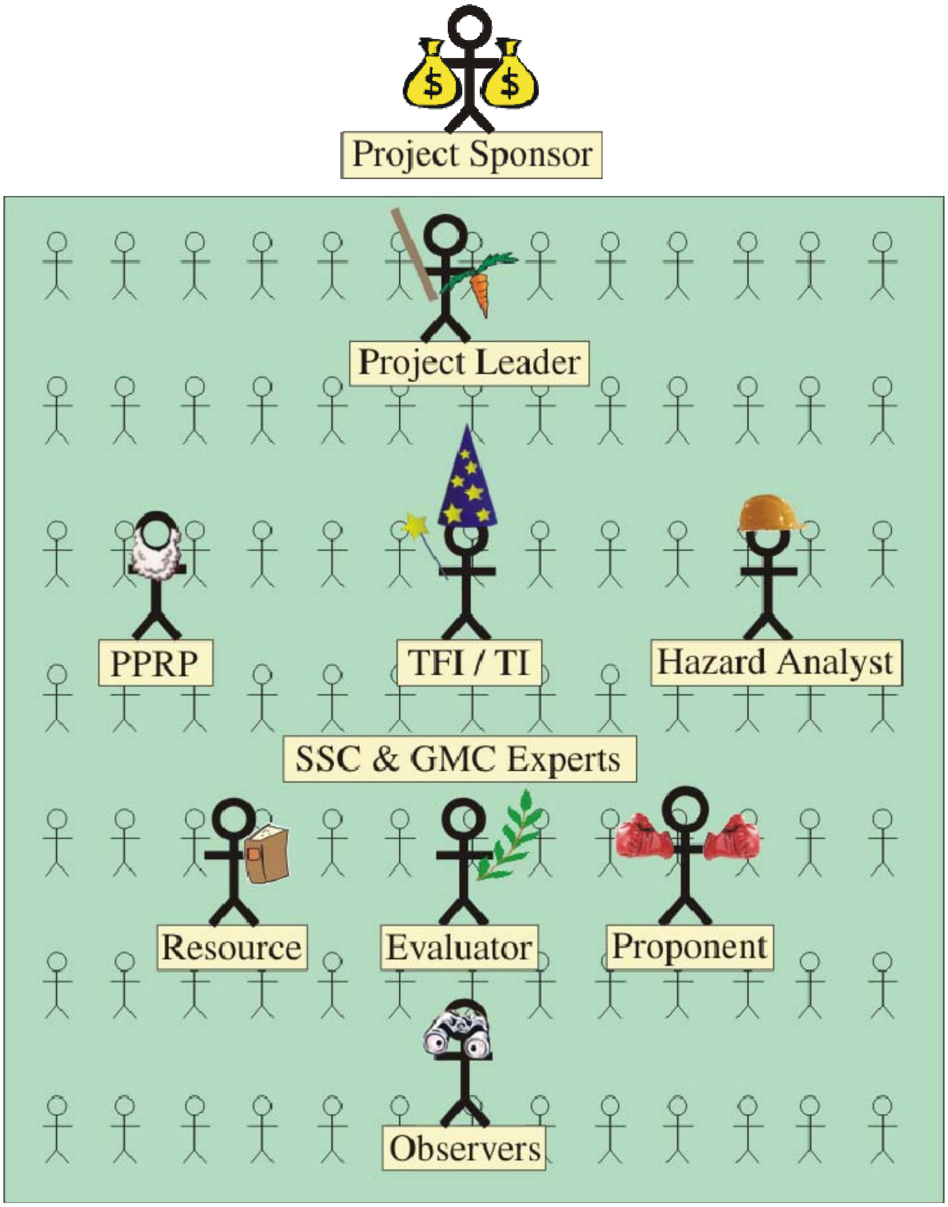

Figure 1. SSHAC participants.

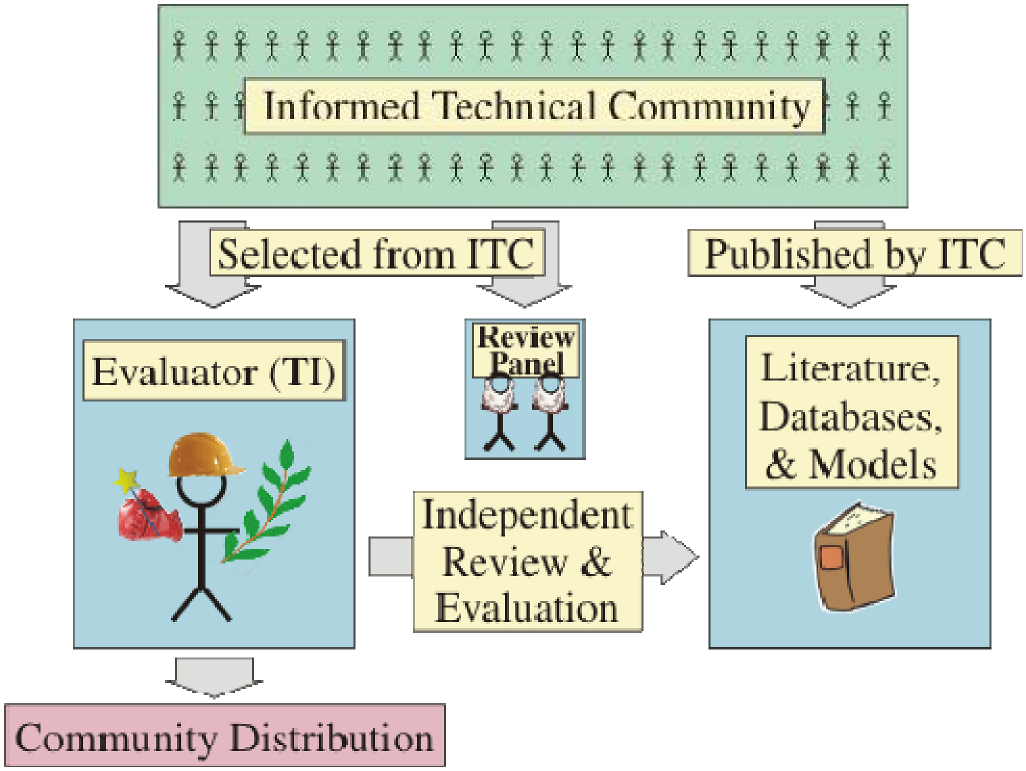

Figure 2. Expert interaction for SSHAC Level 1.

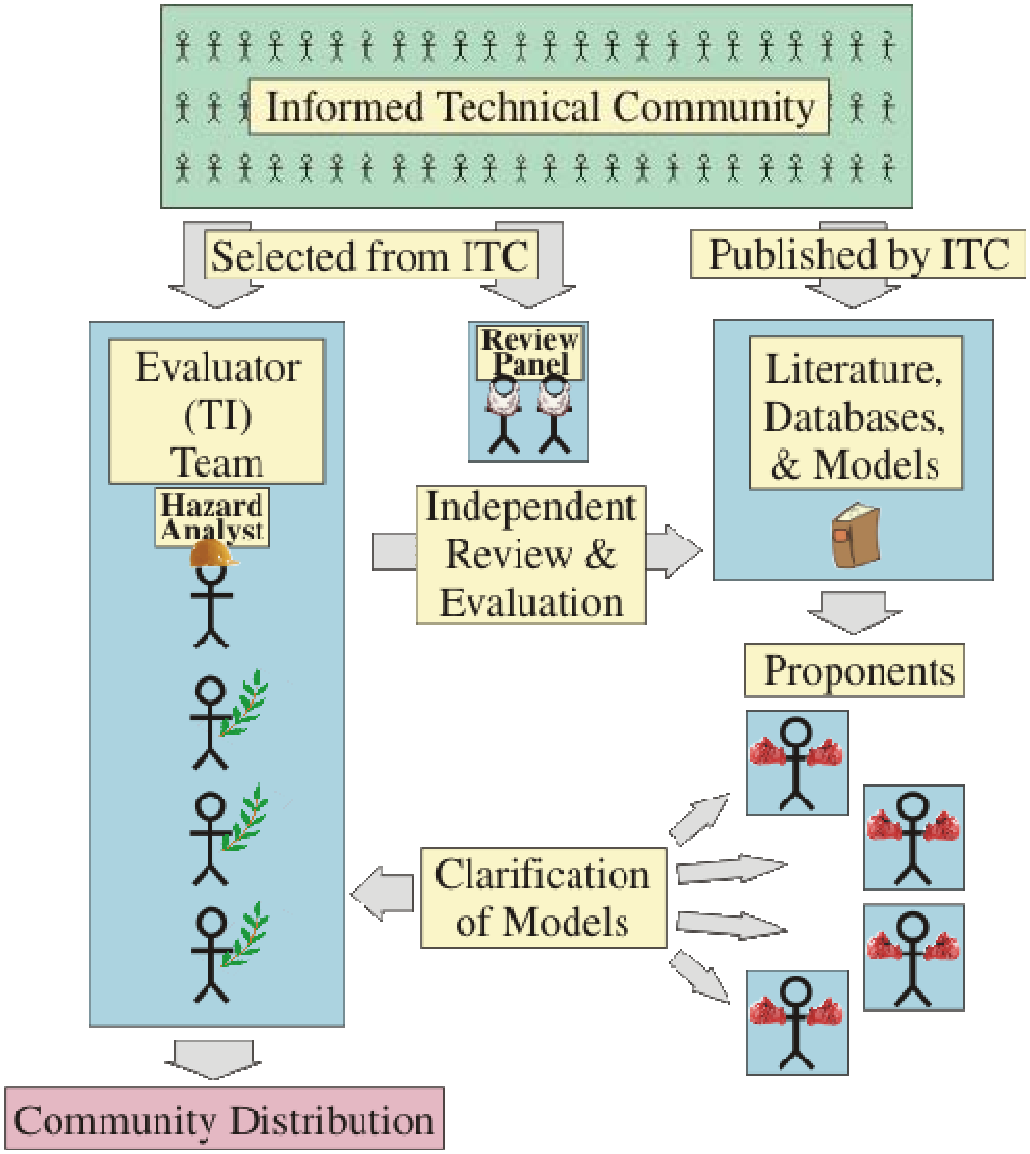

Figure 3. Expert interaction for SSHAC Level 2.

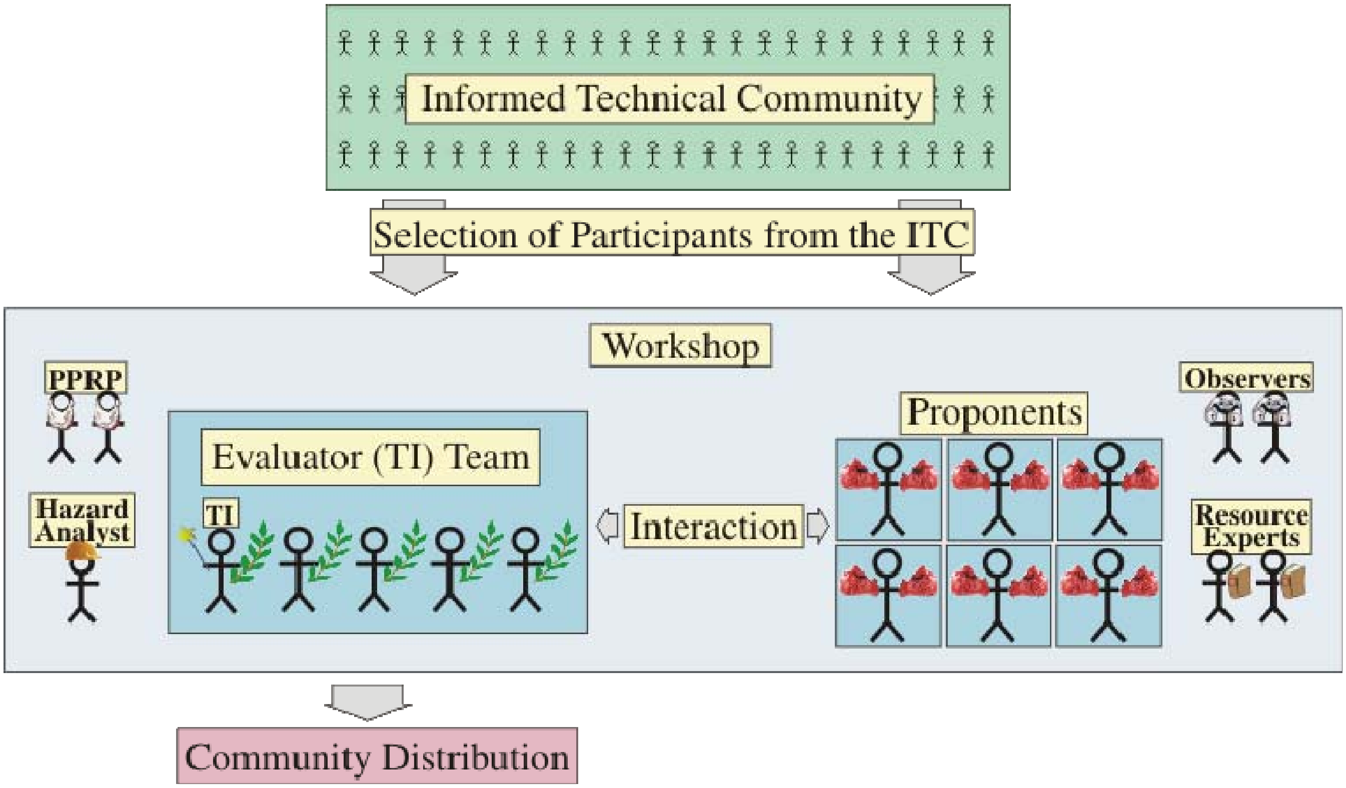

Figure 4. Expert interaction for SSHAC Level 3.

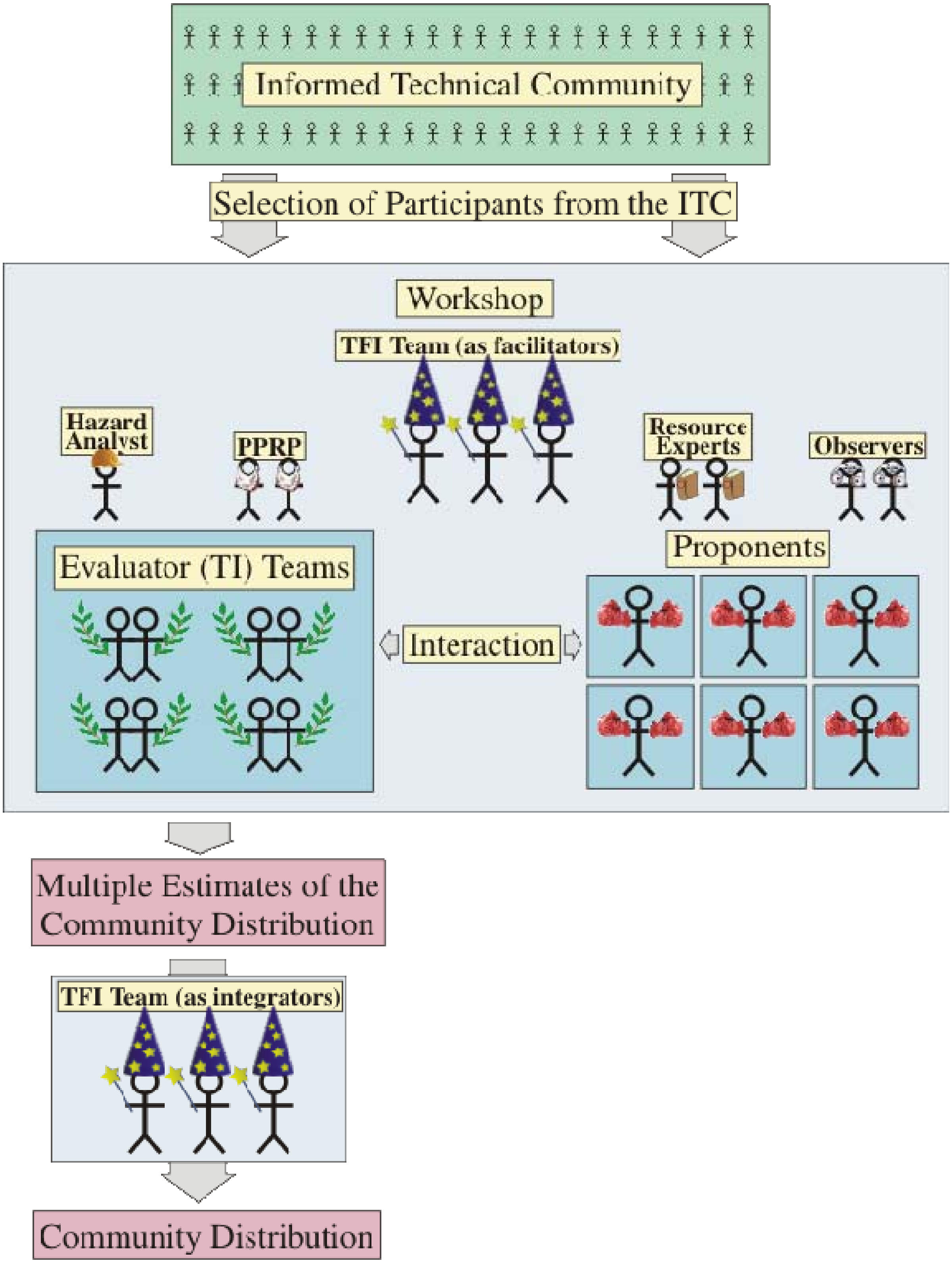

Figure 5. Expert interaction for SSHAC Level 4.

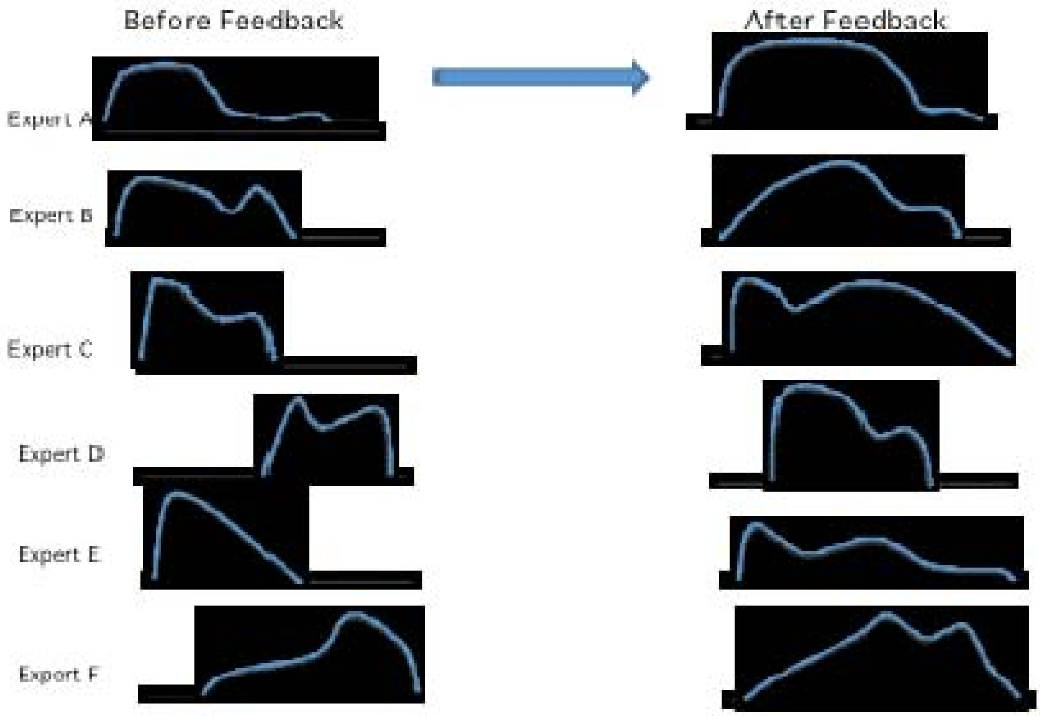

Figure 6. Diagrammatic representation of the two-stage evaluation process showing the resulting evaluator distributions prior to and following feedback.

APPENDICES

Workshop 1—Lessons Learned from SSHAC Level 3 and 4 PSHAs

"Lessons Learned from SSHAC Level 3 and 4 PSHAs" is the first of three workshops conducted as a part of the project "Practical Procedures for Implementation of the SSHAC Guidelines and for Updating Existing PSHAs" funded by the United States Nuclear Regulatory Commission. This workshop was held at the U.S. Geological Survey in Menlo Park, California on January 30-31, 2008. The focus of this workshop was on lessons learned from previous Level 3 and 4 probabilistic seismic hazard analyses (PSHAs). The workshop was attended by 39 people. Following the workshop, two collection of files were prepared (1) a collection of .pdf files made from the email comments sent by participants to the organizers and (2) a collection of .ppt, .pdf, and .doc files from talks at the workshop are available online at ftp://ehzftp.wr.usgs.gov (look in the "nichole" folder for "SSHAC Workshop I").

Agenda

Jan 30-31, 2008
USGS Menlo Park

Day 1

0930	Introductions/Project description/Objectives/Disclaimers and apologies	Hanks Kammerer
1000	Overview of past SSHAC Level 3 and 4 PSHA studies [*ppt*] Level 4: Yucca Mtn (1998), PEGASOS (2004), TIP(??) Level 3: DCPP (1991), EPRI GM (2004)	Abrahamson
1030	Process issues identified from pre- and post-SSHAC applications: 25 years of learning what works and what doesn't [*ppt*]	Coppersmith
1100	Break	
1120	From "probability encoding" to "formal expert assessment" [*ppt*]	Jenni

1230 Lunch

1330 Understanding uncertainty [*ppt*] Toro

1330 Summary of top issues identified by previous study participants: What are the recurring topics? [*ppt*] Boore

1400 Comments from source model and ground motion experts

Source model experts

Foxall [*pdf*]

Smith [*pdf*]

Arabasz [*pdf*]

Ground motion experts

Anderson [*ppt*]

Bommer [*ppt*]

1520 Break

1540 Comments from hazard analysts

Toro [*ppt*]

McGuire [*pdf*]

Abrahamson [*ppt*]

Coppersmith [*ppt*]

Youngs

McCann

1700 Adjourn

Day 2

0930 Participants comments on issues/difficulties with SSHAC Level 3 & 4 Studies

0945 Comments from peer reviewers

Stepp

Brune [*ppt*]

Budnitz [*doc*]

1030 Discussion of comments from peer reviewers

1045 Break

1100 Comments from project managers and regulator/sponsors

Ake [*ppt*]

Abrahamson (for Sprecher) [*ppt*]

Reiter [*pdf*]

Kimball [*ppt*]

1200 Discussion of comments from project managers and regulator/sponsor; Public comments

1230 Lunch

1330 Continued discussion

1500 Br eak

1515 A dditional comments
Liteh iser
Sal omone

1630 Next Steps/Next Workshops Hanks

1645 A djourn

Note: *ppt*, *pdf*, *doc* indicate the type of files available through ftp://ehzftp.wr.usgs.gov in the "nichole" folder.

Key Points from Workshop on Lessons Learned from SSHAC Level 3 and 4 PSHAs

Jan 30-31, 2008
USGS Menlo Park

No one disputed the importance of interaction amongst experts.

- "Expert interaction sufficient that all the experts are expert in all the models" (Hanks).
- Need more formal interaction between the seismic source characterization (SSC) and ground motion (GM) groups (Smith) and with hazard analyst (Arabasz). This happens on typical projects, but not on the Level 4 studies since the work is done in parallel. More interaction between the SSC and GM experts is desirable in order to understand each other's issues and to minimize the potential for disconnects late in the project (Coppersmith).
- Interactive teams for SSC work very well and provide a valuable mechanism for additional interaction and learning among different disciplines (Coppersmith).

Choice of TFI/TIs and Experts is critical

- Because good choices were made in the past, previous elicitations worked well. There was some disagreement on whether the experts could abandon their proponent roles and serve to represent the informed scientific community as evaluators. But Julian Bommer noted that in PEGASOS: " prior to the project none of us would have necessarily described ourselves as "ground-motion modellers" in terms of that being our main activity."
- were not proponents of ground-motion models (GMMs), so the issue of experts wearing different hats did not arise.
- "The replacement of any one of us with certain individuals from European seismology (with a reputation for being somewhat difficult) could have completely sabotaged the process" (Bommer).
- It would not have been possible to run PEGASOS using a European TFI since there was no one qualified" (Sprecher).
- In small countries … historical rivalries may play an important and sometimes dominant role in shaping expert opinions and therefore distort the process" (Gürpinar).
- How do we select TFI's and experts (Hanks)?
- "Establish criteria for what makes a good TFI or TI. Many organizations think they make a good TFI or TI, but how can we tell? Did they even read and understand the SSHAC report?" (Kimball)
- Develop training tools for TFIs and TIs to (1) develop models that represent the informed scientific community's view of a topic and (2) "improve the behavior of subject experts" (Kimball, Hanks).

More and better training on the SSHAC process, PSHA and uncertainties

- Experience has shown that SSHAC is difficult to implement (note: for brevity, from here on "SSHAC" is shorthand for the guidelines and procedures contained in the SSHAC report for conducting level 3 and 4 PSHAs) . Detailed guidance is needed including terminology, definitions, and practical examples (Coppersmith).
- Define community model, community distribution, composite model (Hanks).
- Explain the fearsome foursome of aleatory and epistemic, modeling and parametric uncertainties (Hanks).
- Explain μ, σ_μ, σ, and σ_σ (Hanks).

- Need specific definitions of roles and practical examples for the proponents, evaluators, and integrators (Coppersmith, Hanks).
- As written in SSHAC, the integrator role is "shared" by the TFI and the experts. Is this feasible? Desireable? Possible? Perhaps the experts should just be evaluators who consider the views of the larger technical community in light of available data, and the TFI is the integrator who ensures that, in aggregate, the range of evaluator assessments is consistent with the community distribution. The attributes of a good evaluator should be identified (Coppersmith).
- One of the motivators for the SSHAC study was the need to deal with the "outlier" problem, defined as an expert who forsakes the role of an evaluator for that of a proponent. Have we dealt with this problem effectively? What are the mechanisms for ensuring that it is not a problem (e.g., expert selection process, rules for continuing participation by experts, TFI "weighing") (Coppersmith)?
- The integrator is responsible for representing the larger informed technical community. Are there any tests that this has been done successfully? If it is unattainable, should it be a goal of all hazard studies? The notion is liberating in the sense that it forces people to consider a full range of alternative views. Is there confidence (faith) that following the SSHAC process will lead to a defensible result (Coppersmith)?
- The new guidance should make a clear distinction between the SSHAC process of expert assessment (i.e., interaction and learning) and the classic expert elicitation process. This will help preclude applications of irrelevant procedures (e.g., expert scoring) to the SSHAC processes (Coppersmith).
- A composite model that captures the essence of all significant uncertainties is needed for many subsequent applications. However, it can only be meaningfully constructed after a full expert assessment has been completed, potentially adding to the total duration of the hazard analysis. Ownership of this composite model by the experts is ideal (Coppersmith).
- Explain clearly what is desired from the experts and how it will be used, as well as the role of the TFI or TI. TFI's need to provide a ranked list of things that matter (and things that do not) and computational tools (simple models) that show it (Hanks). Focus experts on the things that matter (Stepp).
- The TI role is key for most studies and it is not clear that the current field of TIs (usually companies or government agencies) has read or is aware of the SSHAC guidance. As a result, studies are uneven with respect to key elements, such as striving to examine and represent the larger informed technical community. Better, more specific guidance will help in this regard, but it will likely take some time (i.e., several years) before we achieve a uniformly high level of quality (Coppersmith).
- "Explain what uncertainties matter most in those things you are asked to provide." (Hanks)
- Time training so that the information comes at a time close to when it is needed and use examples that are relevant to the task at hand. But "Explain the calculations upfront, so everyone knows what input is needed" (Hanks)
- The TFI plays a key role in Level 4 studies and there are few people who have the experience or have been trained for this role. What are mechanisms for developing a larger (and younger) pool of potential TFIs for future studies (Coppersmith)?
- "…more in-depth explanation and training on the SSHAC and PSHA approach [is needed]…many of the team members were not trained in the use or understanding of the theory and quantitative aspects of PSHA. For example, how it works and the input data affect outputs, especially complicated logic trees" (Smith)
- Experts need a lot of training to do hazard right (Youngs).
- "The SSHAC level 4 process seems to have the concept that more logic trees (and model complexity) is better. The experts are "rewarded" for added branches and "harassed" for having few branches" (Sprecher).
- The full logic trees are too complicated for others to use. Need to develop simplified models that capture the main aspects of the experts models (Abrahamson). Though it is difficult to prepare a composite (complete) source model due to the correlation of the geometries (Foxall), a simplified model should still be possible.
- TFI Instructions that ground motion experts had difficulty with:
  - Their model should represent the informed technical community rather than just their own views (Coppersmith)
  - The branches on the logic trees should be collectively exhaustive and mutually exclusive (Abrahamson)
- SSHAC was originally focused on technical *issues*, rather than entire *projects*. Therefore, perhaps Level 4 studies can be done for only certain issues, and the remaining issues dealt with using Level 2 or 3 processes. A benefit could be a shortening of the schedule (Coppersmith).
- Timing of the topics was a problem in the source characterization (Smith). Because of a lack of understanding of PSHA and what matters the most to the hazard, not enough time was spent on the key topics.
- Issue of anchoring and bias is not as big a deal for PSHA because we have more emphasis on learning by the experts. Should we accept some anchoring if favor of getting the experts to focus on what matters most? (Abrahamson)

- SSC would benefit from more help from the hazard analyst to build their logic trees (Arabasz). TFI could provide examples of previous or typical logic trees to get experts started (but this leads to anchoring).
- Be sure not to undercount/estimate or over-count/estimate uncertainties (Hanks).

Feedback from hazard calculations, interactions of source and ground-motion teams, sensitivity analyses

- "The single biggest change that we would have requested would have been earlier and more detailed **feedback on sensitivities in the hazard calculations**. Although such feedback was provided, it came quite late in the project and after we had spent disproportionate amounts of time on secondary issues." (Bommer)
- "Continual feedback to the experts throughout the project is essential, but it is not always accomplished." (Campbell)
- Active, aggressive participatory peer reviews are effective means of dealing with difficult process and technical issues. The role of peer reviewers is especially acute for Level 2 and 3 studies (Coppersmith).
- The sponsors of a hazard study need to have sufficient technical expertise to understand and clearly specify the desired products, to understand the process being followed, and to interpret the results when they become available. In this sense, they must be owners of the study, not just the underwriters (Coppersmith).
- A key weakness of the Level 3 process is the lack of ownership of the results by any experts involved. Is there any process (e.g., additional interaction, feedback) whereby the experts can assume some ownership of the TI results as being representative of the larger informed community (Coppersmith)?
- Feedback is vital for helping experts to understand which issues are most important; serves to focus their efforts and can lead to economies (e.g., pruned trees). The earlier feed back is provided, the better. Perhaps it can be developed from pilot studies prior to involvement of the experts; but there may be a concern about anchoring (Coppersmith).
- Feedback should include unexceeded GM in addition to hazard calculations (Brune).
- Sufficient feedback/thinking time for the experts to assess the importance of what they have done (Hanks).
- Real-time feedback (Smith) and thus a simplified model to provide it (NAA, Gabe, Robin).

Project timing/logistics

- "Schedule tasks in a way that promotes—to the greatest extent feasible—focused attention by the "input experts." Intermittency over an extended period of time arguably results not only in inefficiency but also in lapses of attention to critical details…I've often thought that something closer to an immersion experience at a "Seismic Source Characterization Camp" would be better. At the same time, it's desirable that there be opportunities for some "seasoning" and iterative eliciting of the expert opinion." (Arabasz)
- The typical pace of a Level 4 study is characterized by short bursts of activity (e.g., workshops or elicitation interviews) separated by long periods of inactivity. This intermittency is distracting and counterproductive. A more concentrated, contracted schedule would lead to more continual involvement by the experts (Coppersmith).
- Obtain realistic commitments from experts that do not change with time (Coppersmith).
- "The experts are allowed to change their model until the very end, but if there is a significant change, there needs to be feedback (e.g. expert meeting) to discuss the changes. This leads to the problem of never ending workshops, but we can't just stop after a major change." (Abrahamson)
- "In many cases, short deadlines compress the schedule to the point that the TFI has to make unilateral decisions for which there is insufficient time for feedback, possibly to the detriment of the project." (Campbell)
- "Another thought about time constraints. Stepp said that the analysis should be based on knowledge as of the current date, but several times during the process someone responded to a suggestion by saying: "Yes, that could be important, but we don't have time to investigate" This raises the general question: How should we balance urgency vs accuracy?" (Brune)
- "…panel members were asked to act as proponents by preparing white papers pro or con various tectonic models, etc., which were circulated to stimulate debate. All of the panel members considered this to an indispensable part of the process." (Foxall)
- "All of the panel stressed the need for timely provision of high-quality working material (recurrence curves, preliminary source maps, etc.) between panel meetings/workshops, together with detailed documentation of calculation methods. The TFI team should ensure that the material provided is tailored to the needs expressed by the panel. In a similar vein, meeting minutes need to be provided promptly, and should contain a log of all decisions reached during the meeting." (Foxall)
- A SSHAC study is only as good as its documentation. Detailed guidance needs to be provided for documentation requirements for all Study Levels (Coppersmith). A dedicated note-taker is needed at workshops for documentation (Foxall)

- The level 4 process involves significant learning by the experts. The experts know the most after they have prepared their documentation of their model. Additional feedback in terms of peer reviews of the each other's models would be valuable, but this adds to the time of the project (Abrahamson)
- What triggers the need for an update to a hazard study? Predictable triggers need to be identified and clearly defined (Coppersmith).
- Time schedule for experts could be compressed if additional work is done ahead of time by TFI, but this will cause anchoring (Abrahamson)
- Level 4 studies are often viewed as time- and resource-consuming. Serious consideration should be given to developing guidance leading to much shorter Level 4 studies (less than one year), but maintaining the significant public and regulatory confidence attendant with these studies. The "contracted" studies would likely require much more effort on the part of the management team (for schedule, etc.), the TFI (for ensuring commitment, developing feedback), and the experts (e.g., blocking out more of their schedule). A significant preparation period (pre-expert involvement) could include data collection and exploratory pilot hazard studies, which would serve to focus the subsequent efforts (Coppersmith).
- Consider developing an alternative to the current level 4 approach that still meets the goals, but is faster and cheaper (Stepp).
- How do we deal with new data/models that rise in the course of the project (Brune)? Will new data be collected at all (Hanks)?
- Need someone dedicated to data sets to provide common data bases that are easily accessible to experts (Hanks, Abrahamson, Arabaz). Maximum advantage of available technology (e.g., web pages, ftp sites) should be taken (Coppersmith).
- A composite model that captures the essence of all significant uncertainties is needed for many subsequent applications. However, it can only be meaningfully constructed after a full expert assessment has been completed, potentially adding to the total duration of the hazard analysis. Ownership of this composite model by the experts is ideal (Coppersmith).

Is the right thing being elicited for GM?

- "The models created by the SSHAC level 4 process are too complicated so that the results cannot be easily checked. There should be a requirement to develop a simplified version of the source and ground motion models that captures most of the epistemic uncertainty and can be used by others…[the TFI should] take the initial models developed by the experts and … turn them into a single model that captures the key elements of all of the models." (Abrahamson)
- "I think that trying to include every possible model with the idea of giving extreme or outlier models small weight is an exercise in futility. Not only can such an approach lead to huge and often overlapping uncertainties, but the results themselves tend to be dominated by these extreme opinions at very low probability levels. I think that the process would be better served if only credible models are used and given equal weight, unless there is a very good reason to do otherwise. Any model that is given a small weight by the experts is likely to be included only because the experts have been asked to include all opinions, no matter how extreme, and would probably not be included otherwise." (Campbell)
- Sponsors and TFI/TIs need to think through the potential applications of the study so that all significant issues will be addressed (e.g., ground motions at 10^{-8} AFE) and the outputs will be in a form that is usable to the intended recipient (Coppersmith).
  All experts should be experts in all the models (Hanks).

Change the age-distribution of SSHAC participants

- "Given the demographics of current PSHA experts, foster workshops and other learning forums to progressively broaden the base of available experts for next-generation work." (Arabasz)

Workshop 2—Updating Existing PSHAs

Summary Report: Workshop on Updates to Existing PSHAs

"Updates to Existing PSHAs" is the second of three workshops conducted as a part of the project "Practical Procedures for Implementation of the SSHAC Guidelines and for Updating Existing PSHAs" funded by the United States Nuclear Regulatory Commission. This workshop was held at the U.S. Geological Survey in Menlo Park, California on May 6-7, 2008. The focus of this workshop was on the process of updating existing PSHAs and consequently applies to the standards of new PSHAs. The workshop was attended by 40 people. As the workshop focused on issues discussed in a separate Open-File Report, in preparation, the Workshop agenda will be given in that report.

Workshop 3—Draft Recommendations

The focus on Workshop 3 was the presentation and discussion of the recommendations that form the body of this Open-File Report. For this reason, it would be largely redundant to provide a detailed account of the workshop, thus all that we provide here is the agenda for the workshop.

Agenda

Workshop on Draft Recommendations
SSHAC Implementation Guidance
June 4-5, 2008
USGS Menlo Park

Day 1

9:30 **Introduction** Hanks

9:45 **Draft recommendations related to SSHA implementation** Coppersmith, *facilitated discussion*

- Terms and their usage
- Formal Expert Assessment vs. Expert Elicitation
- SSHAC Study Levels
    - CEUS SSC Project Study Level 3 Case History
- Deciding on the Study Level
- Study Level for Issues versus Projects

11:00 Break

11:15 **Draft recommendations, continued**

- Feedback
- Evaluators and the Informed Technical Community (ITC)
- Training of Experts / Demands on Experts
- Composite Model
- Interaction between SSC and GM / PEGASOS
- Ownership Issues / Results vs. Places for PRPP
- Duration of Level 4 Studies
- Developing Future TI/TFIs
- Documentation / Definitions

12:30 Lunch

1:30 **Draft recommendations, continued**

5:00 Adjourn, proceed to Gordon Biersch in Palo Alto for dinner

Day 2

9:30 **Draft recommendations related to updating a PSHA** — Abrahamson *facilitated discussion*

Conceptual Approach for Developing Community-Based Model

CEUS PSHA

Discussion of current National Hazard Map — Kimball, Mueller

Regional PSHAs: CEUS, California, rest of WUS

Site Specific Refinements

Sites of Existing Units

Non-nuclear facilities

11:00 Break

11:15 **Draft Recommendations Related to Updating, continued**

12:30 Lunch

1:30 **Discussion of All Draft Recommendations**

3:30 **Next Steps (Documentation, USGS Open-File Report, NUREG)** — Hanks, Kammerer

4:00 Adjourn

Table of Participants for the Three Workshops

Workshop 1—Lessons Learned from SSHAC Level 3 and 4 PSHAs (Jan 30-31, 2008)
Workshop 2—Updates to Existing PSHAs (May 6-7, 2008)
Workshop 3—Draft recommendations, SSHAC Implementation Guidance (Jun 4-5, 2008)

Y=Attended workshop
N=Did not attend workshop

1	2	3	Name	Affiliation
Y	Y	Y	Abrahamson, Norman A.	Pacific Gas & Electric Co
Y	Y	Y	Ake, Jon P.	U.S. Nuclear Regulatory Commission
Y	N	Y	Anderson, John G.	University of Nevada Reno
Y	Y	Y	Arabasz, Walter J.	University of Utah
N	Y	Y	Baker, Jack W.	Stanford University
Y	N	Y	Bommer, Julian J.	Imperial College
Y	N	Y	Boore, David M.	USGS
Y	Y	Y	Brune, James N.	University of Nevada Reno
Y	Y	Y	Budnitz, Robert J.	Lawrence Berkeley National Laboratory
N	N	Y	Campbell, Kenneth W.	EQECAT
N	Y	N	Cao, Tianqinq	
N	Y	N	Chokshi, Nilesh	NRC
Y	Y	N	Cline, Mike	Kleinfelder Inc.
Y	Y	N	Cluff, Lloyd S.	Pacific Gas & Electric Co
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Y	Y	Y	Creed, Bob	Department of Energy Idaho

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Y	Y	N	Foxall, William	Lawrence Livermore National Laboratory
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Y	N	Y	Kassawara, Robert	Electric Power Research Institute
Y	Y	Y	Kimball, Jeffrey K.	Defense Nuclear Facilities Safety Board
Y	Y	Y	Kneepprath, Nichole E.	USGS
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Y	Y	Y	Litehiser, Joe J.	Bechtel Corporation
Y	N	N	Lilhanand, Kiat	Rizzo Associates, Inc.
Y	Y	Y	McCann, Martin W.	JBA
Y	Y	Y	McGuire, Robin K.	Risk Engineering Inc
Y	Y	Y	Munson, Cliff G.	US Nuclear Regulatory Commission
Y	Y	Y	Mueller, Charles	USGS
Y	Y	Y	Murphy, Andrew J.	NRC
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Y	Y	N	Purvance, Matthew D.	University of Nevada Reno
Y	Y	N	Quittmeyer, Richard C.	Integrated Science Solutions Inc
Y	N	Y	Reiter, Leon	US Nuclear Waste Tech Review Board
N	Y	N	Renault, Philippe	Swissnulcear
Y	Y	Y	Salomone, Larry	Washington Savannah River Company
Y	Y	Y	Savage, William U.	USGS
N	N	Y	Scherbaum, Frank	Universitaet Potsdam
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Y	Y	Y	Toro, Gabriel R.	Risk Engineering Inc
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N	Y	N	Wong, Ivan	URS Corp
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N	N	Y	Zafir, Zia	Kleinfelder Inc.