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Implementation Guidance for SSHAC Level 3 and 4 Processes

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Abstract: Risk analysis for critical facilities requires a probabilistic assessment of the hazards that could affect the installation. The complexity of the processes that generate geological hazards such as seismic ground shaking and volcanic events is such that there is inevitably large uncertainty associated in the hazard assessment. This uncertainty is reflected in the range of legitimate technical interpretations made by informed technical experts based on the available data. Procedures to develop multiple expert assessments for seismic hazards in a structured process have been established in the SSHAC (Senior Seismic Hazard Analysis Committee) guidelines. The objective of the present paper is to capture and clarify the insights gained from performing a number of detailed assessments using the SSHAC approach over the past 10-15 years. Unlike classical expert elicitation, which attempts to extract information from independent experts, the SSHAC process encourages interaction amongst experts and fosters learning by the experts throughout the process, with the ultimate objective of capturing the full community distribution of technical interpretations. The SSHAC guidelines, written largely in abstract, have now been implemented in practice several times. In these studies valuable lessons have been learned, which are now being distilled into a new U.S. Nuclear Regulatory Commission NUREG-series report to provide practical guidance on implementing SSHAC processes for hazard assessments. A key lesson from these studies is that higher level SSHAC processes (Levels 3 and 4) which specify the use of a Participatory Peer Review Panel (PPRP), provide a higher degree of regulatory assurance and stability for the initial development of hazard models for safety-critical installations. Also, significant technically-informed participation by project sponsors and regulators throughout the process enhances the likelihood of regulatory acceptance.

Keywords: PSHA, Epistemic Uncertainty, Multiple-expert Assessments, SSHAC.

1. INTRODUCTION

This paper summarizes the need for conducting detailed and comprehensive probabilistic seismic hazard analyses for safety-critical facilities. Performing these types of studies presents a unique set of challenges. The objective of this paper is to summarize and illustrate the SSHAC process of capturing expert judgments based on the insights gained from applications of the approach for critical facilities over the past 10-15 years.

Risk-informed design and assessment of critical facilities requires the characterization of external loads such as those related to earthquake-induced shaking in a manner that captures both the rate of occurrence of earthquakes and the randomness in earthquake location and ground-motion amplitudes. This leads to the choice of probabilistic seismic hazard analysis (PSHA) as the preferred approach for

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determining earthquake inputs for seismic design and for risk analysis of critical facilities [1]. The primary output from a PSHA is a seismic hazard curve that displays the relationship between different levels of a selected ground-motion parameter, such as the maximum acceleration, and the associated annual frequency of exceedance. The fragility curve of any structure, system or component in a facility is defined as the probability of a defined damage state being reached under different levels of the ground-motion parameter. The convolution of the hazard curve and the fragility curve determines risk curve, which defines the exceedance probability or frequency of different damage states for the structure, system, or component of interest.

The random nature of earthquake occurrence and the variability in the ground-motion field resulting from an earthquake scenario are both examples of what is referred to as aleatory uncertainty or aleatory variability. These aleatory uncertainties are characterized by probability distributions which are directly integrated in the hazard calculations [2, 3]. The data available for characterizing the sources of future earthquakes, in terms of location, magnitude and recurrence rate, is generally limited, so expert judgment is needed in the interpretation of these data to formulate models for seismicity. Similarly, there is a significant degree of expert judgment in selecting suitable models for the prediction of ground-motion amplitudes from a specific earthquake scenario, especially for those magnitudes and distances beyond the limits of the datasets from which the models are derived. Expert judgments are needed because there is uncertainty regarding the most appropriate model or parameter value for the specific application. This modeling uncertainty reflects the lack of knowledge concerning earthquake processes; and for this reason it is given the name epistemic uncertainty. The tool most commonly used to capture epistemic uncertainty in PSHA is the logic-tree [4, 5], in which alternative models or parameter values are placed on different branches and assigned weights (usually summing to unity at each node) that reflect their relative merit in the view of the analyst. A hazard curve is then calculated for each separate path through the logic-tree, with the total weighting of the curve being the product of the individual branch weights. Epistemic uncertainty therefore leads to suites of weighted hazard curves from which the mean hazard and fractiles of the hazard can be calculated.

Because epistemic uncertainty leads to alternative, but legitimate, interpretations of Earth science data, it stands to reason that the likelihood of fully capturing the uncertainty in the models used to calculate the hazard, and hence in the estimate of the hazard, is increased by combining the assessments of several experts. The SSHAC guidelines provide a framework for bringing together multiple expert assessments. Although the SSHAC guidelines are focused on seismic hazard analysis, the procedural guidance is equally applicable to all natural hazards, including surface fault rupture, tsunami and volcanic hazards.

The origin of the SSHAC guidelines lies in two major PSHA studies in the 1980s for nuclear power plant sites in Central and Eastern United States (CEUS). The CEUS is a region of relatively low seismicity rates where significant earthquakes have occurred but where the tectonic associations of observed seismicity to tectonic features are tenuous and data on long-term recurrence rates are very limited. Recognizing the degree of uncertainty that therefore exists in the seismicity and ground-motion models for this region, the seismic hazard studies undertaken for this region by the Electric Power Research Institute (EPRI) [6] and by Lawrence Livermore National Laboratory (LLNL) [7] involved several experts each developing their own hazard input models. The studies resulted in very different hazard estimates for many locations in the CEUS both between the projects and amongst the experts within each project. In both projects, the problem arose as to how to combine the various expert models into a single hazard assessment. This led to reflection on how the views of multiple experts can be reconciled and the degree of interaction that the experts should have during the process. Concerns about the issues that arose in the EPRI and LLNL studies eventually led the US Nuclear Regulatory Commission (USNRC), Electric Power Research Institute, and the US Department of Energy (DOE) to form the Senior Seismic Hazard Analysis Committee (SSHAC) to review the state-of-the-art in PSHA and to formulate guidelines for greater stability in such studies. The initial finding of SSHAC was that the differences in the PSHA results from the LLNL and EPRI studies were mainly due to procedural—rather than technical—differences. As a result, the work of SSHAC was focused primarily on developing appropriate approaches to the organization and the methodologies used for gathering expert judgments rather than the technical details of how probabilistic assessments are performed. The outcome of the work undertaken by SSHAC was a lengthy report published by the USNRC in 1997 [8] that in many ways defined a new benchmark for expert assessment and uncertainty treatment in seismic hazard analysis.

2. OVERVIEW OF SSHAC PROCESSES

The SSHAC report consists of two large volumes. The first is 256 pages in length and the second, containing several appendices, is almost 900 pages long. There is a wealth of information and detail in these volumes that provide invaluable insight into the theoretical and practical considerations of conducting a PSHA. In the following three sub-sections, we attempt to capture some of the most important elements of the report and the key concepts of the SSHAC process.

2.1. SSHAC Goals

An underlying assumption in the development in the SSHAC methodology is that the most appropriate basis for determining input parameters for a PSHA (e.g., seismogenic sources, activity rates, maximum magnitudes, and ground-motion prediction equations) "*must be the composite distribution of views represented in the appropriate scientific community*". The key statement in the SSHAC guidelines is as follows: "*Regardless of the scale of the PSHA study the goal remains the same: to represent the center, the body, and the range that the larger informed technical community would have if they were to conduct the study*" [8]. This statement is so central to the SSHAC process that it is worthwhile briefly discussing each part.

One key objective of a PSHA is to capture the full range of possible estimates of the hazard at a site. The hazard is a characterization of nature and therefore is theoretically knowable, but in reality a level of existing epistemic uncertainty means that there will be a legitimate range of estimates, within which the actual hazard must lie. The assumption in the SSHAC process is that estimates of the hazard can be captured from the scientifically justifiable interpretations of Earth science and geotechnical data by appropriate experts in these fields. The center of these interpretations can be thought of as the best estimate or the expected value; the body can be thought of as the shape of the distribution of interpretations about this best estimate; and the range refers to the tails of the distributions and the limiting values. The process seeks to capture the center, the body and the range on each component of the hazard study (geographical limits of seismogenic sources, seismic activity rates, maximum magnitudes, ground-motion prediction equations, etc.), which will then result in capture of the center, the body and the range of seismic hazard estimates.

The fundamental goal of a PSHA as stated above is to capture the center, the body and the range of what is referred to as the informed technical community (ITC), which has a very specific meaning in the SSHAC guidelines. The center, body and range (CBR) of legitimate technical interpretations of Earth science and geotechnical data is not captured by taking a poll of all suitably qualified and highly-regarded researchers and practitioners in these fields. The word 'informed' in the concept of the ITC refers specifically to experts having access to the complete database for the region and the site under consideration, and having fully participated in the PSHA study conducted according to the requirements of a SSHAC process. A relatively small number of experts will actually participate in any PSHA study, for purely pragmatic reasons, but their task is to represent the views and interpretations of the broader technical community. The selected expert participants must possess a sufficiently strong technical background in the relevant discipline (geology, seismology, engineering seismology, geotechnical engineering) and have the personal qualities that make their participation constructive rather than disruptive to the process (essentially, being open-minded to receive new information, objectively evaluate it, and update their own views in the light of this information). Provided these criteria are met, then in theory whichever sub-group of the broader technical community actually participates in the project, the SSHAC process is expected to produce the same outcome.

2.2. Essential Components of a SSHAC Process

As explained below in section 2.4, the SSHAC guidelines define four different levels at which PSHA studies can be conducted, increasing in sophistication and complexity from Level 1 to Level 4. Only the higher levels (3 and 4) are appropriate for the initial development of hazard estimates at critical facilities such as nuclear power plants, and these are the focus of this paper. Consistent with major PSHA studies for the CEUS that were conducted in the 1980s, SSHAC Level 3 and 4 processes focus on multiple-expert assessments, but participating experts are now assigned specific roles, each of which carries different responsibilities and attributes. The three specific roles in the SSHAC process are the evaluator expert, resource expert, and proponent expert.

The key role in the SSHAC process is that of an *evaluator expert*, which is an individual or a team that objectively examines available data, diverse models, challenging their technical bases and underlying assumptions, and, where possible, testing the models against observations. The goal for the evaluator expert is to identify the full range of legitimate technical interpretations and to assign weights to each of these that reflect his or her relative degree of belief that this is the most appropriate representation of nature for the application in question. The evaluator expert is not obliged to include all models that have been put forward in the field, but the technical basis for excluding a model must be clearly documented. In a SSHAC process, evaluator experts are asked to go through a two-stage process to arrive at their final estimate of the CBR. In the first stage, they are tasked with defining their own estimate of the distribution of acceptable models and parameters values, and then in the second step to assess how well their own view captures that of the broader community.

In order to inform the assessments of evaluator experts, two other groups of experts are invited to participate in a SSHAC process. The first of these are *resource experts*, who possess (or acquire through extensive review conducted specifically for the study) knowledge of a particular dataset, model or method. The key characteristic of their participation is that the resource expert presents the data, methods or models impartially, highlighting assumptions, limitations and caveats. The evaluator experts will pose questions to resource experts in order to obtain insight into the nature and value of the data, models and methods. The third type of expert is the *proponent expert*, who presents a model or method from a partisan perspective. The proponent expert will propose that the method or model be adopted and will then defend that position in the face of technical challenge from the evaluator experts. The proponent role is a common role in the scientific community, whereby individual researchers develop hypotheses based on the available data and advocate those hypotheses to their peers through publication and professional interactions.

A fourth role in the SSHAC process is that of integrator, which is ultimately an extension of the role of evaluator. The integrator role will be discussed later (section 2.4) after the concept of integration has been presented in section 2.3. Another vital role in a SSHAC process is that of peer reviewer, which is discussed in section 2.4.

Any PSHA must begin with the compilation of databases, gathering all available relevant information and possibly undertaking new data collection. This is very important to emphasize because expert judgments should only ever be used to assess the uncertainty that remains in the seismicity and ground-motion models after all available data has been compiled and analyzed; it should never be an alternative for data or measurements that can reasonably be made. The backbone of a SSHAC process is a series of formal workshops, which are conducted according to strict rules regarding topic, participation, and documentation. The minimum number of workshops is three, the first covering data needs and hazard sensitive issues, which requires the participation of resource experts. Following discussions at the first workshop, additional data gathering can take place. At the second workshop, the data being gathered is presented and alternative candidate models are presented and discussed; this is the main activity in which proponent experts are expected to participate. Proponents of alternative viewpoints are juxtaposed and each is expected to defend his or her model to the evaluator experts in light of the available data. Following the second workshop, preliminary seismic source characterization (SSC) and ground motion characterization (GMC) models are developed and hazard calculations are performed. At the third workshop, the evaluator experts present the preliminary model, receive feedback in the form of sensitivity analyses, showing how different aspects and elements of the SSC and GMC models are impacting on the hazard results. Following this workshop, final modifications may be made to the models as the evaluator experts focus on the most influential parts of their models (but not adjusting the models because of discomfort about the hazard results). The final hazard calculations are then performed and checked. The final task is then to comprehensively document the development of the SSC and GMC models, including the technical basis for all decisions regarding the structure and weights of the logic-tree, and the hazard results, including disaggregation to show the contributions from different seismic sources, magnitude and distance combinations, and ground-motion prediction equations.

2.3. Relation of SSHAC to Classic Expert Elicitation

The SSHAC process aims to obtain not only best estimates of the seismic hazard at a site, but also the full distribution of the uncertainty associated with these estimates. The process results in a model representing not only the evaluations of the experts from whom it was derived, but also views of the larger ITC that the experts, in principle, represent. The SSHAC process is therefore quite distinct from classical 'expert elicitation' since the objective is not simply to obtain answers to well-defined questions from carefully selected experts. In an expert elicitation, the answers are assumed to already exist in the minds of the experts, and so the goal is skillful extraction of the data. By contrast, the SSHAC process is based on the concept that technical evaluators with appropriate backgrounds become 'experts' in the course of the project. Subject matter 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 considering the judgments of the broader technical community of which they are part, and ensuring that those views are appropriately represented in the resulting analyses.

Rather than maintaining the strict independence of each expert, to avoid 'contamination', the SSHAC process expressly encourages and fosters interactions among experts during the assessment process up to and including discussion of preliminary assessments of specific uncertain quantities. The purpose is not to achieve consensus, although if this occurs through genuine convergence of the expert assessments, it is an acceptable outcome. The real purpose of the interactions among the evaluator experts, apart from providing additional technical challenge, is to ensure that at the end of the project any remaining differences in the assessments of individual experts represent genuine epistemic uncertainty and not simply misunderstandings or the exposure to different sets of data or models.

Another sense in which the SSHAC process differs from classical 'expert elicitation' is that the judgments of individuals or teams of evaluator experts are not simply aggregated, but rather they are integrated. In a typical expert elicitation, subject matter 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. For example a climate scientist might be asked to provide an estimate of "the equilibrium change in global average surface temperature" given a specific set of circumstances [9]. 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. Based on this perspective, the elicitors may focus significant effort on ensuring that they have well-calibrated and informative experts; that is, experts who are able to give both accurate estimates and a narrow range of uncertainty in estimates for quantities similar to those of interest in the elicitation but for which a "true" value can be determined (*e.g.*, Chapter 10 of [10]). For narrow assessment tasks, the elicitor may focus on designing elicitation questions to motivate "honest" responses through the use of proper scoring rules [11]. All of these 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. Typically, aggregation of expert assessments, whether through mechanical or behavioral approaches, is conducted for independent estimates of a quantity of interest. Issues inevitably arise regarding the number of samples needed to faithfully represent a "complete" representation of the uncertainties in that quantity.

The SSHAC integration process, in contrast, takes a broader view. Evaluator experts examine the available data, probe the technical bases for proponent experts' models, and, in the integration step, provide their representation of not only their own evaluations but of the larger informed technical community. In this way fewer experts are required to properly capture uncertainties and all of the experts share in the integration process along with the project leads, defined in detail below in Section 2.4.

2.4. SSHAC Study Levels and Relation to Regulatory Assurance

As noted in section 2.2, the SSHAC guidelines define four different levels at which a PSHA can be conducted. The core concept is that of a Technical Integrator (TI), which may be an individual or a team, and which takes on the task of defining the center, the body and the range of ITC. In a Level 1 study, the TI undertakes the assessment based only on the available published and unpublished data and models. The distinction of a Level 2 study is made when the TI (or TI team) interacts with resource and proponent experts – very often authors of the data reports or models that the TI is evaluating – in order to obtain additional insights and information. The majority of PSHA studies are carried out as Level 1 or 2 processes in the SSHAC framework, which will generally be consistent with the importance of the project for which the study is being conducted and with the resources and time made available for the study.

When the degree of uncertainty or controversy regarding technical interpretations of seismicity in a given region is higher, there will be greater onus to engage with more experts and hence adopt a higher SSHAC Level for the PSHA. However, the primary motivation for adopting a higher level of study will generally be the nature of the project or facility for which the PSHA is being conducted. For safety-critical installations such as nuclear power plants, for example, it becomes particularly important to be able to provide assurance that the uncertainty has been fully captured in the hazard analysis. For this reason, in a nuclear regulatory environment, Level 1 and 2 studies will generally not be considered adequate for the initial development of hazard models, and it would be expected for PSHA studies to be conducted as Level 3 or Level 4 processes. However, it may be appropriate to utilize a Level 2 process for updating specific portions of a PSHA developed using a Level 3 or 4 process. Updating the characterization of an individual seismic source if new information becomes available would be an example of this situation. In a Level 3 process, the key entity is still the TI but this will generally be a larger TI Team of evaluator experts, and through formal workshops (see section 2.2) the TI Team will interact with resource and proponent experts. The TI Team is ultimately responsible for the technical evaluations and the integration process.

The most rigorous process defined in the SSHAC guidelines is a Level 4 study, for which the concept of Technical Facilitator-Integrator (TFI) was defined. In a SSHAC Level 4 study, panels of evaluator experts are assembled, who interact in workshops but also develop individual assessments. The TFI coordinates and facilitates the interactions within the workshops and also conducts one-to-one interviews with the evaluator experts regarding the development of their models. In essence, the integration is ultimately performed by the TFI supported by the evaluator experts; the SSHAC guidelines allow for the TFI to apply unequal weights to the members of the evaluator expert panels, but the more desirable approach is that the models from the individual evaluators (or evaluator teams) are assigned equal weights in the final logic-tree. Since the individual evaluators are tasked with performing the same function (representing the center, body and range of the views of the larger informed technical community) anything other than equal weights would suggest a judgment by the TFI as to the relative success of that effort by one or more of the evaluators.

Level 3 and 4 studies are significantly more resource intensive than Level 1 and 2 studies, requiring more time, effort and money, but they provide a much higher level of assurance within a regulatory environment. This is because larger numbers of experts participate and their participation is clearly recorded through participation in workshops and the resulting documentation. Even though the goal of a SSHAC process is always to capture the CBR of the ITC, the challenge for an individual TI conducting a Level 1 study to capture the full distribution of views of the broad technical community is clearly very considerable, and possibly not possible to achieve in practice. When several evaluators work together in a structured fashion, and when they can question and challenge resource and proponent experts in workshop settings, the likelihood that the output will capture the complete range of justifiable technical interpretations made by the broad technical community increases appreciably.

Another feature of the SSHAC process that contributes towards higher levels of regulatory assurance is peer review. The SSHAC guidelines place great emphasis on the importance of peer review and strongly recommend that this be participatory and continual throughout the project, rather than late-stage. This means that the reviewers are engaged from the beginning of the study and have interactions with the TI at regular intervals rather than simply receiving a draft final report to review. The advantage of on-going participatory review is that any required corrections can be made early on in the study before the models are finalized and the hazard calculations executed.

Although participatory, or continual, peer review is recommended at all study levels, in SSHAC Level 3 and 4 processes a formal Participatory Peer Review Panel (PPRP) is formed. The PPRP is compromised of individuals who collectively possess expertise in all of the key disciplines involved in the study, in addition to an understanding of the overall process of PSHA. The members of the PPRP should be familiar with the concepts of SSHAC and aware of the dangers of cognitive bias and anchoring, which can affect expert judgments. The PPRP has two roles to perform, the first being *technical* review, which means ensuring that the full range of technical views has been considered in the study and that the technical bases for all decisions and assessments is adequately presented to justify the final structure and weights on the logic-tree. The PPRP is not charged with giving its own technical views, and this is to be discouraged in order to maintain a high degree of objectivity in reviewing the study. The second role of the PPRP is to review *process*, ensuring that the study has been conducted according to the principles set forth in the SSHAC guidelines, in particular with regards to the conduct of the workshops. In a SSHAC Level 4 study, the process review aspect becomes particularly important, not least because the interactions within the expert panels—and between these panels and the TFI—is assumed to provide a high degree of technical peer review.

The PPRP also plays a vital role in reviewing, for completeness and clarity, the final PSHA report in draft format and when it is finalized following feedback. At the very end of the project, it would normally be expected that the PPRP would issue a signed letter report stating that the PSHA is technically complete and has been conducted in accordance with the SSHAC guidelines; this letter report is then appended to the final project report. Following a SSHAC Level 3 or 4 process and developing thorough and clear documentation cannot guarantee regulatory acceptance of a seismic hazard assessment, but it can be expected to increase the likelihood of acceptance, and to reduce questions from the regulator, thereby potentially shortening review times for license applications.

3. DEVELOPMENT OF NEW SSHAC IMPLEMENTATION GUIDELINES

The SSHAC guidelines were published 13 years ago by the USNRC and have been widely diffused and applied during that time. During the drafting of the SSHAC guidelines, a number of exercises, conducted separately for SSC and GMC issues, were undertaken to explore the viability of the proposed procedures for Level 4 studies. However, apart from these exploratory studies, and the lessons learned from the experiences of the EPRI and LLNL seismic hazard studies for CEUS, the SSHAC guidelines were written largely in abstract. As a result, there is now an opportunity to review the guidelines in the light of over a decade of implementation.

3.1. Case Histories of SSHAC Processes

The key innovation of the SSHAC guidelines was the Level 4 process and the TFI concept. The SSHAC report acknowledged that the TI concept existed de facto in most PSHA studies, although it was not formally recognized with this title and the specific attributes specified in the guidelines at the time. Consequently, a great deal of attention and space in the SSHAC guidelines was devoted to describing the execution of PSHA studies as Level 4 processes. In the field of seismic hazard assessment, two studies have been entirely conducted at SSHAC Level 4, the first being the PSHA for the proposed nuclear waste repository at Yucca Mountain in the Nevada desert [12], which analyzed the hazard from both ground shaking and fault displacement. A probabilistic assessment of volcanic hazard at Yucca Mountain has also been successfully conducted as a SSHAC Level 4 process.

The second PSHA conducted at Level 4 was the PEGASOS project that analyzed seismic hazard at four nuclear power plant sites in Switzerland [13]. The results of the PEGASOS study became the object of some controversial exchanges due the fact that the hazard results were considerably higher than those that had been obtained from earlier PSHA studies conducted in the 1980s as part of the safety assessment of the plants. The increased design levels of ground shaking were due principally to the lack of appropriate treatment of aleatory variability in the original study. The changes in design levels were also in part due to the fact that the PEGASOS study captured a wider range of epistemic uncertainty, leading to an increase in the mean hazard results. This is not untypical and it is important to highlight that does not mean that the SSHAC procedures create greater uncertainty, but rather that the procedures are, by design, more effective at capturing the uncertainty that actually exists. It has become clear that early estimates of epistemic uncertainty in seismic hazard studies were very optimistic: having limited data often leads analysts to conclude that they know much more than is actually the case. The controversy that surrounded the PEGASOS results was largely unwarranted and unjustified, however, since it had been conclusively demonstrated the main contributor to the increased hazard estimates – demonstrated by comparison of the median hazard curves that are less influenced by epistemic uncertainty – was the result of a fundamental error in the early studies whereby the aleatory variability in the ground-motion prediction was not included in the hazard integrations [14].

Table 1: Summary of SSHAC Level 3 and 4 Studies

Project	**Sponsor**	**Date**
SSHAC Level 3 Studies		
Ground Motions in the Central and Eastern US	Electric Power Research Institute (EPRI)	2004
PSHA for BC Hydro Dam Sites, British Columbia	BC Hydro	Ongoing (2010)
Central and Eastern US Seismic Source Characterization Project	USNRC, Department of Energy, EPRI	Ongoing (2010)
Next Generation Attenuation for the Central and Eastern US (NGA-East) Project	USNRC, Department of Energy, EPRI	Ongoing (2014)
Thyspunt PSHA, South Africa	Eskom	Ongoing (2012)
SSHAC Level 4 Studies		
Yucca Mountain Probabilistic Seismic Hazard Analyses for Ground Motions and Fault Displacements	Department of Energy	1998
PEGASOS PSHA for Nuclear Power Plants in Switzerland; Refinement Project (for site-specific ground motions)	Swiss Nuclear Utilities	2004; ongoing (2012)
Yucca Mountain Probabilistic Volcanic Hazard Analysis-Update	Department of Energy	2008

Although the original SSHAC guidelines did focus strongly on Level 4 studies, recent years have also seen the conduct of a number of Level 3 PSHA studies for critical facilities, several of which are ongoing at the timing of writing. Table 1 provides an overview of some of these projects as well as recent Level 4 studies; dates in parentheses are estimated completion dates. Level 4 studies tend to be more time-intensive than Level 3 studies, but they may provide a higher level of assurance within a regulatory environment because of the involvement of multiple experts. On the other hand, Level 3 studies tend to be more flexible and provide significant levels of regulatory assurance through the participation of experts on the TI team, as proponent experts, and as part of the peer review process. Several of the recent major studies in Table 1 (Central and Eastern US Seismic Source Characterization and NGA-East Projects) have chosen to utilize a Level 3 process. This decision was certainly motivated in part by schedule considerations. However, by having direct technically-informed participation of the involved sponsor and regulatory agencies (US NRC and US Department of Energy), the consensus of the sponsors was that adequate regulatory assurance would be achieved in the final product.

3.2. SSHAC Implementation NUREG

The NRC is interested in understanding and documenting lessons learned from recent SSHAC Level 3 and 4 hazard studies and has recently embarked upon a research program entitled "Practical Procedures for Implementation of the SSHAC Guidelines and for Updating PSHAs". This work will ultimately lead to the development of detailed implementation regulatory guidance that will identify both best practices and minimum requirements for the conduct of Level 3 and 4 studies. Leveraging the work done to date in the studies discussed throughout this document, as well as the workshops discussed in section 3.3, the NRC will be developing more detailed SSHAC implementation guidance that will appear as a NUREG-series report that is intended to be a companion to the original guidelines. The new guidance will not supersede the existing SSHAC document but will provide higher levels of specificity – particularly for Level 3 studies – based on actual experience with such studies. Within the NUREG, NRC will also develop guidance related to the issue of updating existing seismic hazard studies.

A particular focus of the NUREG will be to specify the steps required to conform to a SSHAC Level 3 process, something which was not presented in much detail in the original SSHAC guidelines because of the focus on Level 4 studies. These requirements include the formation of a TI Team (rather than the TI role being performed by an individual analyst, which is acceptable at Levels 1 and 2), and the conduct of at least three formal workshops with the participation of resource and proponent experts. An additional imperative element is a formal PPRP that oversees the process and reviews the technical assessments from the inception of the study. Because Level 1 and 2 studies do not include workshops, the PPRP usually reviews only written documentation of the TI's assessments in draft reports. Clarification of these requirements will dispel the widely-held, but incorrect, perception that Level 3 studies are only incrementally more rigorous than Level 2 studies and that there is a quantum leap in going up to Level 4. In reality, the quantum leap in SSHAC processes is from Level 2 to Level 3, and it is for this reason that the two higher levels are both acceptable for use in a nuclear regulatory environment.

3.3. SSHAC Lessons Learned Workshops

During the first half of 2008, USNRC and the US Geological Survey (USGS) conducted three workshops in Menlo Park, California. In the workshops, several case histories of SSHAC Level 3 and 4 studies were evaluated in terms of the strengths and weaknesses of various process steps used in the course of those studies. The specific topics that were discussed at these workshops, attended by a total of 56 people, include the following:

- Selection of participants, including TI/TFI, resource experts, evaluator experts, proponent experts, and Participatory Peer Review Panel members
- Finding the center, body, and range of the Informed Technical Community (ITC) using the SSHAC process of expert interaction
- Workshop topics for Level 3 and 4 studies
- Peer Review
- Evaluator models, logic trees, and optimizing the complexity of evaluator models
- Documentation requirements
- Intellectual ownership Issues

The NRC-USGS effort resulted in a USGS Open-File Report [15] that can be freely downloaded from the following web link: http://pubs.usgs.gov/of/2009/1093/. Another topic that was discussed at the Menlo Park workshops was the updating of PSHA studies, but this topic, which was originally intended for a second Open-File Report, has not yet been documented. However, all of the topics listed above, and updating of PSHA studies, will all be addressed in the forthcoming U.S. Nuclear Regulatory Commission NUREG-series report.

4. CONCLUDING REMARKS

The SSHAC guidelines and the four levels of study they specify provide an effective and transparent framework for conducting probabilistic seismic hazard analyses for critical facilities in a way that ensures effective capture of uncertainties. The procedures differ from classical expert elicitation in several respects and allow participating evaluator experts to learn through exposure to—and analysis of— the complete set of available data and models, and through interactions with proponents and other evaluator experts. For the initial development of hazard models for safety-critical facilities, the Level 3 and 4 processes provide high degrees of regulatory assurance and stability; although adopting a SSHAC Level 3 or 4 process cannot guarantee regulatory acceptance, it will generally increase its likelihood. It has also been found that significant technically-informed participation by project sponsors and regulators throughout the process enhances the likelihood of regulatory acceptance. The precepts of the SSHAC process have been proven in practice and are now being fine-tuned in the light of lessons that are continuously being learned through the experience of implementations.

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