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NUREG-2213

Updated Implementation Guidelines for SSHAC Hazard Studies

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Updated Implementation Guidelines for SSHAC Hazard Studies

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ABSTRACT

This document contains guidance for conducting expert assessments through the structured process that is referred to as the Senior Seismic Hazard Analysis Committee (or SSHAC) process. It serves as an update to the original SSHAC guidance in NUREG/CR-6372, "Recommendation for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and the Use of Experts" (NRC, 1997) and the implementation guidance provided in NUREG–2117, "Practical Implementation Guidelines for SSHAC Level 3 and 4 (NRC, 2012c). This document builds on the framework described in the prior NUREGs and incorporates lessons learned from conducting recent SSHAC studies. This document does not invalidate the prior guidance documents or the studies conducted accordingly; however, the intent of this NUREG is to provide the most current standalone guidance. While the prior NUREGs contain useful concepts and historical context, this document should be used for conducting future SSHAC studies.

Specifically, this document: (i) clarifies terminology and key concepts that are essential for all SSHAC studies; (ii) strengthens the implementation framework for Level 3 studies, based on extensive recent experience; (iii) provides guidance on the attributes of Level 1 and 2 studies; and (iv) presents a revised and more rigorous framework for decision-making regarding the updating of existing SSHAC studies. These updated guidelines describe an acceptable framework to implement the recommendations in Regulatory Guide 1.208 (NRC, 2007) with respect to performing a probabilistic seismic hazard analysis study.

FOREWORD

The complexity of tectonic environments and the limited data available for seismic source and ground motion characterization make the use of a significant level of expert judgment in seismic hazard assessment studies unavoidable. Two landmark probabilistic seismic hazard studies were conducted in the 1980s to evaluate the seismic hazard at nuclear facilities in the central and eastern United States. These studies relied on assessments by experts (either individually or as members of teams) of specific seismic source or ground motion characterization issues. The results of the two studies differed significantly in terms of the assessments of individual experts within each study as well as in the mean hazard results between the two studies. In the mid-1990s, the U.S. Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), and the Electric Power Research Institute (EPRI) sponsored a study to develop recommendations for how studies incorporating the use of expert assessments should be conducted in the future. The Senior Seismic Hazard Analysis Committee (SSHAC) developed a multi-level, structured, assessment process (the "SSHAC process"). Four study Levels were defined in the SSHAC guidelines, increasing in complexity and cost from 1 through 4. The guidance described in NUREG/CR-6372, "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts" (NRC, 1997), has since been used for numerous natural hazard studies.

The guidance contained in NUREG/CR-6372 was high-level, generalized, based on limited project experience, and heavily weighted towards the Level 4 studies. In 2012, after numerous applications of the SSHAC guidelines in practice, the NRC issued NUREG–2117, "Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies" (NRC, 2012c). That document captured lessons-learned from implementation of the original SSHAC guidelines and provided additional focused implementation guidance for the conduct of Level 3 studies. The guidance contained in NUREG–2117 has now been applied for both nuclear and non-nuclear facilities at numerous locations in the United States and internationally.

This NUREG complements and augments the guidance contained in NUREG/CR-6372 and NUREG–2117. This document does not invalidate the prior guidance documents or the studies conducted accordingly; however, the intent of this NUREG is to provide the most current standalone guidance. It has been developed based upon a systematic review of the many projects that have successfully applied the SSHAC guidelines since 1997. This review included outreach to many seismic hazard practitioners who have participated in previous SSHAC studies to develop insights. Specifically, the current document: (i) elaborates on the key features that are essential for all SSHAC studies, (ii) strengthens the implementation framework for Level 3 studies based on extensive recent experience, (iii) provides guidance on the essential attributes of Level 1 and 2 studies (missing from the earlier SSHAC documents), and (iv) develops a revised and more rigorous framework for decision-making regarding the updating of existing SSHAC studies. Continued application and development of these guidelines will enhance regulatory assurance and stability. In summary, these updated guidelines describe an acceptable framework to implement the recommendations in Regulatory Guide 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion" (NRC, 2007) with respect to performing a Probabilistic Seismic Hazard Analysis study.

In addition to applicability to a variety of hazards, the guidelines provided in this document are not limited to applications within the United States, but can be employed internationally. Indeed, these guidelines reflect lessons learned from implementation of the SSHAC process in Canada, Switzerland, South Africa, Spain, and Japan. The expanding use of the SSHAC approach internationally also shows that the approach is not specific to just the regulatory environment of the United States, but it can satisfy the need for regulatory assurance within a range of regulatory environments for both nuclear and non-nuclear critical facilities. This also demonstrates the common goals of a carefully structured, transparent, and thoroughly documented approach to assessing hazards that fully considers available information, quantifies uncertainties, and documents the analysis. Such goals are clearly not unique to the United States or to nuclear facilities and can be applied to other natural hazards other than seismic.

It is recognized that expert assessment methodologies generally—and SSHAC implementation processes specifically—are evolutionary and continually improve with each project application because of innovation and lessons learned. It is the expectation that further advances in the methodology will be made in the future.

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In 1997, the U.S. Nuclear Regulatory Commission (NRC) issued NUREG/CR-6372 entitled, "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and the Use of Experts" (NRC, 1997). The document was the culmination of four years of deliberations by the Senior Seismic Hazard Analysis Committee (SSHAC) regarding the way uncertainties in probabilistic seismic hazard analysis (PSHA) should be addressed using expert judgment. The document describes a formal process for structuring and conducting expert assessments that has come to be known as a "SSHAC process," and the recommendations made in the report are referred to as the SSHAC guidelines. NUREG/CR-6372 defined four levels at which hazard assessment studies can be conducted, ranging from the simplest (Level 1) to the most complicated and demanding (Level 4). That report focused on the conduct of Level 4 studies and provided comparatively little guidance on the lower levels of study.

Much of the discussion and commentary in NUREG/CR-6372 was generalized and forward-looking. In the 15 years following the publication of that document, several Level 3 and 4 studies were completed and significant experience accumulated. The NRC recognized the need for additional and more detailed implementation guidance of the SSHAC Guidelines (for Level 3 and Level 4 studies) that captured the experience accumulated from conducting these studies, and in 2012, the NRC issued NUREG–2117, "Practical Implementation Guidelines for SSHAC Level 3 and 4 Studies" (NRC, 2012c) The insights and guidance contained in NUREG–2117 have subsequently been applied in numerous studies, and based on the lessons learned from these most recent studies, the need for further guidance, clarification, and elaboration became evident. In addition, the experiences gained from many of these recent SSHAC studies highlighted the importance of SSHAC Level 1 and Level 2 studies, especially when evaluating new information regarding the need for updating or replacing existing Level 3 and Level 4 studies or for application to other types of natural hazards.

This document builds on the framework described in the prior NUREGs and incorporates lessons learned from conducting recent SSHAC studies. It is based on insights gained over 20 years of experience and provides the most complete and practical application of the SSHAC guidance to date. This document does not invalidate these guidance documents or the studies conducted accordingly; the intent of this NUREG is to provide the most current standalone guidance. While the prior NUREGs contain useful concepts and historical context, this document should be used for conducting future SSHAC studies. However, it is recognized that expert assessment methodologies generally—and SSHAC implementation processes specifically—are evolutionary and continually improve with each project application because of innovation and lessons learned. It is the expectation that further advances in the methodology will be made in the future.

The process used to develop this updated guidance included extensive outreach to many individuals with experience in seismic or natural hazard evaluation in general and application of the SSHAC guidance specifically. The knowledge and experience of these individuals were important components of the development of this document. This outreach was intended to capture a broad spectrum of experience and insights on specific issues, which subsequently informed the development of this document. Appendix A documents these interactions with the subject matter experts.

The essence of the SSHAC process is the structured interaction among experts to achieve a well-documented hazard study that captures the center, body, and range of technically defensible interpretations (commonly referred to as the CBR of TDI). There are five key features that are indispensable to the SSHAC process and that distinguish all SSHAC studies from non-SSHAC projects:

1. **Clearly defined roles** for all participants, including the responsibilities and attributes associated with each role.

2. **Objective evaluation** of all available data, models, and methods that could be relevant to the characterization of the hazard at the site. This will often include additional new data collected specifically for the hazard assessment. This process includes identifying the limits of the existing data, gaps in the existing data, and the resolution and uncertainties in the available data.

3. **Integration** of the outcome of the evaluation process into models that reflect both the best estimate of each element of the hazard input with the current state of knowledge and the associated uncertainty. This distribution is referred to as the center, body, and range of technically defensible interpretations. This will generally involve the construction of hazard input models for seismic source characterization and ground motion characterization (including site response) that address both aleatory variability and epistemic uncertainties.

4. **Documentation** of the study with sufficient detail to allow reproduction of the hazard analyses. The documentation must identify all the data, models, and methods considered in the evaluation, and justify in detail the technical interpretations that support the hazard input models.

5. **Independent participatory peer review** is required to confirm that the evaluation considered relevant data, models, and methods, and that the evaluation was conducted objectively and without bias. The peer review is conducted following a “participatory” or continual process throughout the entire project. The peer review is also required to confirm that the seismic source characterization (SSC) and ground motion characterization (GMC) models did capture the center, body, and range of technically defensible interpretations and that the technical bases for all elements of the models are documented adequately. For the peer review process to be considered complete, it must be documented in the form of a closure letter from the participatory peer review panel.

These five features are essential for all SSHAC hazard studies, regardless of the SSHAC Level at which the study is performed. The core objective of developing a hazard estimate that reflects the center, body, and range of technically defensible interpretations is the same at every study level. However, by increasing the number of participants and requiring greater interaction among the various experts, including the peer reviewers, the likelihood of effectively capturing the center, body, and range of technically defensible interpretations increases with study level. Thus, the higher study levels result in improved regulatory assurance. Therefore, one of the main criteria in selecting the SSHAC Level for a hazard study is the degree to which regulatory assurance is required.

Previous SSHAC guidance documents did not include significant or explicit detail in the conduct of Level 1 and Level 2 studies. As a result, this updated guidance document describes the minimum requirements for SSHAC Level 1 and Level 2 studies in terms of (i) the size of the technical integration team and participatory peer review panel, (ii) the nature of engagement between the technical integration team and peer review panel, (iii) the engagement of external experts, (iv) hazard sensitivity and feedback, (v) documentation, and (vi) the potential for workshop(s) or other augmentations.

Implicit in a SSHAC study is that it represents a snapshot in time because the study is based on the information available when the study was conducted. With the passage of time, new information can arise that could trigger the need to update an existing hazard study. These changes might be new hazard-significant data, new models proposed by the larger technical community, or new methods for analyzing or interpreting data.

Therefore, this document describes a revised and more rigorous framework for decision-making regarding the updating of existing SSHAC studies. The updating process begins with an evaluation of the existing PSHA, which can be either a site-specific study or a regional PSHA. This evaluation consists of two steps. The first step is to conduct a SSHAC Level 1 study using available information, including any applicable new data, models, and methods that became available since the original SSHAC study was completed. The second step is a comparison of the existing PSHA with the inputs and results of the SSHAC Level 1 study.

Based on the results from the evaluation process, the specific ways that updates can occur are:

- Replace: To completely set aside an existing hazard study and to develop a new study that will serve as the replacement to the previous study. Because the goal is to have a PSHA that can be used for critical nuclear facilities, the new study should be conducted using SSHAC Level 3 or Level 4 processes.

- Revise: To modify a component or components of an existing study using a SSHAC study to incorporate new information that only affects an individual component of the original SSC or GMC model. For example, if over the course of time since the original SSHAC study was completed, the only significant new information is the set of new earthquakes added to the earthquake catalog, then a revision of the original SSHAC SSC model may be appropriate. If the existing study evaluation leads to the conclusion that the updated catalog has a significant impact on the existing hazard (based on a specified set of decision factors), then only that component of the existing SSHAC Level 3 SSC model would need to be revised. Revisions can be conducted using SSHAC Level 2 or Level 3 processes.

- Refine: To adapt an existing regional study to incorporate site-specific information. Thus, in the context of the updating process described here, a refinement only applies to the adaptation of a regional model to a specific site. Refinements can be conducted using SSHAC Level 2 or Level 3 processes.

- Correct: To rectify a non-technical error in the existing documentation. A correction does not require the use of a SSHAC process.

- No Update Needed: To continue using the existing study because it maintains the center, body, and range of technically defensible interpretations.

In summary, these updated guidelines describe an acceptable framework to implement the recommendations in Regulatory Guide 1.208, “A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion” (NRC, 2007) with respect to performing a probabilistic seismic hazard analysis study.

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ABBREVIATIONS, ACRONYMS, AND PARAMETERS

AF	Amplification Function
AFE	annual frequencies of exceedance
ANSI	American National Standards Institute
ANS	American Nuclear Society
APS	Arizona Public Service Company
ASCE	American Society of Civil Engineers
CBR	center, body, and range
CEUS	Central and Eastern United States
CFR	*Code of Federal Regulations*
COI	Conflict of interest
DCPP	Diablo Canyon Power Plant
DOE	U.S. Department of Energy
DRS	design response spectra
EPRI	Electric Power Research Institute
FTP	file transfer protocol
GIS	geographic information systems
GMC	Ground Motion Characterization
GMPE	Ground Motion Prediction Equations
GMM	Ground Motion Models
GMRS	Ground Motion Response Spectrum
HID	Hazard Input Document
IAEA	International Atomic Energy Agency
NGA	Next Generation Attenuation
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
PGA	peak ground acceleration
PG&E	Pacific Gas & Electric
PM	Project Manager
PNNL	Pacific Northwest National Laboratory
POC	point of contact
PPRP	Participatory Peer Review Panel
PSHA	Probabilistic Seismic Hazard Analysis
PTI	Project Technical Integrator
PVNGS	Palo Verde Nuclear Generating Station
QA	quality assurance
RG	Regulatory Guide
SRA	site response analysis
SSC	Seismic Source Characterization
SSHAC	Senior Seismic Hazard Analysis Committee
SSI	soil-structure interaction
STD	standard
SWUS	South Western United States
TI	Technical Integrator
TDI	technically defensible interpretations
TFI	Technical Facilitator Integrator
UHS	uniform hazard response spectrum
USGS	U.S. Geological Survey

1 INTRODUCTION

In 1997, the U.S. Nuclear Regulatory Commission (NRC) issued NUREG/CR-6372 entitled, "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and the Use of Experts" (NRC, 1997). The NUREG/CR was the culmination of four years of deliberations by the Senior Seismic Hazard Analysis Committee (SSHAC) regarding the manner in which uncertainties in probabilistic seismic hazard analysis (PSHA) should be addressed using expert judgment. The NUREG/CR describes a formal process for structuring and conducting expert assessments that has come to be known as the "SSHAC process," and the recommendations made in the report are referred to as the "SSHAC guidelines." To account for different project needs and projects undertaken in different regulatory frameworks, the SSHAC report describes four "Study Levels" (1 to 4) that define the processes, scope, and complexity of the recommended project activities. Study Levels 3 and 4, typically referred to as "SSHAC Levels 3 and 4," are the most complex and involve the greatest effort.

Much of the discussion and commentary in NUREG/CR-6372 was generalized and forward-looking. In the 15 years following the publication of that document, several Level 3 and 4 studies were completed and significant experience accumulated. The NRC recognized the need for additional and more detailed implementation guidance of SSHAC Guidelines (for Level 3 and Level 4 studies) that captured the experience accumulated from conducting these studies; and, in 2012, the NRC issued NUREG–2117, "Practical Implementation Guidelines for SSHAC Level 3 and 4 Studies" (NRC, 2012c). These insights and guidance contained in NUREG–2117 have subsequently been applied in numerous studies; and based on the lessons learned from these most recent studies, the need for further guidance, clarification, and elaboration became evident. In addition, the experiences gained from many of these recent SSHAC studies highlighted the importance of SSHAC Level 1 and Level 2 studies, especially when evaluating new information regarding the need for updating or replacing existing Level 3 and Level 4 studies. Finally, scientists and engineers who evaluate other types of natural phenomena hazards, such as flooding or high winds, are beginning to recognize the benefits of the SSHAC process to develop probabilistic hazard analyses.

1.1 Purpose of this NUREG

This document builds on the framework described in the prior NUREGs and incorporates lessons learned from conducting recent SSHAC studies. This document does not invalidate the prior guidance documents or the studies conducted accordingly; however, the intent of this NUREG is to provide the most current standalone guidance. While the prior NUREGs contain useful concepts and historical context, this document should be used for conducting future SSHAC studies. Specifically, this document: (i) clarifies terminology and key concepts that are essential for all SSHAC studies, (ii) strengthens the implementation framework for Level 3 studies based on extensive recent experience, (iii) provides guidance on the attributes of Level 1 and 2 studies, and (iv) presents a revised and more rigorous framework for decision-making regarding updating existing SSHAC studies.

Expert assessment methodologies generally—and SSHAC implementation processes specifically—are evolutionary and continually improve with each project application as a result of innovation and lessons learned. There is no presumption that documenting today's best advice regarding SSHAC implementation guidance should put an end to the evolutionary process that has characterized the past 20-plus years. On the contrary, this information and guidance is provided with the assumption—and the belief—that further advances will continue to be made in the future.

These updated guidelines describe an acceptable framework to implement the recommendations in Regulatory Guide (RG) 1.208, “A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion” (NRC, 2007), with respect to performing a probabilistic seismic hazard analysis study.

1.1.1 Background

Some of the earliest regulatory guidance on the use of expert judgement for technical evaluations in support of nuclear safety is described in NUREG–1563, “Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program” (NRC, 1996). NUREG–1563 provides general guidelines for those circumstances that may warrant the use of a formal process for obtaining the judgments of more than one expert (i.e., expert elicitation). It also describes acceptable procedures for conducting expert elicitation when formally elicited judgments are used to support a demonstration of compliance with NRC’s geologic disposal regulations.
While subsequent guidance on the use of experts in the SSHAC process (as described in NUREG/CR-6372, NUREG–2117, and this document) has substantially improved and refined the essential elements needed for successful application of expert judgement in the regulatory framework, these later documents do not contradict or invalidate the guidance in NUREG–1563.

The SSHAC study in NUREG/CR-6372 was motivated by the need for a methodological framework that could be reliably applied and would lead to increased consistency in the hazard results obtained from different studies. The development and application of this framework was designed to provide enhanced regulatory assurance. A detailed history of the SSHAC process is contained in NUREG–2117 and, as such, is not repeated in this document.

A number of recent SSHAC studies have been completed or conducted since the development of NUREG–2117. Insights developed from these studies have added significantly to our body of knowledge on the effective implementation of the SSHAC process. In 2012, after the Great Tohoku earthquake and disaster at the Fukushima Dai-ichi nuclear power plant, the NRC issued a request for information to all operating commercial nuclear power reactors in the United States, pursuant to 10 CFR 50.54(f) (NRC, 2012a). In response, the licensees re-evaluated the seismic hazard at their sites, consistent with present-day NRC guidance. These hazard analyses were conducted as SSHAC Level 3 studies. Table 1-1 of this document supplements the compilation in Table 2-2 of NUREG–2117 and identifies the SSHAC studies that have been completed or are ongoing since the publication of that document, including the re-evaluated hazards at U.S. plants.

Valuable input for the development of this NUREG came from a series of focused workshops conducted in 2015 and 2016. Each of these workshops focused on a particular issue. Specific questions were formulated to clarify or investigate each particular issue. A number of seismic (or other natural hazard) practitioners/experts that were well versed in the SSHAC process were contacted and interviewed. The results were summarized and a workshop held to assess and discuss the results of the interviews. The project team then summarized the discussion; these summaries have provided input for the development of this document. Workshop summaries, dates, and list of participants are contained in Appendix A.

Table 1-1 Ongoing or recently completed SSHAC Level 3 hazard studies			
Study	**Completion Year**	**Significance**	**Reference**
BC Hydro PSHA	2012	Major regional study for BC Hydro service area in British Columbia, Canada. Used for dam safety evaluation. Both SSC and GMC.	BC Hydro (2012)
Thyspunt, South Africa PSHA	2013	Site-specific PSHA for a proposed nuclear power plant. Includes SSC, GMC, and SRA.	Bommer et al. (2015)
Hanford PSHA	2014	Site-specific study for existing nuclear facilities. Includes SSC, GMC, integration with SRA.	PNNL (2014)
Diablo Canyon SSC	2015	Site-specific SSC study. Used for existing nuclear facility.	PG&E (2015)
Palo Verde SSC	2015	Site-specific SSC study. Used for existing nuclear facility.	APS (2015)
SWUS-GMC	2015	Regional GMC study. Includes regionally specific ground motion models and adjustments for Diablo Canyon and Palo Verde plant sites.	GeoPentech (2015)
NGA-East GMC (in progress)	2017	Major phased regional GMC study.	Report not yet available; see http://peer.berkeley.edu/ngaeast/
Ikata PSHA, Japan	2018	Site-specific including SSC and GMC. To be used for risk analysis of existing nuclear facility.	(In progress)
Taiwan	2018	Site-specific PSHA for four NPP sites. Includes SSC and GMC; integration with SRA.	(In progress)
Spain PSHA for NPP Sites (in progress)	2020	Integrated regional study for SSC, GMC and SRA. For multiple nuclear facilities.	(In progress)
Notes: PSHA = Probabilistic Seismic Hazard Analysis; SSC = seismic source characterization; GMC = ground motion characterization; SSHAC = Senior Seismic Hazard Analysis Committee; SRA = site response analysis; PNNL = Pacific Northwest National Laboratory; PG&E = Pacific Gas & Electric; APS = Arizona Public Service Company; SWUS = South Western United States; NGA = Next Generation Attenuation; NPP = Nuclear Power Plant			

1.1.2 Objective and Audience of these SSHAC Guidelines

To fulfill the objective of providing a consistent, structured framework for conducting hazard analyses, these guidelines provide sufficient detail regarding implementation to ensure that various practitioners will interpret the guidelines in a reliable and consistent manner. Proper application of these guidelines will enhance regulatory assurance that the studies properly identify the sources of uncertainty and that the full range of available information and interpretations will be considered. In addition, use of the SSHAC process provides assurance to stakeholders—including the public—that hazards have been appropriately and robustly investigated and considered in regulatory decision-making.

The audience for this document is varied and includes Sponsors, regulators, hazard analysts, technical experts, reviewers, and stakeholders. Sponsors of probabilistic hazard analyses are ultimately responsible for commissioning these studies and therefore need to understand the essential elements of a SSHAC study. In addition, a clear understanding of the essential elements of SSHAC studies conducted at particular Levels is of clear benefit to regulators who will be responsible for reviewing a hazard study that is being prepared to support a license application or a safety review for a nuclear facility. Hazard analysts, technical experts, and reviewers should use this document to understand the details of the implementation processes and the roles that various project participants are expected to play.

1.2 Relationship of this NUREG with NUREG/CR-6372 and NUREG–2117

This document provides the most recent guidance for applications of the SSHAC process. As described in Section 1.1, it builds upon the principles and implementation guidance provided in NUREG/CR-6372 and NUREG–2117. The recommendations in NUREG/CR-6372 provide a very useful framework but are generally at a very high level. In addition, the SSHAC guidelines in NUREG/CR-6372 devoted most of the effort to discussing SSHAC Level 4 studies and provided very little guidance regarding the specific approaches that would be appropriate for Level 3 studies. For this reason, NUREG–2117 focused a significant amount of effort on developing and describing the appropriate methods and approaches for Level 3 studies but did not include guidance for Level 1 and 2 studies. The previous NUREGs also contain significant background information that users may find helpful in understanding the development of SSHAC concepts for hazard studies. This document does not invalidate these previous guidance documents or the studies conducted accordingly; however, the intent of this NUREG is to provide the most current standalone guidance.

In turn, the current document

- clearly identifies the five key features that define a SSHAC study and allow an objective distinction to be made from non-SSHAC studies

- enhances the implementation framework for Level 3 studies based on lessons learned from recent SSHAC studies

- provides guidance on the essential attributes of Level 1 and 2 studies

- develops a revised and more rigorous framework for decision-making regarding the updating of existing SSHAC studies.

As described in NUREG–2117, based on actual project applications, the conceptual underpinnings of the SSHAC guidelines in NUREG/CR-6372 remain strong. As discussed in Section 2, the concept of implementing a two-step evaluation and integration process that is focused on capturing the center, body, and range of technically defensible interpretations (commonly referred to as the CBR of TDI) remains fundamental to the SSHAC process at all levels. The requirement for robust peer review and clear, transparent documentation continues to be necessary to achieve these SSHAC objectives and establishes the credibility of the process.

1.3 Scope and Application of these Guidelines

The SSHAC report in NUREG/CR-6372 provided guidelines that describe and endorse the basic philosophy of a properly conducted probabilistic hazard project that completely accounts for the associated uncertainties. NUREG–2117 and this NUREG follow the SSHAC guidelines with the same level of "prescription" and offer additional levels of specific guidance based on experience gained from actual applications and projects. From the time that NUREG–2117 was issued, multiple SSHAC studies have been conducted and are underway for nuclear facilities in the United States and internationally (see Table 1-1). As a result, this document updates the NUREG–2117 document and provides additional details regarding aspects of SSHAC studies that can enhance their success.

With the conduct of SSHAC studies, as well as non-SSHAC hazard studies, has come the realization that a clear distinction needs to be made between hazard studies conducted according to the SSHAC guidelines and those that have not. In other words, what is required to make the claim that a particular hazard study is a SSHAC study? Further, what are the requirements that would distinguish a hazard study conducted according to SSHAC Level 2 procedures from one conducted at Level 3? To address this need, two items are required: (i) a clear explication of the key features that distinguish SSHAC studies and (ii) clearly defined essential steps that must be taken to implement a SSHAC study. Section 2 of this document identifies the five key features that define a SSHAC study and allow a distinction to be made from non-SSHAC studies. Section 3 of this document establishes the essential steps that must be conducted to make the claim that a study can be considered a SSHAC hazard study. In addition, the essential steps for each SSHAC Level are also specified in that section. The goal of these discussions is to assist the sponsors, implementers, regulators, and reviewers of potential hazard studies in their decisions regarding the attributes of the hazard study that they are planning to conduct or that is being conducted. In this sense, the attributes and steps given in this document are intended to be informative, if not highly prescriptive, such that it is clear whether a given study can be claimed to be a SSHAC study and, if so, the SSHAC Level that has been followed.

Despite the focus on seismic hazards in this document, the methodology can be applied to other natural hazards as well. These hazards include, for example, tsunami, fault displacement, volcanism, and liquefaction. As discussed in Appendix A of this document, one of the workshops held as part of the development of this document explored the potential applications of the SSHAC methodology to other hazards. The general consensus from that discussion was that all natural hazards have a common framework or basic elements, which are summarized in Figures 1-1 and 1-2. Figure 1-1 shows the basic elements of a PSHA that define the seismic source geometries, earthquake recurrence, ground motion models, and seismic hazard curves. A basic framework for natural hazards is the same and consists of information related to the source of the hazard, the path that it takes, and the site characteristics, as illustrated in Figure 1-2. In all cases, there are measures of the magnitude of the hazard and rate at which it occurs. Likewise, all of these basic elements of the hazard include epistemic uncertainties, such that the basic framework defining the input models must be further characterized to include the uncertainties in those

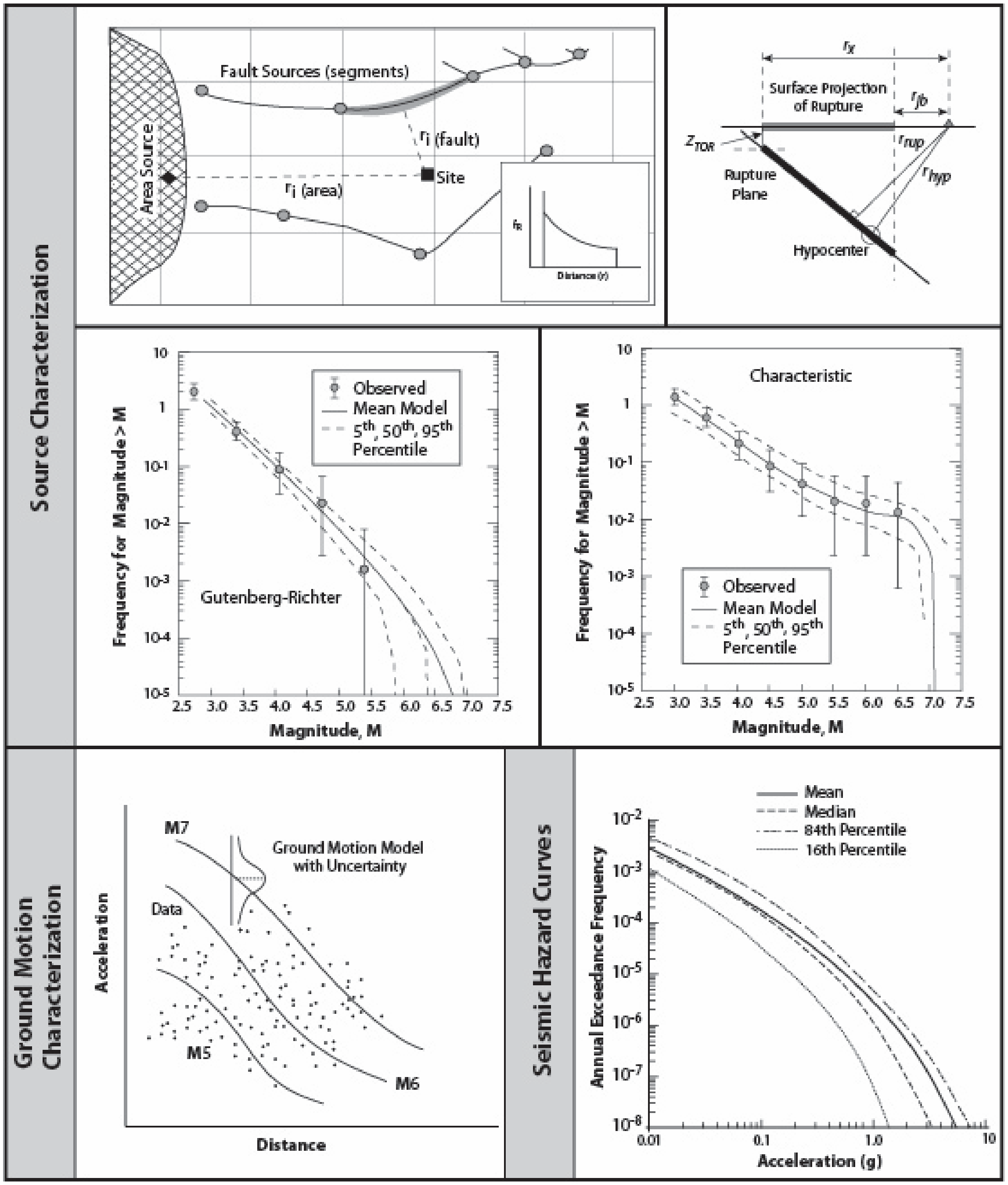

Figure 1-1 **The basic elements of a probabilistic seismic hazard analysis include both source and ground motion characterization. For source characterization, fault and areal sources are characterized in terms of their location and subsurface geometry relative to the site, and the size and frequency of occurrence of earthquakes generated by the sources. For ground motion characterization, the resulting intensity of ground shaking at the site depends on a number of factors, including distance, attenuation, and damping. The resulting hazard curves are expressed as the annual frequency of exceeding a given ground-motion level.**

Source	+	Path	+	Site	=	Hazard
How Big How Often Where		Dispersion Attenuation		Location Site Characteristics Size		Time Exceedance of Intensity Measure

Ground Motion Hazard (seismic)	• M_{MAX} • Recurrence • Fault Geometry • Faulting Style	• Attenuation • Kappa • Q • Source Model	• V_S Profile • Damping • G/G_{MAX}	Annual Probability of Exceeding Spectral Ground Motion Level
Ash Fall (Volcanic)	• Volcano Type • Eruption Rate • Intensity • Distance • Particle Size	• Atmospheric Conditions	• Facility Location • Site Area	Annual Probability of Exceeding Ash Fall Depth
Tsunami	• Location, Size, and Frequency of Submarine Earthquakes • Location, Size, Velocity, and Frequency of Submarine Landslides	• Wave Propagation • Inundation • Bathymetry	• Site Topography • Land-Use Configuration • Infrastructure	Annual Probability of Exceeding Wave Height or Run-Up Height
Faulting	• Magnitude • Recurrence • Fault Geometry • Faulting Style	• Model for the Decay of Displacement with Distance	• Bedrock Type • Soil and Soil Profile • Site and Facility Configuration	Annual Probability of Exceeding Fault Displacement Level
Earthquake-Induced Liquefaction	• Magnitude • Recurrence • Duration • Depth	• Attenuation • Kappa • Q • Source Model	• Water Table • Soil Strength • V_S Profile • Damping	Annual Probability of Liquefaction Susceptibility

Figure 1-2 Basic framework model for natural hazards that includes the source, path, and site. Characterizing these basic elements and quantifying the epistemic uncertainties in each can be implemented using a SSHAC approach.

elements. Clearly, the SSHAC process is designed to assist in the characterization of these entities. Despite the analogies that can be drawn between seismic and other natural hazards, there is widespread consensus among the technical community that detailed implementation guidelines cannot be developed at this time for the other natural hazards due to a general lack of experience in applications. Limited voluntary efforts are being made to conduct SSHAC studies for other natural hazards at the time this document is being written, so future revisions of SSHAC guidelines may include additional guidance for other non-seismic hazards.

In addition to applicability to a variety of hazards, the guidelines provided in this document are not limited to applications within the United States but can be employed internationally. Indeed, these guidelines reflect lessons learned from implementation of the SSHAC process in Canada, Switzerland, South Africa, Spain, and Japan. The expanding use of the SSHAC approach internationally also shows that the approach is not specific to just the regulatory environment of the United States, but it can satisfy the need for regulatory assurance within a range of regulatory environments for both nuclear and non-nuclear critical facilities. This also demonstrates the common goals of a carefully structured, transparent approach to assessing hazards that fully considers available information, quantifies uncertainties, and documents the analysis. Such goals are clearly not unique to the United States or to nuclear facilities.

As with other NUREG series documents, the guidelines presented here are not legally binding rules or regulations. Rather, they are intended to provide practical guidance regarding processes that can be used to develop products that meet rules and regulations. It is recognized that innovative approaches to achieving the SSHAC goals will continue to be developed in the future and that project-specific refinements to the approaches discussed here may be appropriate. However, the application of the guidance given in this document will most likely lead to greater stability and longevity of the hazard analysis being made. Likewise, higher levels of regulatory assurance are likely to be gained with careful and conscientious application of this guidance. Proper application of the guidance given in this document is not guaranteed to lead to acceptance of the hazard results by the NRC or any other regulator. However, use of these guidelines should lead to reduced regulator review times and an increased likelihood of acceptance of the hazard results.

1.4 Overview and Roadmap of this Document

The format of this report is designed to lead the reader from introductory material that describes the purpose of this NUREG, develops some historical context, discusses the relationship of this NUREG to previous versions of the SSHAC guidelines, and provides a discussion of the scope and applications of these guidelines.

Following this introductory section, which establishes the purpose of the document and its relationship to the existing SSHAC guidelines, Section 2 is designed to provide a summary of the key SSHAC concepts that are the underpinnings of all SSHAC projects. This section describes the concept of establishing the center, body, and range of technically defensible interpretations and the role of Evaluation, Integration, and Documentation in achieving this goal. This section also defines the SSHAC study levels and provides descriptions of the key roles and responsibilities of the various participants in a SSHAC process. These roles are an important part of what sets SSHAC processes apart from other studies.

Section 3 provides a description of the essential steps in the SSHAC process, including for Level 1 and Level 2 studies. The goal of this section is to define the minimum set of required activities in each step that must be conducted for the hazard study to be consistent with the

SSHAC guidelines and with a particular SSHAC Level. This section discusses how to select an appropriate SSHAC level, including whether a regional or site-specific study is warranted and also includes a discussion of the Project Plan, selection of project participants, the evaluation process, the integration process (Section 3.6), and the preliminary hazard calculation and sensitivity analysis (Section 3.7). Section 3.8 is an enhanced discussion of the participatory peer review panel (PPRP) briefing. The final hazard calculation is discussed in Section 3.9, and Section 3.10 includes recommendations for clear and comprehensive documentation.

Section 4 discusses replacing, revising, and refining a hazard study. A hazard study represents a snapshot in time, and the technical community will develop new data, models, and methods after the study is completed. This section discusses the ways that a SSHAC process addresses NRC regulations and regulatory guidance. It also considers alternative approaches for assessing whether a hazard study needs to be replaced, whether new data and findings are significant and would require revision of the study, and whether site-specific refinements to a regional hazard model are necessary.

Section 5 summarizes key points and recommendations of this NUREG.

2 KEY SSHAC CONCEPTS

This section is designed to provide a summary of the key Senior Seismic Hazard Analysis Committee (SSHAC) concepts that are the underpinnings of all SSHAC projects. This section describes the five essential features for all SSHAC hazard studies; the concept of establishing the center, body and range of technically defensible interpretations (commonly referred to as the CBR of TDI); and the role of Evaluation, Integration, and Documentation in achieving this goal. This section also defines the SSHAC study levels and provides descriptions of the key roles and responsibilities of the various participants in a SSHAC process. These roles are an important part of what sets SSHAC processes apart from other studies.

The key concepts described in this section are indispensable to the SSHAC process. These concepts have evolved through practical implementation of the guidance in NUREG–1563, “Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program” (NRC, 1996); NUREG/CR-6372 “Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts” (NRC, 1997); and NUREG–2117, “Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies” (NRC, 2012c). Although many of these key concepts were discussed in NUREG–2117, the document did not provide the specificity needed to delineate SSHAC Level 1 and 2 studies. Based on lessons learned, this section clarifies these concepts to facilitate discussions in Sections 3 and 4 regarding how the key concepts are specifically applicable to all four levels of SSHAC study.

2.1 The Five Essential Features of a SSHAC Study

Fundamentally, there are five essential features required for any study to be considered a SSHAC study:

1. Clearly defined roles for all participants, including the responsibilities and attributes associated with each role (Section 2.6).

2. Objective evaluation of all available data, models, and methods that could be relevant to the characterization of the hazard at the site (Section 2.3). This will often include additional new data collected specifically for the hazard analysis. This process includes identifying the limits of the existing data, gaps in the existing data, and the resolution and uncertainties in the available data.

3. Integration of the outcome of the evaluation process into models that reflect both the best estimate of each element of the hazard input with the current state of knowledge and the associated uncertainty (Section 2.3). This distribution is referred to as the center, body, and range of technically defensible interpretations (CBR of TDI) (Section 2.2). This will generally involve the construction of hazard input models for seismic source characterization (SSC) and ground motion characterization (GMC) that address both aleatory variability and epistemic uncertainties.

4. Documentation must provide a complete and transparent record of the evaluation and integration process. Specifically, the documentation must identify all of the data, models, and methods considered in the evaluation, and justify in sufficient detail the technical interpretations that support the hazard input models (Section 2.3). In addition, the documentation must be sufficiently detailed to allow the hazard analyses to be reproduced by an external reviewer.

5. Independent participatory peer review is required to confirm that the evaluation considered relevant data, models, and methods, and that the evaluation was conducted objectively and without cognitive bias (Section 2.4). The peer review is also required to confirm that the SSC and GMC models captured the center, body, and range of technically defensible interpretations, and that the technical bases for all elements of the models are documented adequately. The participatory peer review panel must provide a closure letter to the Sponsor for the peer review process to be considered complete (Section 2.6.9).

2.2 The Center, Body, and Range of Technically Defensible Interpretations

The motivation for developing the SSHAC process in the late 1990s was a clear recognition that any objective estimation of a probabilistic seismic hazard is highly complex and inherently uncertain. The authors of NUREG/CR-6372 noted that substantial gaps persist in our understanding of the mechanisms that cause earthquakes and of the physical processes that govern how earthquake energy propagates from the source to the site, even in light of the many years of active seismology research. Those authors also noted that the limited scientific information about earthquakes that does exist can be legitimately interpreted by experts in various ways, and that these varied interpretations regularly translate into important differences in the resulting Probabilistic Seismic Hazard Analyses (PSHAs). Because of these complexities and uncertainties in probabilistic earthquake studies, the authors of NUREG/CR-6372 recognized that an objective, transparent, and comprehensive process was needed to properly account for the wide diversity of expert judgment and available technical information to produce an impartial seismic hazard analysis—one that represents an objective estimate of hazard, including a full incorporation of uncertainties.

Since the publication of NUREG/CR-6372, the SSHAC process has been successfully applied to developing probabilistic seismic hazards for numerous site-specific and regional PSHA studies. In these applications of SSHAC, the process has evolved from what was essentially an informed aggregation of expert judgments in the pre-SSHAC era into a significantly more structured and effective process—one that now allows practitioners to arrive at unbiased and independent estimates of seismic hazards based on significant evaluation and integration of all relevant information by the Technical Facilitator Integrator (TFI) or Technical Integrator (TI) Teams.

The fundamental goal of the SSHAC process is to produce a probabilistic hazard analysis that captures the center, body, and range of technically defensible interpretations. Based on the process described in this NUREG, this outcome is achieved through faithful execution of the two phases of the SSHAC method. In the first phase, the TI Team(s) evaluate available data, models, and methods of potential relevance to the region and site in question that exist within the larger technical community. In the second phase, the TI Team(s) or the TFI integrate these data, models, and methods into the inputs to the SSC and GMC models that capture the center, body, and range of technically defensible interpretations. This concept is illustrated in Figure 2-1. In this conceptualization, the center is the best estimate of the resulting interpretations, the body describes the shape of the distribution about the best estimate, and the range encapsulates the upper and lower limits of the TDI.

From the outset, it is important to stress that there is no quantitative test to prove that the center, body, and range of technically defensible interpretations have been properly represented. In fact, the presence of such a test would itself obviate the need to conduct a SSHAC study in the first place. The SSHAC process is designed to develop reliable and robust estimates of seismic hazard in the absence of such certainty. This is because the current set of data, models, and methods used to assess seismic hazards includes significant complexity and uncertainty that

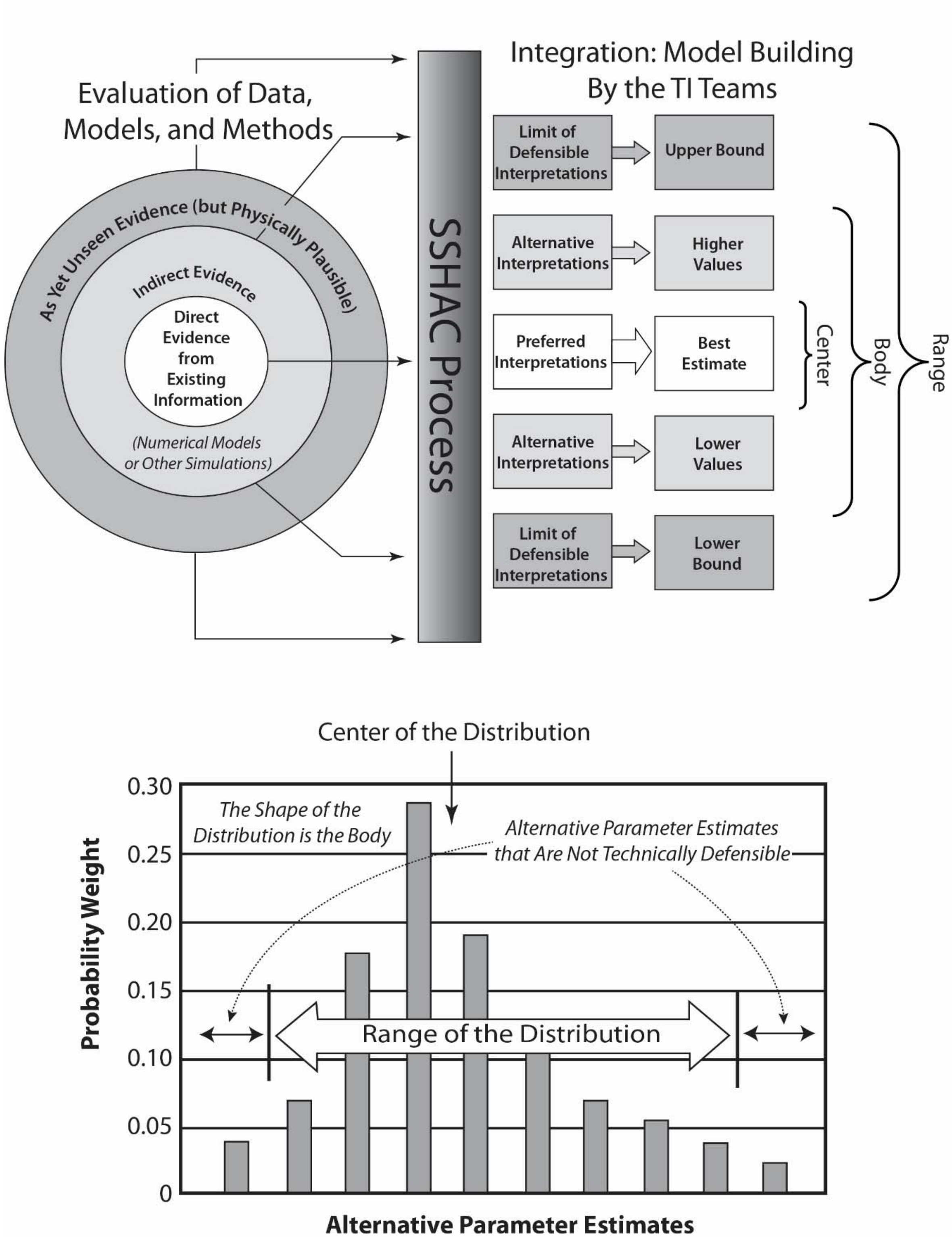

Figure 2-1 Diagrammatic representation of the center, body, and range of technically defensible interpretations

requires detailed evaluation and integration by technical experts, necessitating some degree of their judgment. Thus, in the absence of any realistic means to prove that the CBR of TDIs have been captured, confirmation comes from the fidelity of the SSHAC assessment process itself and the endorsement from the Participatory Peer Review Panel (PPRP) that the project adhered to the principles of the SSHAC process.

In giving its endorsement, the PPRP assures all stakeholders that all the relevant information was considered and evaluated, that the varied proponent interpretations were heard and objectively considered, that all decisions were made based on technically defensible interpretations, and that the entire process was clearly documented and defended. The essential steps outlined in Section 3 of this document define the basic standard that is expected to lead to the PPRP's assurance that the goals of the SSHAC process have been met. In addition, the clarity of the SSHAC documentation should be sufficient for reviewers (e.g., users or regulators) to confirm the significant conclusions of the PPRP.

The imperative to capture the full range of the integrated distribution should not lead the experts doing the model-building to include alternatives in their models only as a means to convey the impression of broad capture of epistemic uncertainty. The integration process need not be inclusive of all available interpretations and those interpretations deemed not credible by the TI Team must be culled from the analysis. Only defensible models and parameter values should ever be included in the SSC or GMC models. The practice of giving low weights in the SSC or GMC logic trees to those interpretations the experts consider indefensible, in order to be inclusive of all ideas should not occur, because it (i) corrupts the fundamental evaluation and integration goals of the SSHAC process, (ii) unnecessarily increases computational complexity, and (iii) may lead to unintended and unforeseen hazard results.

On the other hand, there may be a genuine tendency for the distributions to be too narrow, partly because of the natural human tendency to underestimate epistemic uncertainty and the issues of anchoring (see Section 2.4). Another contributor to this tendency in some situations is that the experts may limit their assessments to published models, which by themselves may not span a sufficient range of outcomes to be considered as adequately capturing the full range of possibilities. Section 2.3 provides for additional discussion of the evaluation process.

2.3 Evaluation, Integration, Documentation

This section provides a description and definition of key terms and concepts that support the goal of capturing the center, body, and range of technically defensible interpretations. This goal is achieved through three primary activities defined below and the key steps that support them. These specific steps are described in more detail in Section 3. The terminology in the discussion below assumes a SSHAC Level 3 project. However, all of the concepts are applicable to other SSHAC levels.

The fundamental activities of a SSHAC process are defined as:

- Evaluation: The consideration of the complete set of data, models, and methods proposed by the larger technical community that are potentially relevant to the hazard analysis.
- Integration: Representing the center, body, and range of technically defensible interpretations in light of the evaluation process (i.e., informed by the SSHAC assessment of existing data, models, and methods).

- <u>Documentation</u>: Thorough documentation of the project databases, the evaluation process, and the technical bases for the final integrated distributions, including evidence of the participatory peer review.

As discussed later in Section 2.6, “Key Roles and Responsibilities,” the experts who are responsible for conducting the evaluation and integration processes are termed in this document the “Technical Integration Team” or TI Team members. It is recognized that Level 4 studies do not necessarily involve “teams” of experts, but the general terminology of “TI Team” will be used to refer to those who are responsible for the assessments in any SSHAC Level study.

The evaluation process begins with the TI Team engaging in data gathering, database compilation, and an assessment of hazard significance. With input from Resource and Proponent Experts, the TI Team will identify all available hazard-relevant data, models, and methods—including all those previously produced by the larger technical community. This body of knowledge may be supplemented by new data gathered within the project. The first workshop (see Section 3.5.4) assists with the identification of hazard-relevant data. The TI Team then evaluates these data, models, and methods and documents both the process by which this evaluation was undertaken and the technical bases for all decisions made regarding the quality and usefulness of these data, models, and methods. This evaluation process includes interaction among members of the technical community. The interaction includes subjecting the data, models, and methods to technical challenge and defense. Workshop #2 (see Section 3.5.5) provides a forum for proponents of alternative viewpoints to debate the merits of their models. The successful execution of the evaluation is confirmed by the concurrence of the PPRP that the TI Team has provided adequate technical bases for its conclusions about the quality and usefulness of the data, models, and methods, and has adhered to the SSHAC assessment process. The PPRP also will provide feedback regarding meeting the objective of considering all of the views and models existing in the technical community.

Informed by this evaluation process, the TI Team then performs an integration process that may include incorporating existing models and methods, developing new methods, and building new models. The objective of this integration process is to capture the center, body, and range of technically defensible interpretations of the available data, models, and methods. Justification for the technical bases for the weights on different models in the final distribution, as well as the exclusion of any models and methods proposed by the technical community, needs to be documented. Workshop #3 (see Section 3.6.2) provides an opportunity for the TI Team to review hazard-related feedback on their preliminary models and to receive comments on their models from the PPRP. To conclude the project satisfactorily, the PPRP also will need to confirm that the SSHAC assessment process was adhered to throughout and that all technical assessments have been sufficiently justified and documented.

A distinguishing attribute of a SSHAC process is the interaction and learning that takes place. A key element that contributes to learning is feedback, which is information that provides a perspective to the evaluators that can assist them in their subsequent evaluations. Feedback occurs in many forms throughout the project, such as the information that is received when TI Team members challenge the Proponents in Workshop #2 to defend their interpretations, or when the TI Team members present and defend their preliminary models to the PPRP at Workshop #3 in a Level 3 or 4 study. This information allows the evaluators to further consider their assessments in terms of whether they have properly and completely accounted for uncertainties and whether they have been successful at considering the views of the larger technical community. This feedback, interaction, and learning process is distinctly different from the classical expert elicitation process, which assumes that experts come to the project equipped to answer the questions required for the project, and that the answers simply need to be extracted through a series of focused questions and elicitation techniques.

Documentation of the evaluation and integration activities is a key component of successful completion of the SSHAC process. The acceptability of a SSHAC project ultimately depends on the transparency and traceability of its documentation. The project documentation is the fundamental basis for the reader to understand (i) what process was used in the hazard analysis; (ii) what data were available and used in the evaluation process; (iii) how the data, models, and methods of the larger technical community were considered; (iv) the elements of the models and their technical bases; (v) how the models capture the center, body, and range of technically defensible interpretations; and (vi) the hazard results and instructions for their use. The draft report is subject to review by the PPRP and, on a project-specific basis, by other stakeholders. Documentation of the PPRP review comments and interactions among the TI Team, TFI, and PPRP are essential elements of the process.

These definitions provide the framework for the concepts embedded in the evaluation phase and integration phase that will be used throughout the remainder of this document.

2.4 Expert Judgment and Cognitive Bias

Due to large uncertainties in our understanding and models of earthquake processes and the lack of empirical data to eliminate this uncertainty, expert judgments are always required in seismic hazard analysis. Further, as discussed extensively in NUREG/CR-6372 and NUREG–2117, the SSHAC process represents a formal, structured approach to eliciting the judgments of experts. Drawing on the field of decision analysis, a wealth of studies have been conducted, and can be utilized, regarding the use of experts to make estimates of uncertain quantities. There are several known issues that can plague expert assessments; most are not deliberate or intentional, but they must be countered. These problems are collectively referred to here as cognitive bias. These concepts were previously described in NUREG/CR-6372 and NUREG–2117 and are re-emphasized here for two reasons. First, this concept is inherent in all expert judgment processes in which there is significant uncertainty; and second, this document is intended to provide stand-alone guidance.

Although there is a very extensive literature on the subject of cognitive bias, the treatment given here is necessarily brief and deliberately simplified. Consequently, it is unlikely to reflect the state-of-the-art in understanding of cognitive bias. However, for the purpose here, sophisticated philosophical discourses on the topic may be less useful than a succinct warning—repeated frequently during a PSHA project—about the existence and nature of cognitive bias.

In psychology, heuristics are simple, efficient rules that people often use to form judgments and make decisions. They are mental shortcuts that usually involve focusing on one aspect of a complex problem and ignoring others. These rules work well under most circumstances, but they can lead to systematic deviations from logic, probability, or rational choices. The resulting errors are called “cognitive biases,” and many different types have been documented (Tversky and Kahneman, 1974; Kahneman et al., 1982). These have been shown to affect people’s choices in situations like valuing a house, estimating the likelihood of a rare event, or making an investment decision. Heuristics usually govern automatic, intuitive judgments but can also be useful when working from limited information.

Examples of heuristics leading to cognitive biases that are of clear relevance to conducting seismic hazard analyses include the following:

- Overconfidence: overestimating what is known (i.e., underestimating uncertainty).

- Anchoring: focusing on a specific number or model and not adjusting it sufficiently in light of new information.

- Availability: focusing on a specific, dramatic, or recent event; being inclined toward models that one is more familiar with or that one feels an affinity for because of knowing personally or by reputation the authors of a given model (or indeed, by being an author).

- Coherence/vividness: over-estimating the likelihood of an event because there is a "good story."

- Ignoring conditioning events: these are often unstated assumptions that influence the assessments that experts make.

It is important to note that (with the exception of motivational biases, which come from deliberate attempts to affect an outcome) the common cognitive biases, including those listed above, are inherent to all expert judgments and are not deliberate. They are simply the way that scientists and engineers commonly process information and offer our technical judgments. Fortunately, studies have shown that the most effective way of countering cognitive biases is simply to make the experts aware that they exist and to encourage the experts to counter them. For example, the TI Lead or TFI can counter overconfidence by probing the limits of an expert's expression of uncertainty to ensure that the full range is being provided. Indeed, the technical challenge and defense interactions that are encouraged in SSHAC projects help to counter overconfidence biases. Availability biases can be countered by asking the expert for the technical reasons that a particular model is preferred or that other models are considered less credible. The presence of ignored or unstated conditioning events can be brought to light by asking the expert for all assumptions that went into a particular expert assessment.

To capture the center, body, and range of technically defensible interpretations, the TI Team members must be able to act as impartial and objective assessors of all available data, models, and methods (see Section 2.6). To achieve this, it is important to avoid cognitive bias in the assessments. Toward that end, the TI Lead/TFIs should discuss cognitive bias with the experts and make them aware that efforts will be devoted throughout the project to countering them, particularly in working meetings where the experts are offering their judgments. Likewise, the PPRP Chair should similarly remind the PPRP of the importance of being alert to cognitive bias, both in terms of the potential among the TI Team(s) and among the PPRP. The expert interactions that specifically include technical challenge intended to reveal the genuine bases for experts' assessments is also a key component of countering cognitive bias.

Countering cognitive bias in the evaluations is an inherent part of the SSHAC process and is a responsibility of the TI Leads to implement. Basic procedural tools, which are all closely related to one another, can be employed to mitigate the influence of cognitive bias:

- During the evaluation phase of the project, ensure that all data, models, and methods are made available to all the evaluators. This is the responsibility of the Project Technical Integrator (PTI) and TI Leads, and the PPRP must ensure that it is achieved. Rather than selecting only data and models that may be familiar, where availability and familiarity may introduce bias, all potentially applicable data and models should be explicitly identified by the TI Teams, duly considering the data, models, and methods that will come to light during the interactions with Resource Experts and Proponent Experts in Workshops #1 and #2.

- Proponents of a wide range of relevant models and methods should participate in workshops, including the authors of differing or controversial models. Interactions between the Proponent Experts and the TI Team will help the Team to understand the technical support for various models and methods and avoid biases arising from familiarity with particular models.

- Preliminary SSC and GMC models developed by the TI Teams must be subjected to technical challenge to ensure that there are transparent and defensible bases. Technical bases should be provided for both the weights assigned to the models included on the logic-tree branches and for the exclusion of other models. As noted in Section 3.6.2, at Workshop #3, it is recommended that the PPRP participates directly in this technical challenge. Such interaction will lead to discussions of unstated assumptions or conditioning events, and the TI Lead or TFI has responsibility for ensuring that uncertainties are fully characterized in the SSC and GMC models after the discussions at the workshop have occurred.

A particular type of bias that can arise is related to expectations about actual values, whether these are maximum magnitudes, recurrence rates, ground-motion amplitudes, sigma values, or even the hazard itself. When an expert's assessment is influenced by a preconceived value, it is referred to as "anchoring," or the anchor-and-adjustment heuristic, which is illustrated when experts are provided with an initial estimate (anchor) that is then adjusted up and down (O'Hagan et al., 2006). The approach has been shown to often produce "biased judgments because people often make insufficient adjustment from the initial anchor" (O'Hagan et al., 2006). Anchoring usually occurs unintentionally, and it is important to be watchful for its appearance in a SSHAC evaluation process. The TI Team members should not be constrained by the assessments of other experts, the views of the TI Lead or TFI, or even their own previous assessments, if new data or information has become available that should prompt them to update their judgments.

Another way that bias can be introduced through anchoring is if experts become reluctant to move significantly away from models and inputs developed early in the project for purposes of sensitivity analysis. For example, preliminary SSC and GMC models are developed and discussed at Workshop #3 (Section 3.6.2) along with hazard calculations and feedback from the PPRP. It is recommended that the TI Teams do not document in detail their preliminary models and their technical bases in the project report. The reason for this is if the expert has invested considerable effort and time in documenting early-stage assessments, they may become reluctant to update these assessments, even if the feedback and discussions at the workshop would prompt them to do so. This is one of the ways in which anchoring and availability biases can be related. Another example is when experts become anchored on a recent event, such as a published paper that has just become available in print. Other ways in which information can become an anchor through "availability" include being a current focus of attention in research or events in the news, being dramatic (unexpected but noticeable), being vivid (easily pictured), and being in some sense "official" (i.e., argument by authority).

It is common for experts in PSHA to have worked on other projects in which the actual amplitude of calculated ground motions can have a profound effect on the manner in which the PSHA is used for design or safety purposes. For example, judgments are made about whether a site is a "high" or "low" hazard site based on comparisons of calculated ground motions at a given annual frequency of exceedance. Initial comparisons of this type are not useful during the development of a hazard model and can lead to potential bias in constructing the model such that it achieves a predetermined hazard result. To avoid early-stage hazard calculations becoming anchors to experts' assessments, it is suggested that any hazard results calculated early in the project for purposes of sensitivity analyses to define important issues (e.g., prior to Workshop #1) be presented in normalized format (e.g., dividing all ground-motion values by the corresponding value for a well-defined base case and given annual exceedance frequency). Any format or presentation device is acceptable provided that it does not provide the evaluators with explicit associations of annual exceedance frequencies and ground-motion amplitudes. This is because this information could become an anchor and prevent sufficient updating of the experts' assessments when the data and analyses developed in the project would warrant significant changes to their earlier models. However, the normalization should not conceal the annual frequency of exceedance so that evaluators can see at what return period important changes occur. In some successful projects, the hazard curves have been normalized in acceleration so that at 10^{-4} the selected base case hazard input model yields a dimensionless value of unity. These precautions, with respect to the use and interpretation of early-stage hazard calculations, are not meant to dissuade their use as a tool to identify important issues during the initial stages of the project.

Other factors may act as anchors on the hazard estimates. Significant examples of such anchors external to the PSHA project include the following:

- Existing seismic hazard estimates for the region where the site is located or for closely located sites.
- Previous seismic hazard studies for the same site.
- If the sponsor has chosen a prequalified plant technology for which there is a specified ground-motion response spectrum (e.g., Bommer et al., 2011), there may be a tendency to influence the model such that the design response spectrum (DRS) emerging from the PSHA does not exceed the certified design (or other reference) spectrum. In such cases, it becomes very important that the evaluator experts and hazard analysts are not aware of the numerical hazard results mid-project, because inevitably the relationship between the spectral accelerations at certain annual exceedance frequencies and the ordinates of the design spectrum to which the plant technology has been pre-qualified could become a focus.

As is the case for other potential cognitive biases, the best way to counter these potential biases is to bring them to light, to discuss the potential biasing effect that previous studies or design levels might have, and to encourage the depiction of hazard information in a manner that does not allow the TI Teams to anchor on particular hazard levels or numbers. Experience on several SSHAC projects has shown that this can be completed successfully.

2.5 SSHAC Study Levels

The SSHAC guidelines in NUREG/CR-6372 specified four different levels of SSHAC hazard studies, increasing in complexity from Level 1 to Level 4. The five key features of a SSHAC process listed at the start of this section—clearly defined roles, objective evaluating of existing data and models, integration to capture the best estimates and the range of uncertainty, clear and comprehensive documentation, and independent peer review—are required at all four SSHAC Levels. The core objective of developing a hazard estimate that reflects the center, body, and range of technically defensible interpretations (Section 2.2) is the same at every study level. However, with the increased number of participants and greater interaction among the various experts, including the peer reviewers, the likelihood of effectively capturing the center, body, and range of technically defensible interpretations is expected to be greater at the higher study levels. This is, in turn, expected to result in greater likelihood of regulatory assurance. Therefore, one of the key criteria in selecting the SSHAC Level for a hazard study is the degree to which regulatory assurance is required (Section 3.2.1).

In view of how central the concept of *regulatory assurance* is to these discussions, it is worthwhile to clearly define this term. For the purpose of this document, regulatory assurance is defined to mean confidence that the data, models, and methods of the larger technical community have been properly considered and that the center, body, and range of technically defensible interpretations have been appropriately represented. In other words, it is confidence that the basic objectives of a SSHAC process have been met. This is distinct from the term "reasonable assurance," which has a specific definition within the U.S. Nuclear Regulatory Commission's (NRC's) regulatory framework related to compliance with regulations. In contrast, "regulatory assurance" is a qualitative term that is applicable to the SSHAC process because of the confidence that is engendered by its proper execution.

Because adopting a Level 3 or a Level 4 process to conduct a PSHA results in a significant increase in terms of cost and duration of the study over that required to conduct a Level 1 or Level 2 PSHA, it is important to highlight the benefits that can be expected to be gained by moving to these higher levels. These benefits are associated with the greater levels of regulatory assurance in Level 3 and 4 studies. For example, the data identification and evaluation process is more explicit and comprehensive because members of the technical community have directly participated in sharing their knowledge of pertinent databases. One benefit is that the study and its technical bases will be more transparent, having been presented in formal workshops and clearly documented. Of course, Level 1 and 2 studies also should be clearly documented, but the documentation is likely to be more extensive in a Level 3 or 4 study. One reason for this is that a Level 1 or 2 SSHAC report will summarize the data, models, and methods considered during the evaluation phase and explain the choices of models included in the logic-tree; whereas at Level 3 or 4, a greater onus exists to demonstrate that the full range of data, models, and methods has been considered, and the technical justification for the models built during the integration phase is expected to be more rigorous. In higher SSHAC Level studies, the decisions involved in constructing the logic tree for the PSHA will have undergone extensive technical challenge and will have been subjected to ongoing review by the PPRP. The result of this increased scrutiny during the process is that the input to the hazard calculations and, consequently, the hazard estimates themselves are less likely to be subsequently challenged. In addition, the participation of several well-regarded technical experts acknowledged as authorities in their respective fields and interacting within the formal constraints of a Level 3 or 4 process increases the likelihood that the full spectrum of knowledge and uncertainty in the inputs—and therefore the full range of uncertainty associated with the hazard—have been represented.

A desirable outcome of a Level 3 or 4 study is increased longevity and stability of the hazard assessment. This means that the numerical results of the hazard analysis can be expected to remain stable for a reasonable period of time after the completion of the hazard study. Of course, the appearance of significant new information—such as an earthquake larger than anticipated, the discovery of a previously unknown active fault, or a collection of ground-motion recordings that fundamentally contradict all current models—at any time can lead to the necessity to revisit the hazard analysis (see Section 4). However, such a re-visitation is far less likely to be required in

Level 3 or Level 4 studies as a result of the significant efforts to identify all existing information and models and model-building that captures current knowledge and uncertainty.

A stable assessment of the hazard at a site—determined by experts in a transparent process under the continuous review by a panel of separate but equally experienced experts—provides greater assurance to the NRC (or another regulator) that uncertainties have been effectively captured. In turn, a strong hazard study provides the underpinnings for determination of the design basis ground motions for a critical facility. The technical basis for the PSHA can be more easily defended should contentions be raised. This increased regulatory assurance is the primary benefit obtained by conducting a Level 3 or Level 4 study. However, it is very important to emphasize that adoption of a Level 3 or Level 4 process does not guarantee regulatory acceptance even if the project fully conforms to the procedural requirements.

In the progression through the SSHAC Levels, the largest increments of time, effort, complexity, and cost occur in passing from Level 2 to Level 3, which is expected to lead to significantly greater regulatory assurance. Levels 3 and 4 are generally considered to be equivalent in terms of regulatory assurance and are viewed as alternative ways of organizing the study. The key elements of Level 3 and 4 studies are essentially the same, but the organization structure is slightly different. This is discussed in detail in Section 3.1.

2.6 Key Roles and Their Responsibilities and Attributes

The essence of the SSHAC process is the structured interaction among experts to achieve a well-documented hazard study that captures the center, body, and range of technically defensible interpretations. Central to the success of the process, therefore, is clear definition of the different roles within a project, and of the responsibilities that each role entails.

The main roles and their relationships in the project structure for a SSHAC Level 3 project are illustrated in Figure 2-2. All of the roles depicted in this organizational chart are described in the following subsections, including a description of their key responsibilities. Distinctions in the roles involved in other SSHAC Levels are discussed in the context of those identified for Level 3 projects.

There are attributes that are required for an individual to be able to contribute effectively in their role within a SSHAC process. These attributes are among the key criteria for selection of project participants (see Section 3.4) because the SSHAC process is based on the assumption that the experts in each role possess the required knowledge, experience, and skill sets. For several of the key technical roles, the degree to which each individual would be expected to possess key attributes is illustrated schematically in Figure 2-3. These attributes include those related to knowledge that the individual (e.g., being a subject matter expert) and experience (e.g., having participated in previous SSHAC studies), as well as being prepared to conduct themselves according to the specific duties of their specific role (e.g., ability to act as an impartial evaluator). As noted previously in Section 2.3, the terminology of TI Leads and TI Teams in this context is to indicate the experts responsible for conducting the assessments at all SSHAC Levels.

For leadership roles, there is greater onus in terms of attributes since it is indispensable that individuals assuming these roles satisfy the basic requirements of knowledge and experience. For those roles that correspond to membership of a team or panel, the criteria may be more relaxed because it is sufficient for the group to collectively satisfy the requirements. For example, it would not be expected that all the members of a TI Team (Section 2.6.7) have extensive

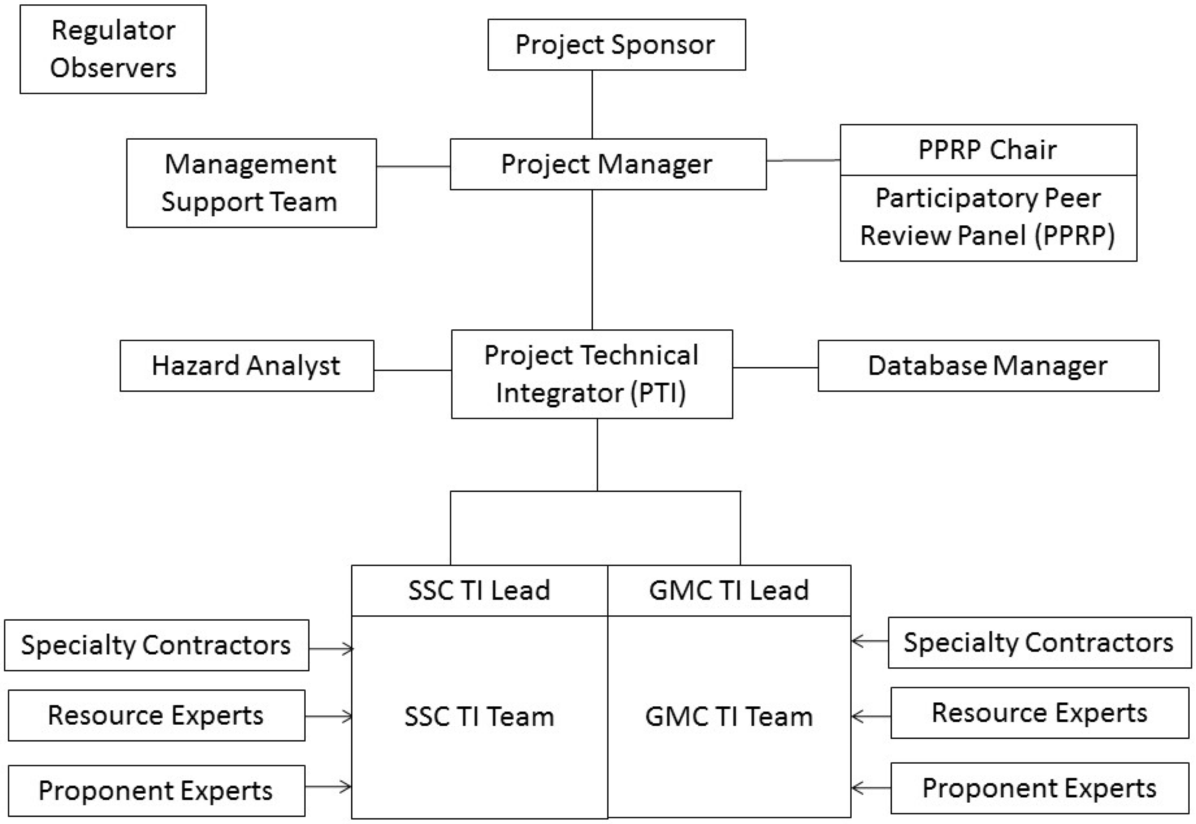

Figure 2-2 Organizational structure for a SSHAC Level 3 project

experience of participation in SSHAC studies. Indeed, it is to be expected that in most projects some members of the TI Teams and possibly also the PPRP (Section 2.6.9) would have no prior SSHAC experience, because only in this way can a pool of suitably qualified individuals be grown. Another factor to take into account during the selection process for SSHAC participants is the potential for cognitive bias resulting from possible conflicts of interest (COI). Although COI do not necessarily disqualify participants, best practice is to document these potential COI for transparency.

2.6.1 Sponsor

The sponsor is the organization or organizations that fund a SSHAC hazard study and therefore own(s) the products of the project. There may be a single sponsor or multiple sponsors, but for the sake of discussion throughout this document, the role will simply be referred to as the "Sponsor." For regulated facilities such as nuclear power plants, the Sponsor will submit a safety case or license application on the basis of the hazard study. The Sponsor, therefore, needs to specify all of the requirements of the study in terms of deliverables (see Section 3.3.1). In this regard, the Sponsor must assume responsibility for the quality assurance (QA) aspects of the project, ensuring that appropriate procedures and guidelines are identified.

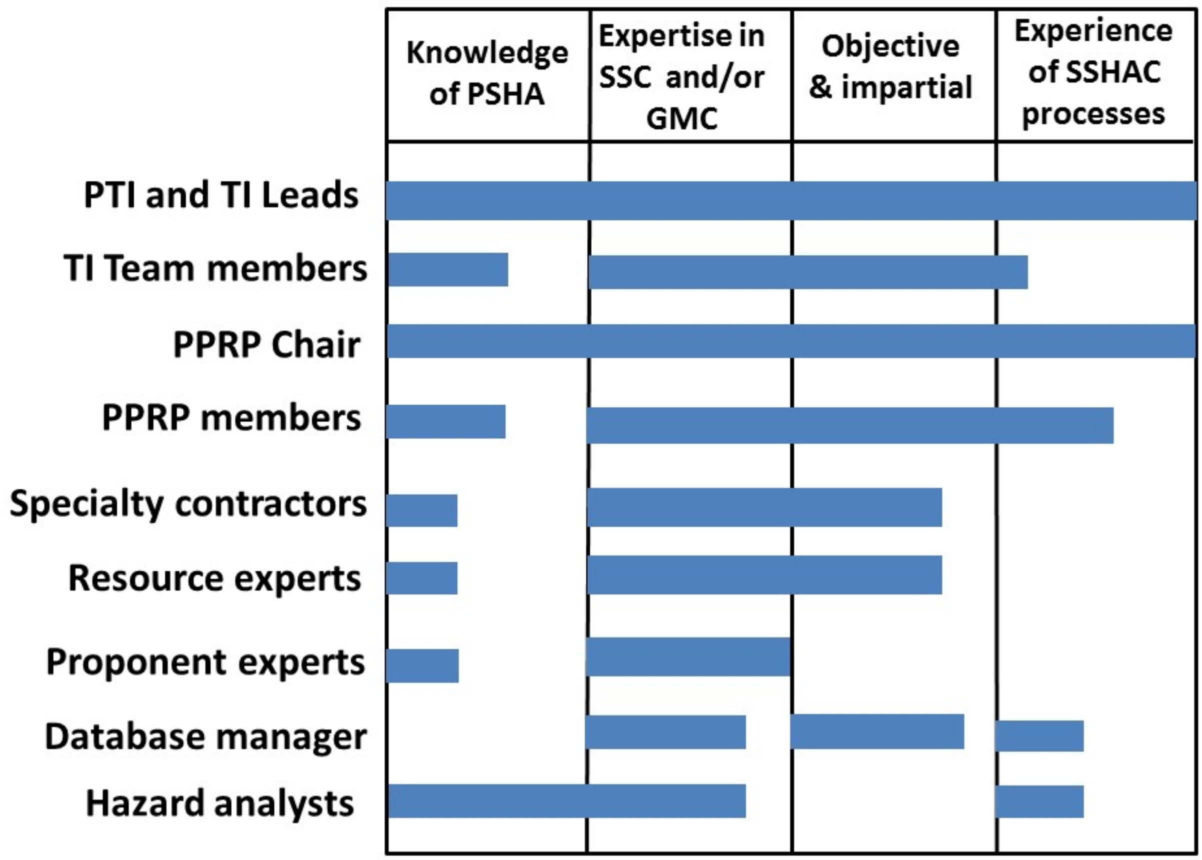

Figure 2-3 **Some of the main attributes required for key roles in a SSHAC Level 3 project. The length of each bar indicates the degree to which the attribute is desirable for each role; where the bar fills the width of the column, the attribute is considered to be indispensable.**

The Sponsor may also specify the schedule for the SSHAC study on the basis of the schedule for other tasks that will make use of the outputs, provided that the schedule is sufficient to allow the study to be conducted properly. The Sponsor is expected to identify and appoint the Project Manager (PM) (Section 2.6.2), who serves as their primary point of contact (POC) throughout the project. The Sponsor may assist with the appointment of the individual(s) responsible for QA (see Section 2.6.3) and identifying suitable candidates for other key roles, including the PPRP Chair (Section 2.6.8).

Once the project has begun, the Sponsor will be kept informed of progress by the Project Manager but should not intervene in any way other than to communicate any changes in terms of schedule or deliverables or else to respond to requests and questions communicated via the Project Manager. The Sponsor is generally expected to be present at the workshops in the role of an Observer (Section 2.6.15).

2.6.2 Project Manager

The Project Manager is one of the most vital roles within a SSHAC project and is key to the successful execution of the project. The Project Manager is at the center of the communication structure in a SSHAC project, serving as the unique POC for both the Sponsor and the PPRP, as well as for the technical teams through the PTI (Section 2.6.4) in Level 4 and Level 3 studies. A key duty of the Project Manager is to keep the Sponsor informed of progress, and this will generally entail regular meetings with the Sponsor and liaison with the PTI.

The PM has overall responsibility for running the project, including adherence to schedule, budget, and scope, including compliance with QA requirements. At the outset of a project, the PM will be involved in the appointment of the PTI and the TFI (for SSHAC Level 4 studies, see Section 2.6.5) or TI Leads (for SSHAC Level 1 through 3 studies, see Section 2.6.6). The PM is responsible for contracting all participants shown in Figure 2-2, as well as making logistical arrangements for the kick-off meeting, the workshops, and the PPRP briefing. The PM also provides whatever logistical support required by the TI Leads for the formal working meetings. The PM also has ultimate responsibility for delivery of the final report and any associated products to the project Sponsor. In executing this wide range of tasks, the PM is likely to benefit from support staff (see Section 2.6.3), including the individual responsible for QA with whom the PM must work very closely.

A specific responsibility of the PM that needs to be emphasized is to be present at all workshops and formal working meetings of the TI Teams. The reason for this is that the PM is responsible for reporting on the status of the project to the Sponsor on a regular basis. Being present at these meetings will provide first-hand information regarding the progress being made. Further, the PM is the point of contact with the PPRP (Section 2.6.9) and, as such, should be present at all meetings where the PPRP will be represented, to ensure that the proper observer roles are being respected.

The PM must have excellent skills in resource prioritization and project risk management, as well as experience of managing large projects. Clear understanding of QA requirements and of the SSHAC process are indispensable attributes for a PM. Technical knowledge related to the hazard being assessed may be beneficial, at least to the degree that this facilitates clear communication to avoid misunderstandings between the PM and the PPRP Chair and the PTI. However, such technical knowledge is not a requirement for the role of PM, and the PM should never assume responsibility for communication of specialized technical issues; for such issues, the PM should defer to the PTI or the TFI/TI Leads, as appropriate.

SSHAC projects have been seen to benefit considerably from PMs who, in addition to being highly organized, are also able to create an atmosphere within the project that is both professional and congenial. Workshops that are well structured and conducted in pleasant surroundings have been seen to be conducive to greater engagement and more effective discussions. Equally, when the PM has been able to foster a positive working environment and facilitate effective communications for the project participants, it has been found to enhance their contributions. At the same time, the PM may need to be very firm in order to avoid situations leading to unnecessary departures from the established scope or schedule.

The role of PM in a SSHAC Level 3 or 4 hazard study requires at least a half-time—if not full time—engagement, and it is important that the person assuming this key position is fully aware of the level of the commitment and the need to be frequently available to the project in a responsive manner to deal with the resolution of issues as they arise.

2.6.3 Management Support Team

In view of the critical role that the PM plays in a high-level SSHAC study and the potentially onerous workload that this may entail, it has often been found very beneficial for the PM to be supported by a staff team in which individuals can be delegated specific responsibilities.

One indispensable role in a SSHAC Level 3 or 4 study is the QA officer, which will generally be a separate role from (but working closely with) the PM to ensure compliance with all QA requirements that are specified by the Sponsor.

Another support role that can be valuable is a technical editor who assists with the coordination and production of the final documentation, with specific focus on consistency of formats and presentation style, as well as general layout and quality of the documentation.

The PM can also benefit from support in several other specific areas, such as contracting and workshop logistics. For example, experience has shown that a SSHAC Level 3 or 4 study can include the need to develop contracts for a large number of project participants coming from a variety of academic, government, and private institutions. Having these contracts in place prior to the associated work activities can be a challenge that requires management support.

2.6.4 Project Technical Integrator

In a SSHAC Level 3 or 4 hazard study, in which there are multiple subprojects each under the direction of a TFI/TI Lead, the role of the Project Technical Integrator (PTI) is to provide overall technical coordination. In essence, the PTI role is complementary to that of the PM and includes being the technical lead and spokesperson for the technical products of the project. The PTI would be expected to accompany the PM to most Sponsor briefings to address all technical issues that are outside the remit of the PM. In liaison with the Sponsor, the PTI ensures that the project deliverables will satisfy the requirements of the project Sponsor and also any regulatory body that will ultimately assess the hazard study. In this regard, the PTI and PM also work closely together with the QA officer.

The PTI also needs to liaise closely with the TFI/TI Leads with particular attention to interface issues. To perform this role most effectively, the PTI attends some of the formal working meetings of the TI Teams. The PTI also coordinates the work of the Database Manager (Section 2.6.12) to ensure the timely and convenient provision of all relevant data, models, and methods to the TI Teams. Another key responsibility of the PTI is to coordinate the work of the Hazard Analyst, including QA aspects. The PTI needs to work closely with the PM and the TFI/TI Leads to ensure that adequate time is made available for the preparation, execution, checking, and reporting of the hazard calculations.

The PTI must have extensive experience of both hazard studies and application of the SSHAC process, as well as a good understanding of all elements of the hazard input model and an appreciation of the downstream use of hazard results. At the kick-off meeting and the workshops, the PTI would be expected to provide overviews of the basics of PSHA, the overall objectives of the specific project, and training on the SSHAC process.

The time commitment of the PTI role is not necessarily very large in terms of total commitment, but the person in this role does need to be available to attend many meetings and to engage in regular communication with several other key participants as indicated above.

In many ways, the PTI relieves the TFI/TI Leads to focus almost exclusively on the core activities of evaluation and integration leading to the development of the input models for the PSHA calculations. In a number of successful SSHAC Level 3 projects, the PTI role has been played by one of the TI Leads. This works well in terms of addressing the SSC-GMC interface issues but can lead to a very considerable workload to the individual filling both the TI Lead and PTI positions.

2.6.5 Technical Facilitator Integrator

The position of Technical Facilitator Integrator (TFI) is unique to Level 4 studies. The role carries responsibilities very similar to those of a TI Lead in a SSHAC Level 3 study (Section 2.6.6) except that the TFI does not act as an evaluator expert but rather facilitates the evaluation and integration by a panel of individual experts or expert teams. The TFI would generally be expected to play a central role in the selection of the evaluator and integrator experts.

The primary role of the TFI is to facilitate interactions among the experts or expert teams conducting the evaluation to ensure that all assessments are challenged and adequately defended and that the evaluators act at all times as objective and impartial assessors. The TFI must encourage the evaluators to challenge one another within the workshops. The facilitator also ensures that the evaluators consider all available data, models, and methods, and ultimately produce SSC or GMC models that reflect their assessments of the center, body, and range of technically defensible interpretations. All of these tasks are reinforced through closed working meetings between the TFI and individual experts.

In a Level 4 study, the role of TFI is of pivotal importance, and it becomes imperative to appoint an appropriately qualified individual. The necessary attributes include all of those listed in Section 2.6.6 for the TI Lead. The TFI particularly requires a good understanding of the various cognitive biases that evaluators can be subjected to in their assessments. The facilitator should have the ability to communicate effectively and clearly and possess the willingness to encourage participants to fulfill their roles while maintaining a structured and efficient process.

The TFI role is one of the most demanding positions in a SSHAC study. For this reason, it is essential that anyone assuming this role be willing to commit a great deal of time to the project and be more or less continuously available throughout the project duration. This means, for example, that the TFI can be relied upon to provide clear and complete responses to questions and requests from the evaluator experts in a timely manner.

2.6.6 Technical Integrator Lead

As discussed in Section 2.3, the core activities in a SSHAC process are evaluation and integration to develop SSC and GMC models used as inputs to PSHA. In SSHAC Level 1 to 3 studies, the TI Lead coordinates the development of one of these models by a group of experts (Section 2.6.7) forming a TI Team. The TI Leads will also need to communicate closely with each other and with the PTI throughout the project to ensure that all technical issues are being dealt with. The ultimate responsibility of the TI Lead is to ensure timely delivery of an SSC or GMC model that captures the center, body, and range of technically defensible interpretations. It also falls to the TI Lead to ensure that the TI Team, collectively and individually, assumes full intellectual ownership of the final model. The TI Lead also has responsibility for ensuring that all members of the TI Team are made aware of the potential for cognitive bias and are alerted to when biases may be influencing their assessments. The TI Lead also will be responsible for instructing any members of the TI Team who are not fully conversant with the concepts of aleatory variability and epistemic uncertainty and their application to PSHA.

To reach the final goal, the TI Lead assumes several specific duties during the course of the project. One responsibility is identification of suitable Resource and Proponent Experts, in liaison with the full TI Team, and their invitation to the relevant workshops, including clear instructions of the scope for their participation. In the case of an invited Resource or Proponent Expert being unable to attend a workshop, the TI Lead must ensure that their views are fully represented to the TI Team.

The responsibilities of the TI Lead also include running the workshop sessions and ensuring that all participants clearly understand the workshop objectives, their individual roles, the required output from the workshops, and the implications of the issues under discussion for the seismic hazard analysis. The TI Lead also convenes and runs several working meetings with the TI Team during the course of the study. The TI Lead is responsible for ensuring that all TI Team members have full access to all of the available data and information they need to construct their models. A key responsibility of the TI Lead is to ensure that the documentation of the SSC or GMC model is complete and comprehensive.

If a TI Team member is found to be insufficiently qualified, is failing to engage with the tasks, or else demonstrates a repeated tendency to be partial in their assessments, it is the responsibility of the TI Lead to address these issues. If the individual in question is unwilling or able to address the issues, then the TI Lead must arrange for their removal from the team.

The main attributes of a TI Lead are a very strong technical background in SSC or GMC issues (as appropriate) and experience in the conduct of PSHA studies. It is desirable that the TI Lead has a good standing in the technical community because it is necessary for members of the TI Team to view the TI Lead as a peer. The TI Lead must be willing and able to make a very major commitment of time and effort to the project.

2.6.7 Technical Integration Team Members

As explained in Section 2.3, the SSHAC process essentially consists of three key activities: (i) evaluation of available data, models, and methods; (ii) integration of the interpretations into SSC and GMC models that capture the center, body, and range of technically defensible interpretations; and (iii) documentation of the study. The central roles of the SSHAC process are therefore those of the evaluator expert and the integration expert, which are invariably combined in the roles of the same individuals whether as members of the TI Team in a Level 3 study or members of an expert panel in a Level 4 study. As noted previously in Section 2.3, for simplicity in this document, evaluator and integrator experts are referred to as the "TI Team members," acknowledging that the experts in a Level 4 study may be individuals or teams.

The role of the TI Team as evaluator experts is to objectively identify existing data, models, and methods and to evaluate these in terms of their general quality/reliability and their specific applicability to the assessments being made. The TI Team evaluates data and diverse models, challenges their technical bases and underlying assumptions, and, where possible, test the models against observations. The evaluation phase includes interaction among the experts in workshops (i.e., challenging Proponent Experts and interrogating Resource Experts). During the integration phase of the project, the TI Teams are charged with constructing SSC and GMC models. The TI Team must present a clear technical justification and rationale for their choices both in terms of selected models and the weights assigned to them. The TI Team is not obliged to include in the logic tree all proponent viewpoints but must provide documented justification for excluding any particular model that exists within the technical community. The TI Team member executes this responsibility as part of a team and, therefore, must interact openly and constructively with the other members of the team.

The attributes required for a TI Team member include a strong technical background in relevant subjects, the ability to objectively evaluate the strengths and weaknesses of alternative models and methods, and at least some familiarity with approaches to quantifying uncertainties for hazard analysis. The strong technical background is required to enable the TI Team member to make informed evaluations of existing models and the impact of the models on seismic hazard. For this reason, TI Team members also should ideally have an understanding of the basic mechanics of PSHA and how the elements that they are charged with evaluating influence and impact the hazard estimates. The last criterion, however, should not preclude the selection of an otherwise suitable expert, because the project leaders can provide instruction on these issues as part of the process.

In a Level 3 or lower study, TI Team members also must have the ability to work in teams, and a congenial and respectful approach to other team members is obviously very desirable. At the same time, a TI Team member should have good communication skills to challenge proponent views and to defend their own assessments. In addition, they must be able to act with objectivity and be willing to forsake the role of proponent, up to and including critical assessment of models that they may have themselves developed. A TI Team member also must be able to commit significant time and effort to the project. Whereas Resource and Proponent Experts generally only need to attend one or perhaps two workshops, a TI Team member must be present at all workshops and relevant working meetings and commit to the entire duration of the project.

Because interaction among TI Team members is an integral and valuable part of the process, it is important that TI Team members bring different perspectives to the project. For this reason, it is desirable that the TI Team is not dominated by a single organization or group. In addition to technical diversity, this reduces the likelihood of cognitive bias in the form of perceived organizational COI.

In summary, the responsibility of a TI Team member is to evaluate data, models, and methods from the larger technical community and then to construct an SSC or GMC model for input to PSHA that captures the center, body, and range of technically defensible interpretations and to provide complete and clear justifications of the technical bases for all elements of the model. The main attributes of a TI Team member are the ability to objectively evaluate the views of others and to be capable of developing models that express the knowledge and uncertainties of the TI Team. The TI Team member also needs to be able to produce clear and complete documentation in a timely manner. They must be willing and able to make a major commitment of time and effort to the project.

2.6.8 Participatory Peer Review Panel Chair

The successful completion of a SSHAC hazard study is marked by the concurrence of an independent peer review panel, referred to as the Participatory Peer Review Panel (PPRP) (Section 2.6.9). Vital to the effective function of the PPRP is the role of a Chair of this panel. The first duty of the PPRP Chair is to coordinate with the PM regarding the selection and appointment of the Panel members.

Through the course of the project, the PPRP Chair is the point of contact with the Project Manager and the spokesperson for the Panel in all situations. The PPRP Chair is charged with coordinating the work of the Panel and to ensure that the Panel remains independent and impartial in its assessment of the adherence to the SSHAC principles and its assessment of the technical evaluation and integration process.

Specific duties of the PPRP Chair relate to the drafting of written reports (see Section 2.6.8) and organizing pre- and post-workshop meetings of the Panel. The PPRP Chair should also ensure the selection of appropriate observers from the Panel to attend each of the formal working meetings of the TI Team(s). The responsibilities of the PPRP chair include ensuring that the Panel is able to arrive at a consensus view, ensuring that concerns are communicated clearly and in a timely fashion to the Project Manager, and energetically follow up on these issues if a satisfactory response is not received.

The PPRP Chair is responsible for compiling the views and comments from the Panel members into a single coordinated document and also to ensure that feedback is provided on schedule. At the same time, it falls to the PPRP Chair to ensure that the comments and feedback from the Panel is clear, objective, and relevant to the goals and objectives of the hazard study. For example, individual members of the PPRP may have comments that are motivated by personal scientific curiosity, rather than consensus views by the Panel as a whole and pertaining specifically to the project objectives (e.g., development of models that capture the center, body, and range of technically defensible interpretations). The PPRP Chair must ensure that such comments are not included in the formal project documentation.

The attributes of the PPRP Chair include a working knowledge of PSHA, extensive experience in SSHAC projects, and being held in high regard as a technical expert in their own right. The ability to maintain congenial relationships within a group while achieving consensus conclusions is another important characteristic required of the chair.

2.6.9 Participatory Peer Review Panel

The Participatory Peer Review Panel (PPRP) is a key and indispensable element of a SSHAC study. Following issuance of the final SSHAC report, the PPRP is expected to produce a closure letter that indicates whether the project has conformed to the requirements of the specified study level and whether all technical assessments have been adequately defended and documented. The project may be considered to have been executed successfully, provided that the PPRP closure letter gives concurrence on both of these questions. Because such an endorsement is viewed as the qualifying stamp of approval for a SSHAC study, it is important that the PPRP be composed of experienced and highly regarded specialists in the field of seismic hazard assessment.

The PPRP fulfills two parallel roles, the first being technical review. This means that the PPRP is charged with ensuring that the full range of data, models, and methods have been duly considered in the assessment; that the models developed capture the center, body, and range of technically defensible interpretations; and that all technical decisions are adequately justified and documented. The second role of the PPRP is process review, which means ensuring that the project conforms to the requirements of the selected SSHAC process level. Collectively, these two oversight roles assure that the evaluation and integration are performed appropriately.

One point that is important to emphasize is that membership of the PPRP is always on an individual basis and not as an affiliate of any organization. Each member of the PPRP in the employ of an organization must ensure that it is clearly understood that they are not representing their employer or organization on the panel but are serving in their own right as a recognized leader in their respective field.

The responsibility of the PPRP is to provide clear and timely feedback to the PTI and TI Leads through the PM to ensure that any technical or process deficiencies are identified at the earliest possible stage so that they can be corrected. More commonly, the PPRP provides its perspectives and advice regarding the manner in which ongoing activities can be improved or carried out more effectively. In terms of technical review, a key responsibility of the PPRP is to highlight any data, models, or proponents that have not been considered. Beyond completeness, it is not within the remit of the PPRP to judge the weighting of the logic trees in detail, but rather to judge the justification provided for the models included or excluded, and for the weights applied to the logic-tree branches.

The PPRP can only fulfill its vital role by engaging with the project at several different stages to observe the process, review the technical evaluations, and to provide feedback as appropriate. It is recommended that the key responsibilities of the PPRP include all of the following:

- Review the Project Plan, including the composition of the TI Team(s).
- Attend the kick-off meeting.
- Attend all workshops and participate in daily closed debriefing meetings during the workshops with the PM, PTI, and the TFIs or TI Leads.
- Timely provision of written comments following each workshop.
- Review Workshop #2 agenda and lists of invited Resource and Proponent Experts, providing suggestions for additional or alternative experts as appropriate.
- Attendance of one or more representatives of the PPRP at each formal working meeting to review the evaluation and integration processes (in each case, the representative is then expected to report back to the other panel members).
- Discussion of the preliminary SSC and GMC models for capture of the center, body, and range of technically defensible interpretations and direct interrogation and challenge of TI Team’s assessment at Workshop #3.
- Review the final Hazard Input Document (HID) and participate in a PPRP Briefing by the PTI and TFI/TI Leads on the final meeting, during which the final SSC and GMC models will be presented and discussed.
- Review the draft final project report.
- Issue PPRP Closure Letter, following completion and acceptance of final project report.

Another responsibility of a PPRP member is to preserve their independent status throughout the project. This means to maintain objectivity and not be drawn into the technical assessments. It also involves resisting any temptation to represent the views of the organization to which they are affiliated, because PPRP members must always serve in an individual rather representative capacity. The members of the PPRP must remain constantly cognizant that their duty is not to determine whether they agree with the SSC and GMC models being developed, but, rather, whether they are satisfied that the technical bases of those models have been adequately justified.

The attributes of the PPRP can be defined both for individuals and in collective terms. A key requirement is that each member of the PPRP has an understanding of, and commitment to, the SSHAC principles. Although it is desirable that some members of the panel have prior SSHAC experience, this is not an indispensable requirement for all members. In addition, the panel members must collectively cover all technical aspects of building SSC and GMC models and conducting a PSHA. The members of the PPRP also should be prepared to commit sufficient time to the project to become familiar with the issues, data, and models, and be able to review thoroughly the documentation developed.

2.6.10 Hazard Analyst

The role of the hazard analyst is to perform all of the PSHA calculations the TI Teams require. These include sensitivity analyses run for discussion at Workshop #1, the hazard calculations based on the preliminary SSC and GMC models discussed at Workshop #3, and the final PSHA calculations that are documented in the final project report. The Hazard Analyst must liaise closely with the PTI to ensure that the TI Teams are aware of any limitations or input requirements specific to the hazard calculation code being employed, and also to understand the way that the SSC and GMC models are being specified. The Hazard Analyst will also coordinate with the PTI and the PM to ensure that there is sufficient time allocated in the schedule for the hazard calculations to be executed and checked. The hazard analyst will also work with the QA officer to ensure that appropriate QA checks are applied to the hazard calculations.

The Hazard Analyst must have a thorough understanding of PSHA and experience in running PSHA calculations. Understanding of SSC and GMC models is also very important from the perspective of implementing the models. While an appreciation of the SSHAC process is beneficial—especially because the Hazard Analyst will usually present results at Workshops #1 and #3—prior SSHAC experience is not considered to be a requirement for this role.

2.6.11 Specialty Contractor

A Specialty Contractor is an individual or a group engaged to conduct data collection or analyses to inform the TI Teams in their evaluations. Specialty Contractors will generally be required to deliver clear and complete documentation of their work, including provision of any numerical data or results in digital format. It is common for Specialty Contractors to also be invited to present their results in a workshop, at which time they effectively assume the role of a Resource Expert (Section 2.6.13).

Specialty Contractors clearly need to be qualified and experienced experts in the specific area related to the work that they are engaged to undertake, but they do not necessarily need to be experts in the development of SSC or GMC models. Understanding of PSHA and the SSHAC process are also not required, although an appreciation of the nature of scientific uncertainties and their quantification is needed. Impartiality and objectivity are important attributes for a Specialty Contractor because all caveats, limitations, and assumptions in their work should be clearly identified.

If the work conducted by a Specialty Contractor involves new data collection, then it is also important that the individual or group liaise with the QA officer—usually through the PTI and PM—to ensure compliance with applicable QA requirements.

2.6.12 Database Manager

The role of the Database Manager is to compile, maintain, and distribute all the relevant data, models, and methods that are to be evaluated by the TI Teams. The database will generally consist of papers from the professional literature, reports developed for the site or vicinity, maps and images, and data files, all in electronic format. The inputs to the database will be provided by the TFIs/TI Leads and the PTI, and will include information identified by TI Team members, by Resource and Proponent Experts at the workshops, and also data collected or generated by Specialty Contractors. The duties of the Database Manager include cataloging of the information, ensuring secure back-ups, and effective distribution to the TI Team members. Access may be granted to other interested parties, including the PPRP, as needed. Commonly, the database will be hosted on a web-based platform.

The point of contact for the Database Manager is the PTI, as indicated in Figure 2-2. The Database Manager role can be filled by an individual or group working exclusively on this task, but it has also been found that a member of the TI Team can effectively absorb this role as well. In a full PSHA study, it is more likely to be a member of the SSC TI Team, given that the SSC databases are invariably much larger than those compiled for the GMC subproject.

2.6.13 Resource Expert

The role of a Resource Expert is to present information in an impartial manner at workshops. While the Resource Expert will make this presentation in the setting of a formal workshop in a SSHAC Level 3 or Level 4 study, they may also provide the information less formally in SSHAC Level 1 or 2 studies. The Resource Expert is expected to present their understanding of a particular data set, including how the data were obtained, their limitations and caveats, and resolution and uncertainties. A Resource Expert may also be asked to present models or methods as long as that can be done without advocating any particular model or method. In all cases, a Resource Expert is expected to make the presentation without interpretation in terms of hazard input. The reason for this is that they are not playing the role of a Proponent Expert, who advocates particular models or methods.

The main responsibility of a Resource Expert is to share their technical knowledge in an impartial way in their presentations to the TI Team. This means that their presentation should make full disclosure, including all caveats, assumptions, and limitations. The Resource Expert is also expected to respond candidly and impartially to questions the TI Team poses. A Resource Expert has full responsibility for the material that they present but does not have vested ownership of the hazard models.

The necessary attributes of a Resource Expert are knowledge and impartiality. Resource Experts must possess a deep and broad knowledge of the tectonics, geology, or seismicity of a particular region (or a data set, model, or method) and will often have worked on that topic for many years and have a number of publications related to the subject of their presentation.

2.6.14 Proponent Expert

The role of a Proponent Expert is to advocate a specific model, method, or parameter that is deemed to be relevant and credible for the hazard analysis. There are several reasons why a Proponent Expert may be requested to advocate a model. The Proponents may present their own model; other researchers' published models, which may be widely known or controversial; or new models that may not yet be published. The Proponent Experts will advocate the model within the forum of a formal workshop for higher SSHAC Levels. Proponent Experts will be contacted and their literature reviewed as part of Level 2, 3, and 4 studies.

The responsibility of a Proponent Expert is to promote the adoption of a model as input to the hazard calculations. The Proponent is required to justify this assertion, to demonstrate the technical basis for the model, and to defend the model in the face of technical challenge. The Proponent should present the benefits and limitations of the model, including all underlying assumptions. A Proponent Expert has full responsibility for the material that they present but does not participate in any way with the TI Team in the weighting of alternative hypotheses, nor do they have vested ownership of the resulting hazard models.

An individual who has another role in the project (such as Resource Expert or even a member of the TI Team) could, at a designated point during the project, adopt the role of a Proponent Expert. Everyone present must be made very clearly aware of this switch in roles and (in the case of a TI Team member) the individual must be prepared to subsequently return to the role of impartial evaluator. This flexibility has been useful in practice because these individuals have been willing to reveal specific weaknesses or limitations of their models, and in some cases, to propose that their models should not be adopted.

The attributes required of a Proponent Expert are knowledge (the same criteria as described for a Resource Expert) and the ability to defend a model and its basis. They also must be willing to acknowledge the assumptions, uncertainties, and limitations of their models in a workshop forum.

2.6.15 Observers

Observers are individuals who attend the workshops but do not actively participate in the discussions. For several groups, the opportunity to observe the SSHAC process at the workshops is valuable, and projects are encouraged to offer this opportunity wherever possible. The project Sponsor will invariably send one or more observers to the workshops. It is also common to offer this opportunity to any regulatory body that may subsequently be asked to evaluate the results of the project, and this has always been found to be very beneficial. In essence, this allows the regulatory bodies or other decision-makers to witness, first-hand, the process that they are relying on to provide regulatory assurance.

In addition to these groups, there have been several positive experiences related to opening up the possibility of attendance as observers to other interested groups or stakeholders. Examples of these have included utilities and regulators from other countries that may be contemplating adopting the SSHAC process, as well as representatives of bodies such as the International Atomic Energy Agency (IAEA), who have an interest in promoting best practice in the assessment of hazards at nuclear sites.

Although it is important to insist on adherence to the role of observer during the workshop sessions, it has been widespread practice to open the floor at the end of each day or at the end of the workshop to allow those present in this role to either ask questions or make comments.

2.6.16 Role of the Regulators

A common use of SSHAC hazard studies is to contribute to licensing or safety evaluations of safety-critical facilities. Prior experience has shown it to be advantageous for representatives of the NRC or other relevant regulatory body to attend and observe the workshops. As noted above in Section 2.6.15, observers in a SSHAC workshop are precluded from the technical discussions, but prior practice has shown the benefit of allocating time at the end of each workshop day for questions and comments from observers. This allows the regulator to provide feedback, raise concerns, or ask for points of clarification. In addition to observing workshops, the regulator can be provided with a copy of the Project Plan for information as well as other interim written products that are made public, such as the workshop summaries. The regulator should have input into the choice of the SSHAC study level (see Sections 3.1 and 3.2).

The benefits of such engagement between the project and the regulator are enhanced assurance associated with the assessment of seismic hazard at the site and enhanced familiarity with the specifics of the study. This familiarity can lead to efficient and effective regulatory reviews that focus on hazard-significant issues. In addition, increased knowledge of the project allows the regulator to effectively engage with stakeholders to explain key concepts and aspects of the study that contribute to ensuring public health and safety. Key to these outcomes is the confidence and reassurance that may be provided by the PPRP who, as impartial and experienced recognized experts in the field of PSHA, will be able to give the regulator confirmation that a proper process was followed and that sound technical assessments have been made. However, it is very important to emphasize that adoption of a SSHAC process does not guarantee regulatory acceptance, even if the project fully conforms to the procedural requirements.

Although the SSHAC process requires formal participatory peer review, it is ultimately the responsibility of the regulator to review the final report for applicability to safety evaluations. Upon completion of the PPRP closure letter, the regulator can (i) accept the SSHAC study without reservation, (ii) accept with some clarifications or exceptions, or (iii) reject the SSHAC study. Although rejection of a properly conducted SSHAC study is highly unlikely and would require significant justification, if the regulator either rejects or takes exception to aspects of the study, modifications to the study (replacements, revisions, corrections) should be conducted consistent with the processes outlined in Section 4.

Practical experience from recent use of SSHAC studies has shown that effective regulatory reviews typically involve consideration of the following types of questions:

- Did the SSHAC process reasonably follow appropriate guidance (e.g., NUREG/CR-6372, NUREG–2117, and this document)?
  - — Was the potential for cognitive bias discussed early in workshops?
  - — Did the PTI or TI Lead identify or address potential cognitive bias issues in workshops?
  - — Did the scope of the workshops support logical development of a PSHA?
- How effective was the Participatory Peer Review Panel?
  - — Was the PPRP engaged throughout the SSHAC?

- Were early PPRP comments/concerns addressed in later workshops/meetings?
- How were PPRP review comments resolved?
- Are there unresolved PPRP review comments that might affect results significantly?

- Was applicable data considered?
  - Was a common database developed?
  - Was the database easily accessible to participants (including the PPRP)?
  - Were updates to the database made, and were all participants aware of updates?
  - Were local experts engaged in identifying potentially relevant data?
  - Is there indication that some potentially relevant data was not considered?
  - Are the data summarized and presented sufficiently to support use in the PSHA?

- Were data uncertainties identified and considered?
  - Were uncertainties in original measurements maintained in compilations?
  - If data were collected in different studies, were issues of calibration/bias addressed?
  - Were data quality issues considered by the TI team(s) and PPRP?
  - How have data uncertainties been propagated in resulting models/calculations?

- Was an appropriate range of potentially applicable models considered?
  - How was the range of potential models developed and documented?
  - Did an appropriate range of model proponents participate in workshops?
  - How well did the TI team(s) engage with the proponents?
  - Were alternative views appropriately represented?
  - Are there indications that potentially relevant models were not considered?

- How were models selected and weighted in the analyses?
  - Is the basis for inclusion or exclusion of models well supported?
  - Is there appropriate documentation for how model weights were developed?
  - Were models tested or supported by independent information?

- Were there interactions to openly discuss inclusion or exclusion of models?
- If new models were developed, are limitations in existing models documented?

- How were models and data assembled into the PSHA?
  - How were models abstracted into logic-tree branches and weighted?
  - How were sensitivity studies used to refine logic-tree branches or weights?
  - How was uncertainty partitioned into aleatory and epistemic components?
  - How were these uncertainties propagated into ensemble results?
  - Is it clear how ensemble results were generated?

Given the nature of these questions, observation of the workshops by the regulator is strongly recommended. Direct observation facilitates a thorough understanding of both the process and technical details of the SSHAC study that may be difficult to discern from documentation alone. Note that these questions are provided for information based on prior experience but are not meant to preclude development of further review criteria by any given regulator.

3 ESSENTIAL STEPS IN THE SSHAC PROCESS

As explained in Section 2.5, there are four levels of Senior Seismic Hazard Analysis Committee (SSHAC) studies, which are further described in this section. The higher levels (Levels 3 and 4) are more likely to ensure that the hazard study captured the center, body, and range of technically defensible interpretations (commonly referred to as the CBR of TDI), resulting in greater regulatory assurance that a natural hazard has been appropriately characterized. For a hazard study to qualify as SSHAC, it is necessary to follow all of the required steps. The differences among the SSHAC levels are related to the effort and complexity afforded each step.

This NUREG provides additional clarifications and descriptions of the SSHAC levels and processes beyond those in NUREG/CR-6372, "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts" (NRC, 1997) and NUREG–2117, "Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies" (NRC, 2012c). In particular, this section includes expanded descriptions of the SSHAC levels (Section 3.1), with specific new guidance for SSHAC Level 1 and 2 processes and optional augmentations to Level 2 studies. Section 3.2 discusses how to select an appropriate SSHAC level, including whether a regional or site-specific study is warranted. The section also includes a discussion of the Project Plan (Section 3.3), selection of project participants (Section 3.4), the evaluation process (Section 3.5), the integration process (Section 3.6), and the preliminary hazard calculation and sensitivity analysis (Section 3.7). Section 3.8 is an enhanced discussion of the participatory peer review panel (PPRP) briefing. The final hazard calculation is discussed in Section 3.9, and Section 3.10 includes recommendations for clear and comprehensive documentation.

3.1 Description of SSHAC Levels

As previously noted, NUREG/CR-6372 specified four different levels of SSHAC hazard studies, increasing in complexity from Level 1 to Level 4. It is important to note that the basic attributes of SSHAC studies apply to all levels; however, there are differences in implementation. NUREG/CR-6372 and NUREG–2117 focused on conduct of Level 3 and 4 studies. The purpose of this section is (i) to provide guidance on conduct of Level 1 and 2 studies; and (ii) expand upon previous guidance for Level 3 and 4 studies, incorporating clarifications, corrections, and lessons learned from recent SSHAC studies. The following subsections describe the essential characteristics of all SSHAC studies and the similarities and differences among the levels.

3.1.1 Level 1 Studies

The requirements of a Level 1 process are illustrated in Figure 3-1. Several features of this flowchart are worthy of some brief commentary. First, as is the case with all SSHAC studies, a Level 1 study must include the three phases of all SSHAC studies: Evaluation, Integration, and Documentation (see Section 2.3). Second, the Evaluation and Integration are undertaken by a Technical Integration (TI) Team, rather than by an individual. The TI Team may be a smaller team than for high-level SSHAC studies. The need for more than one Technical Integrator (see Section 2.6.7) arises from the benefits that are obtained from interactions among the team members, as well as the obvious advantages of including individuals with different expertise. This is especially true if the SSHAC study is to encompass Seismic Source Characterization (SSC), Ground Motion Characterization (GMC), and site response modeling. Furthermore, some prior studies that were not conducted explicitly as SSHAC studies have been assumed *de facto* to be SSHAC Level 1 studies. However, unless a study was conducted with an overt and documented goal of meeting the SSHAC requirements, it should not be considered a SSHAC study of any level.

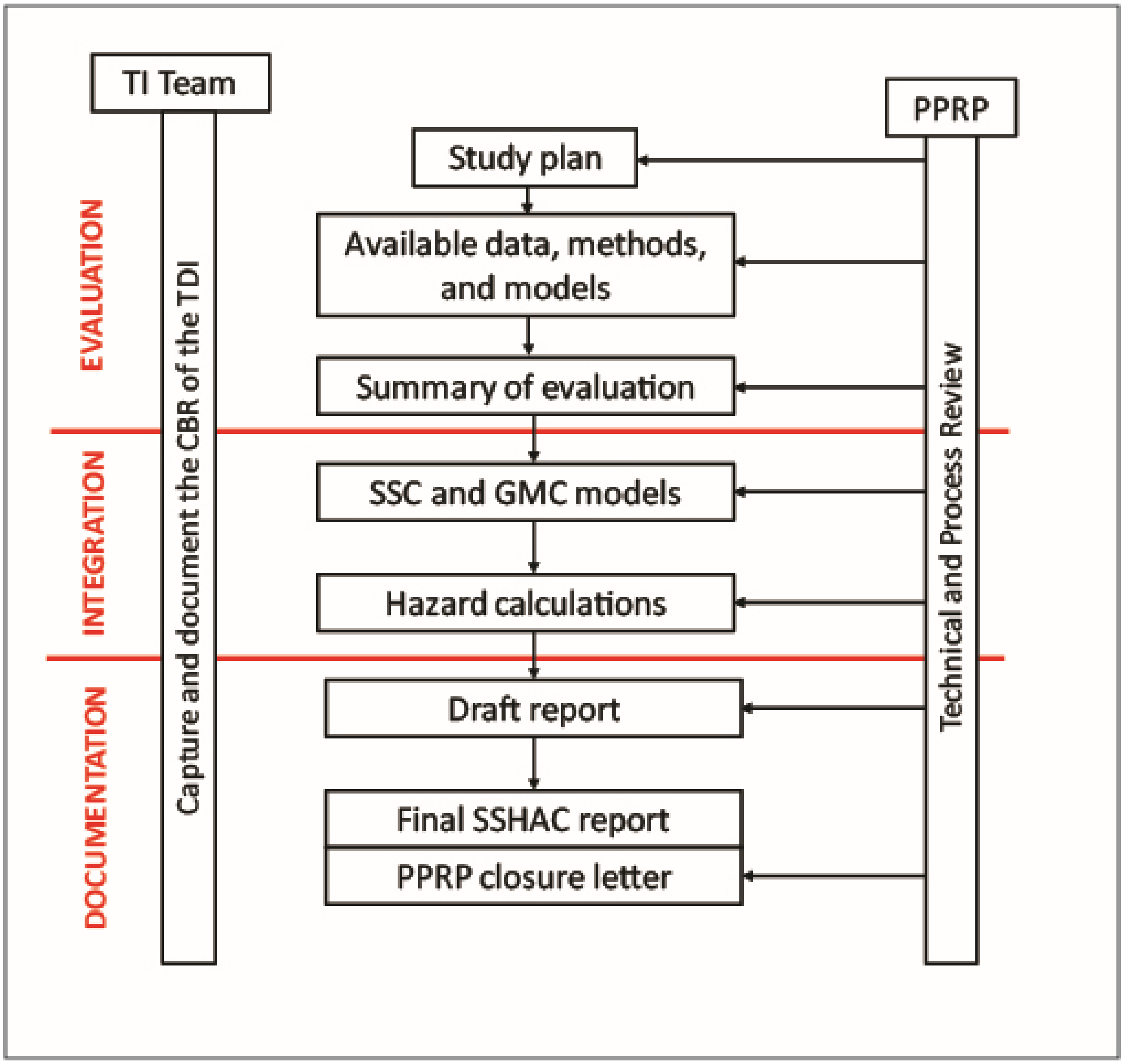

Figure 3-1 Flowchart for a SSHAC Level 1 Probabilistic Seismic Hazard Analysis (PSHA) study, with order of events running from top to bottom.

Another important feature of a Level 1 study, which is illustrated in Figure 3-1, is the requirement for a PPRP (Section 2.6.9). Specifically, this includes two important factors: (i) the peer review must be undertaken by more than one person and (ii) the peer review cannot take place only at the end when the study is effectively completed (termed a "late-stage" review in NUREG/CR-6732). The reasons for insisting on a panel of peer reviewers rather than an individual are similar to those for requiring a TI Team; namely, coverage of multiple fields of expertise and the benefits from interactions among experts and reviewers. The requirement for continuous rather than late-stage review is motivated by the fact that if the reviewers engage with the project at various stages, it becomes possible to alert the TI Team to concerns and omissions early on, and these can be addressed before the final SSC and GMC models are constructed. With late-stage review, the identification of such issues may require almost a complete repetition of the study, which is clearly undesirable. Another advantage of continuous or participatory review is that it enables the PPRP to observe and assess the process being followed by the study as well as the technical bases for the models developed. Figure 3-1 indicates several suggested points at which the PPRP can be engaged and provide feedback, starting with review of the Project Plan that lays out the objectives of the study; the general approach to be adopted; and the data, models, and methods to be considered. As guidance for reviewers in such studies, Figure 3-2 indicates the questions that the PPRP might address at each stage.

A point that needs to be stressed very strongly is that SSHAC Level 1 does not simply refer to any hazard studies that do not qualify as one of the higher levels. As discussed in Section 1.3, one purpose of these guidelines is to make a clear distinction between those studies that qualify as SSHAC studies and those that do not. Therefore, the five features that characterize all SSHAC studies given in Section 2 must be present, and the participants, organization, and activities given in this section must also be included. Therefore, the roles, responsibilities, and activities given in Figure 3-1 must exist in order for a study to call itself a SSHAC Level 1 study. Many, if not most, seismic hazard studies currently would not qualify as being SSHAC compliant at any level, because they usually fail to meet some of the basic requirements.

3.1.2 Level 2 Studies

The requirements of a Level 2 process are illustrated in Figure 3-3. Two additional steps are required for a Level 2 study in addition to the steps and components required for a Level 1 study. These are (i) outreach to external experts, and (ii) a cycle of review and feedback regarding the preliminary SSC and GMC models (Figure 3-3). The purpose of reaching out to external experts is to obtain information and greater insights into relevant data, models, and methods and to ensure that a broad range of information was considered as part of the evaluation process. These individuals may be Resource Experts (Section 2.6.13) who have knowledge of a particular dataset, such as the earthquake history, the geology, or the strong-motion database of a region, or Proponent Experts (Section 2.6.14) who advocate for the use of a particular model or method either in general or specifically to the application under study. The nature of the communication between the TI Teams and these external experts is not specified because it will depend on the availability of the latter and also on location or issue. Whether the communication is in the form of face-to-face meetings, remote video or audio conversations, or even email exchanges, the TI Team is required to document the discussion and to obtain written concurrence from the experts that the interactions have been accurately recorded. Lessons learned from past SSHAC studies have shown that remuneration for the time and effort of these experts is beneficial because it helps to ensure that they are engaged sufficiently to complete the cycle of interaction and documentation.

The other additional feature of a Level 2 study over a Level 1 study is that a preliminary hazard model is developed and hazard calculations are run to provide insights regarding the consequences of the modeling choices and, in particular, which elements of the total uncertainty are exerting the greatest influence on the hazard estimates. These hazard insights are meant to benefit both the TI Team and the PPRP. Following this feedback and review cycle, the models are finalized and the final hazard calculations run. In addition to these basic requirements, Level 2 studies can be augmented by a number of other activities, as discussed further in Section 3.1.5 and described in Table 3-1.

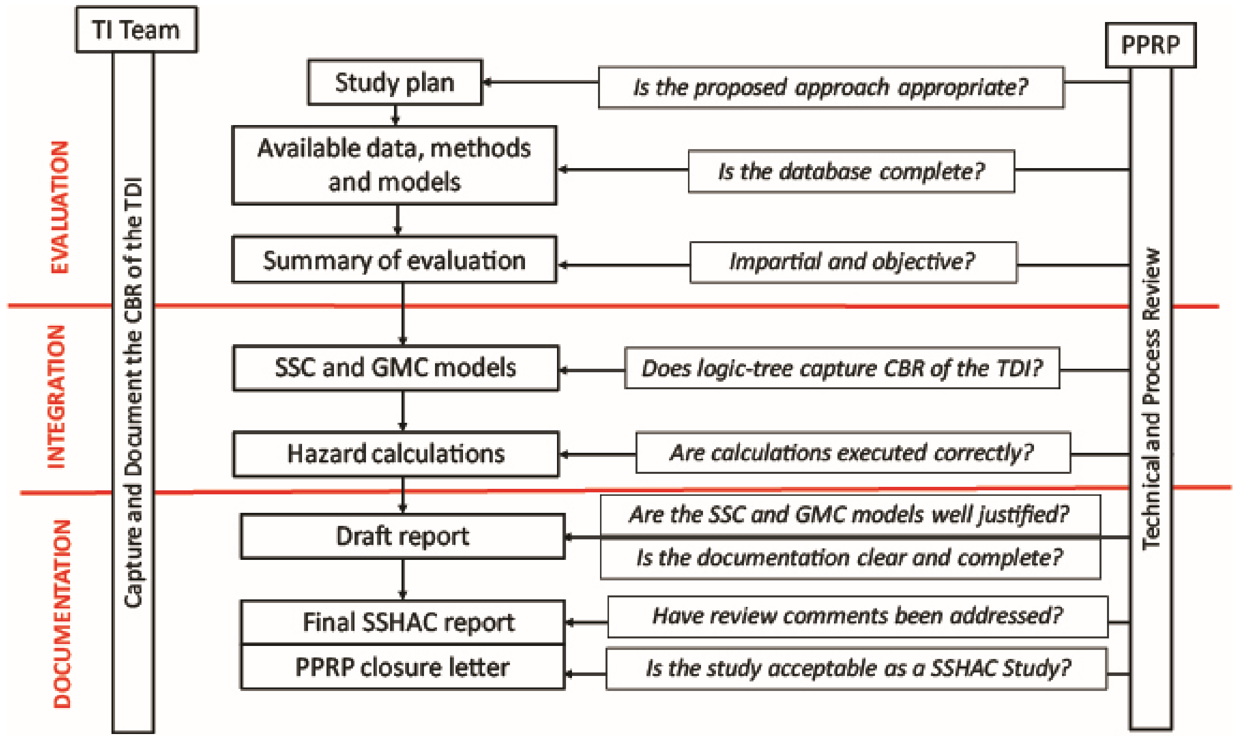

Figure 3-2 Flowchart for a SSHAC Level 1 PSHA study, indicating the review criteria and potential questions at each point of engagement by the PPRP.

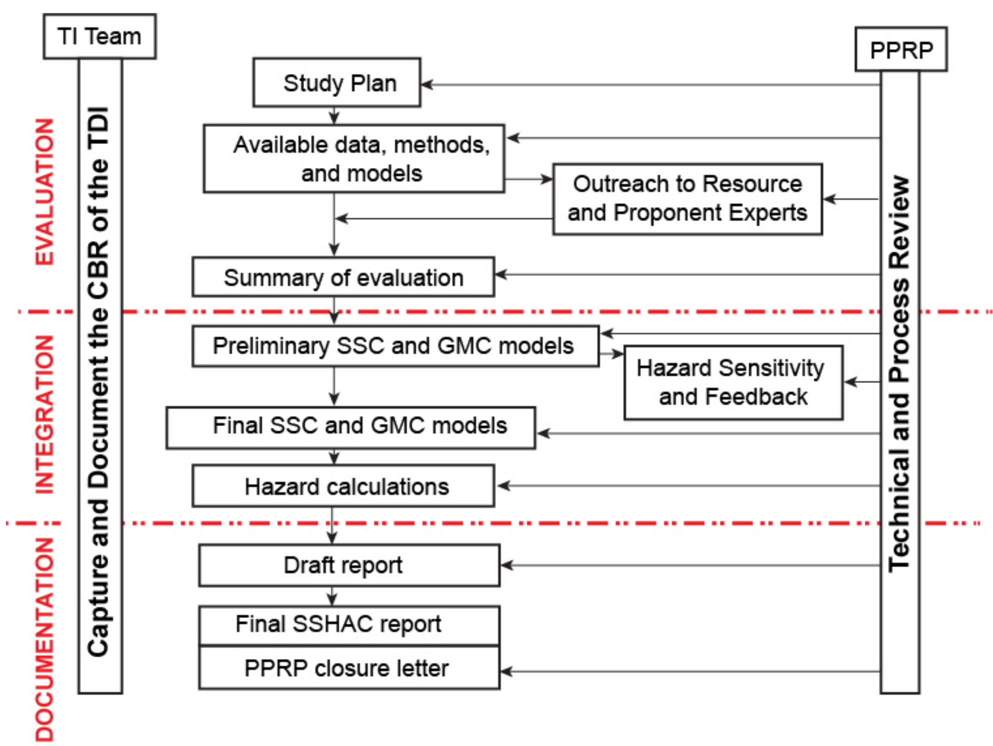

Figure 3-3 Flowchart for a SSHAC Level 2 PSHA study, with time running from top to bottom.

Table 3-1 Attributes of SSHAC level studies from Level 1 to Level 3*				
	Level 1	**Level 2**	**Level 2 Augmentation Options**	**Level 3**
Peer Review	At least two reviewers; Communication with PPRP during evaluation and integration	Two or more reviewers; Feedback on preliminary models	One or more PPRP representative(s) observes working meetings, TI Team interactions with external experts, and/or workshops	Ideally five reviewers; Engagement during evaluation and integration process; PPRP briefing of final model
Technical Integration Team	Small TI Team (depending on nature and complexity of issues)	Small TI Team; possibly multiple teams (e.g., seismic source characterization and ground motion characterization)	Larger TI Team	Five or more TI Team members
Evaluation	Sensitivity analysis to identify significant issues; Systematic review of literature	Outreach to proponents and resource experts (e.g., phone interviews)	Add Workshop #1, #2, or hybrid that includes resource experts and/or proponents	Two workshops with resource expert and proponents; Data summary tables
Integration	Develop models that capture the CBR of TDI	TI Team interaction and hazard feedback during model-building	Add Workshop #3 with feedback from PPRP	One workshop to discuss preliminary models; PPRP briefing
*All attributes are additive, moving from left to right on the table; Level 4 is essentially the same as Level 3 with respect to these attributes.				

3.1.3 Level 3 Studies

For a Level 3 study, the key features and project workflow are illustrated in Figure 3-4. As indicated by the red lines and text, the steps define the three essential elements of Evaluation, Integration, and Documentation, as described in Section 2.3. The blocks on the right-hand side of the diagram illustrate the key participants involved throughout the duration of the project: the Project Manager (PM), the Project Technical Integrator (PTI) and the TI Teams, as well as the PPRP. Whereas the PM, PTI, and TI Leads are effectively engaged continuously, the PPRP engages at specific points during the project as indicated by the arrows emerging from the PPRP block. The solid arrows correspond to the activities in which the entire Peer Review Panel is engaged, whereas the dashed arrows indicate times when the PPRP is represented by selected members of the Panel.

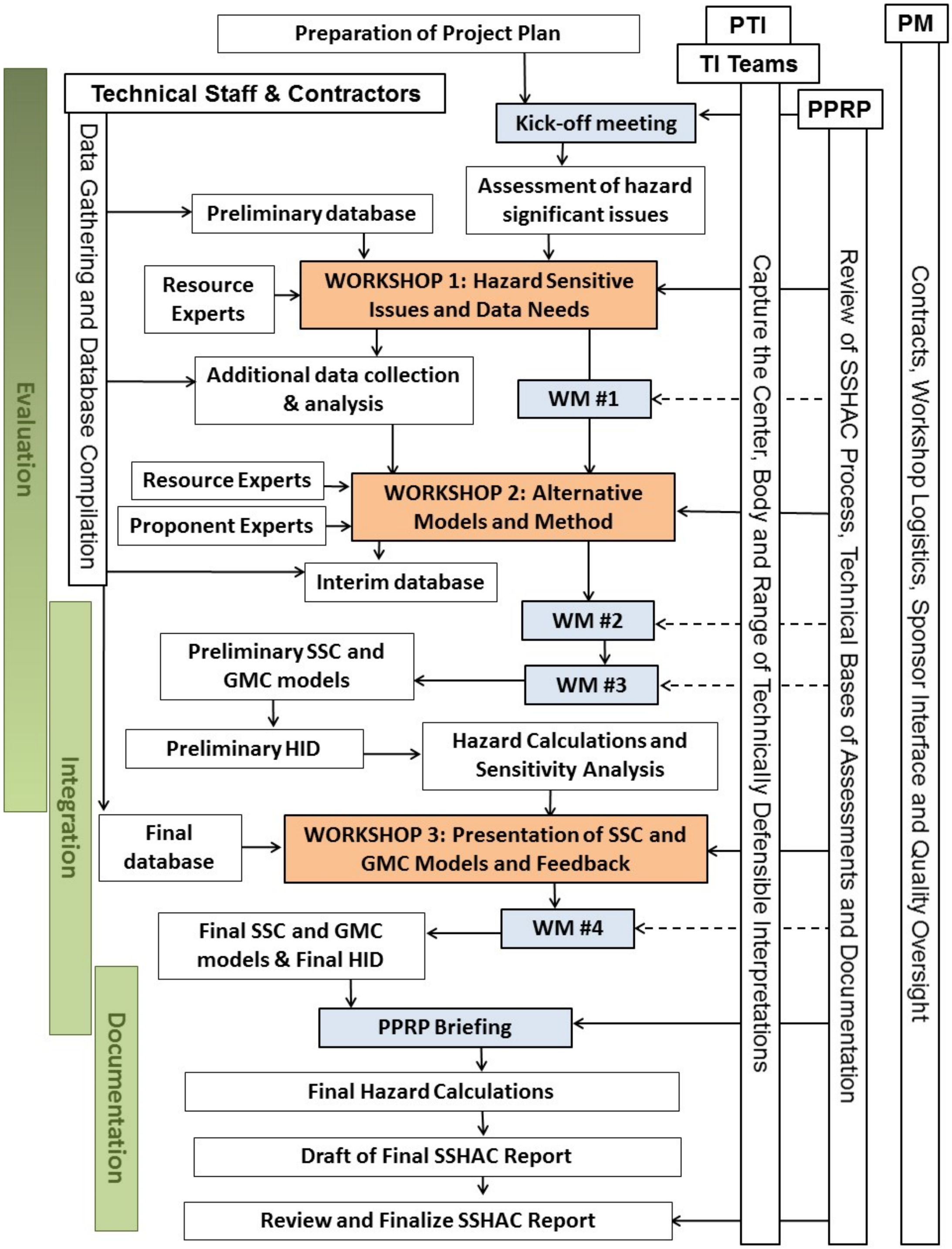

Figure 3-4 Flowchart illustrating the key features in a SSHAC Level 3 process. The order of activities runs from top to bottom of the diagram. The timing of the working meetings reflects one suggested arrangement and alternative schemes may be used, although one meeting after Workshop #3 is essential. Dashed arrows indicate activities where one (or more) PPRP member(s) is selected to observe and represent the larger panel.

Looking at the center of the diagram, it is clear that the process is built around three major workshops. The first two workshops are held within the evaluation phase of the process and where Resource and Proponent Experts are engaged.

The TI Teams work throughout the project and will have numerous group interactions through email, telephone conversations, webinars, and informal encounters that may involve all or some of the TI Team members. However, it is recommended that a number of formal working meetings also take place. These meetings provide an opportunity for the PPRP (through a representative) to observe the TI Teams' deliberations first hand. The formal working meetings also serve as useful markers in the development of the SSC and GMC models. For a Level 3 study, it is suggested that there be a minimum of four such formal working meetings. The timing of the working meetings is project-specific and may vary considerably from one project to another. The timing of the working meetings indicated in Figure 3-4 is based on experience in some successful projects, but other arrangements have also worked well where the specific requirements and boundary conditions of the project favored alternative schedules. In the scheme of Figure 3-4, three of these four meetings take place in the integration phase, which is when the TI Teams undertake the work of developing the SSC and GMC models. Note that the evaluation phase, which includes the development of the project database, continues and overlaps with the integration phase up to the time that the final database is completed at the time of Workshop #3. The third and final workshop also takes place in the integration phase and marks the first opportunity for the PPRP to question the SSC and GMC TI Teams about their preliminary models. Based on the interactions among the TI Team(s) and the PPRP, the models are then finalized at the final working meeting. Subsequently, the TI Teams meet once again with the PPRP for a briefing to explain the final models in detail before the final hazard calculations are run and before the TI Teams complete the documentation of the study. This briefing, discussed in greater detail in Section 3.8, is intended to streamline the subsequent PPRP review and resolve any technical concerns before the project goes into its final documentation phase. The outcome of the briefing is an enhanced recognition by the TI Teams of those elements of the final models that should be subject to particular emphasis in the final documentation.

In light of the project activities identified in Figure 3-4, it is also useful to acknowledge the essential steps in a SSHAC Level 3 or 4 project. Table 3-2 summarizes the recommended essential steps for a hazard study to be designated as a SSHAC Level 3 or 4. Note that following the selection of the SSHAC level, the subsequent discussions in this section will be related to Level 3 or 4 studies, with appropriate distinctions made to discuss the approaches that are recommended for Level 1 or 2 studies.

3.1.4 Level 4 Studies

A SSHAC Level 4 study is very similar to a Level 3 study in terms of the essential steps and the basic sequence of activities. However, there are some important organizational differences, as illustrated in Figure 3-5. The fundamental difference is how the technical experts interact and develop the logic trees. In a Level 3 study, the technical experts produce a single logic tree that captures the overall distribution agreed by the evaluators through the process of technical challenge and defense. This process occurs throughout the duration of the project, but most intensely during the formal working meetings. In a Level 4 study, although the experts or expert teams interact at the workshops, the primary interactions—and the main form of technical challenge and defense—take place in the elicitation meetings between individual TIs and the Technical Facilitator Integrator (TFI) (see Section 2.6.5). Each expert or expert team is charged with producing a logic-tree reflecting their view of the distribution that captures the center, body,

Table 3-2 Summary of essential steps in SSHAC Level 3 and 4 studies

Essential Step	Description
1. Select SSHAC Level	• Document decision criteria and process
2. Develop Project Plan	• Includes project organization and all technical and process activities
3. Select project participants	• Includes all management, technical, and peer review participants
4. Develop project database	• Includes compilation of existing, available data • Can include focused new data collection • Data dissemination to all evaluator experts
5. Conduct Workshops #1 and #2	Workshop topics: • #1: Hazard-significant issues and available data • #2: Alternative models and methods
6. Develop preliminary SSC and GMC models and Hazard Input Document (HID)	• Preliminary SSC and GMC models developed in working meetings prior to Feedback workshop • HID provides input to hazard calculations
7. Perform preliminary hazard calculations and sensitivity analyses	• Intermediate calculations should display the impact of elements of the expert models • Hazard calculations should show the significance of all elements of the models • Sensitivity analyses should include the contributions to uncertainties
8. Conduct Workshop #3	• #3: Preliminary SSC and GMC model feedback • Review hazard sensitivity analyses • Interactive discussion of preliminary models between TI Teams and PPRP
9. Hold PPRP Briefing	• TI Teams present and discuss final SSC and GMC models
10. Finalize models in light of feedback	• Feedback provides a basis for prioritizing and focusing the finalization process • Implement expert combination process across all evaluator experts in SSHAC Level 4
11. Perform final hazard calculations and sensitivity analyses	• Should be conducted to develop the required deliverables for subsequent use of the hazard results
12. Complete draft and final project report	• Developed from documentation of the process, technical bases, and results produced throughout the project • PPRP observations of workshops and working meetings • Periodic written reviews from PPRP of key products and activities
13. Participatory peer review closure	• Written review of draft report • Final written review of technical evaluations and process used

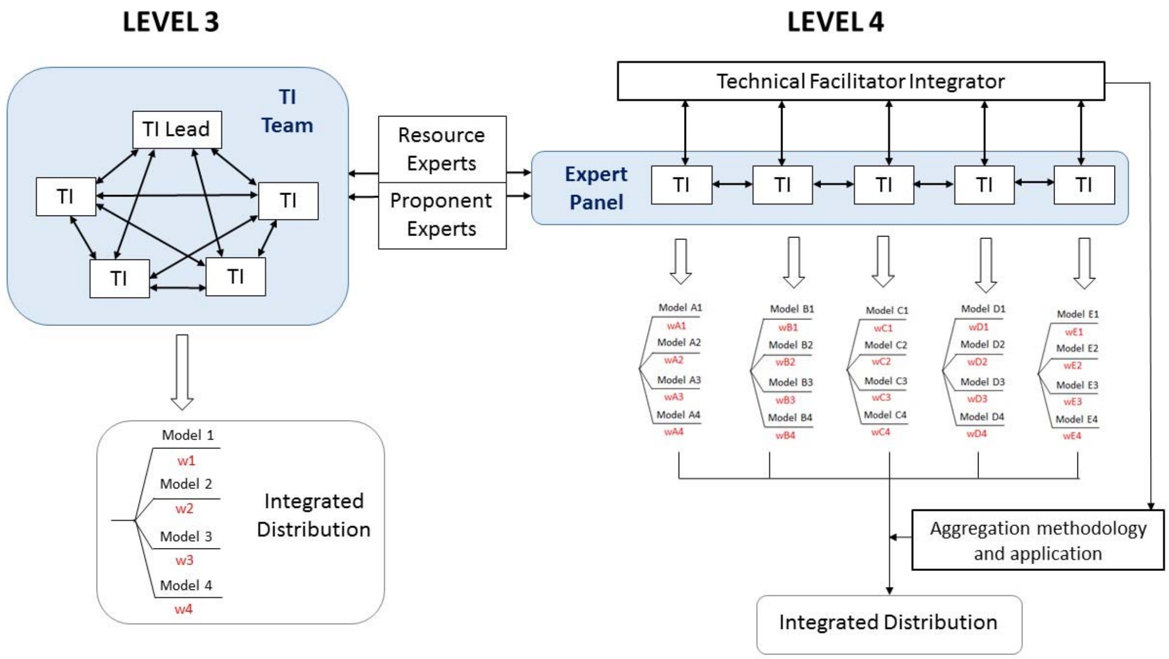

Figure 3-5 Organizational and structural differences between Level 3 and Level 4 studies. The role of the PPRP is identical in both cases and the same sequence of at least three formal workshops is also followed in both cases.

and range of technically defensible interpretations. The TFI is then charged with aggregating these individual logic trees into the final integrated distribution. The simplest way of doing this, which will often be the default in a Level 4 study, is simply to combine the logic-trees, with equal weighting, into a single overall logic tree. However, in a Level 4 study, the TFI has the responsibility to justify the weights assigned within the aggregated distribution.

3.1.5 Level of Effort

As can be discerned from the summaries of the key features and the details of the essential steps given above, the numbers of participants and workflow complexity increase significantly from SSHAC Level 1 to higher levels. Table 3-1 summarizes the key attributes that characterize each of the SSHAC levels, based on the experience gained from actual projects. The attributes are cumulative from left to right across the table (Level 1 to Level 3). Recognizing that the step from Level 2 to Levels 3 or 4 is large, the “Level 2 Augmentation Options” column is provided in Table 3-1 to indicate options for augmenting a Level 2 study—in order to increase the degree of regulatory assurance—without necessarily fully adopting all of the requirements of a Level 3 study. In exchange for the increase in regulatory assurance associated with the augmentation options, the resulting study would be expected to incur higher costs and longer durations. As discussed in Section 3.2, these types of trade-offs are expected to occur as the SSHAC level is selected for any given study.

To complete the descriptions of the various SSHAC levels and before moving to the discussion of the decisions involved in the selection of the SSHAC level for any given study, the various features of SSHAC Levels 1 through 4 are given in Table 3-3. The descriptions provided are

Table 3-3 Features of various SSHAC levels

SSHAC Level	Level 1	Level 2	Level 3	Level 4
Number of participants	• Project Manager • Small TI Team (~2) • PPRP (~2) • Hazard Analyst	• Project Manager • Small TI Team (>2) • PPRP (>2) • Resource Experts • Proponent Experts • Database Manager • Hazard Analyst	• Project Manager • Project TI • SSC & GMC TI Teams (greater than 5) members in each) • PPRP (~4-7) • Resource Experts • Proponent Experts • Database Manager • Hazard Analyst	• Project Manager • Project TI • TFI for SSC, GMC • SSC & GMC 5-10 Experts in each or 4-6 small expert teams • PPRP(4-7) • Resource Experts • Proponent Experts • Database Manager • Hazard Analyst
Interaction	• Limited, if any, contact with Proponent and Resource experts	• Proponent and resource experts contacted individually	• Proponent and resource Experts interact with TI Team in facilitated workshops • PPRP interacts with TI Team at WS3	• Proponent and Resource Experts interact with evaluator experts in facilitated workshops • PPRP interacts with Experts at WS3
Peer review	• Participatory	• Participatory	• Participatory	• Participatory
Ownership	• TI Team	• TI Lead • TI Team	• PTI • TI Lead • TI Team	• PTI • TFI • Experts
Transparency	• Dependent on documentation	• Dependent on documentation	• Interested parties can view interactions at workshops • Participatory peer reviewers observe workshops, participate in Workshop #3 • Documentation	• Interested parties can view interactions at workshops • Participatory peer reviewers observe workshops, participate in Workshop #3 • Documentation
Regulatory assurance	• Limited or no interaction with proponent and resource experts reduces confidence • Depends on TI Team and PPRP adherence to SSHAC guidelines and quality and completeness of documentation.	• Documented. Individual interaction with proponent and resource experts increases confidence over Level 1 • Depends on TI Team and PPRP adherence to SSHAC guidelines and quality and completeness of documentation	• Interaction among proponent, resource, and evaluator experts in facilitated workshops greatly increases confidence over Level 2 • Multiple feedbacks from PPRP enhances probability that SSHAC process is compliant with SSHAC guidelines • Documentation of evaluation and integration process by TI Team key to high levels of confidence	• Interaction among proponent, resource, and evaluator experts in facilitated workshops greatly increases confidence over Level 2 • Multiple feedbacks from PPRP enhances probability that SSHAC process is compliant with SSHAC guidelines • Documentation of evaluation and integration process by TI Team key to high levels of confidence

Table 3-3 Features of various SSHAC levels (Continued)

SSHAC Level	Level 1	Level 2	Level 3	Level 4
Cost	• Lowest because of limited number of participants	• Somewhat greater than Level 1 because of time required for interaction with proponent and resource experts	• Significantly greater than Level 2 because of larger number of participants and use of facilitated workshops • Greater likelihood that TI Team members are physically dispersed, leading to travel costs and costs for systems to remotely access data and information • Labor and travel costs associated with multiple TI Team working meetings	• Comparable to Level 3 in terms of use of facilitated workshops, numbers of participants, systems to remotely access data and information • Somewhat greater costs than Level 3 for working meetings because of need for TFI to interact individually with each expert or expert team
Duration	• Shortest because of limited or no interaction with proponent and resource experts	• Slightly greater than Level 1 because of time required for interaction with proponent and resource experts	• Significantly greater than Level 2 because of workshops, working meetings, briefings, multiple rounds of hazard calculations, and difficulties in synchronizing schedules with all participants	• Similar to Level 3 or longer because of workshops, working meetings, briefings, multiple rounds of hazard calculations, and difficulties in synchronizing schedules with all participants
Management challenge	• Least because of fewer participants and activities,	• Somewhat greater than Level 1 because of larger TI Team and the need to interact individually with proponent and resource experts whose schedules cannot be controlled	• Significantly greater than Level 2 because of increased number of participants and the need to issue contracts for each, logistics of organizing workshops and working meetings, and maintaining schedules over the duration of the project	• Comparable to Level 3 in terms of number of participants and the need to issue contracts for each, logistics of organizing workshops, and maintaining schedules over the duration of the project • Somewhat higher challenge due to the need to hold and schedule separate working meetings with each expert or expert team

clearly subjective and based on experience, but they are intended to give the reader an idea of the distinctions among the various levels. It is also true that as one moves from the lowest to the highest SSHAC level, the changes in the features define a spectrum and not necessarily sharp differences. The exception is the difference between Level 2 and 3 studies, but, as discussed above, augmentation options can be added to a Level 2 study that allow it to enjoy a higher level of regulatory assurance and, in the process, diminish the differences between the augmented Level 2 study and a Level 3 study.

3.2 Selection of Study Approach

At the outset of a hazard analysis, there are two important decisions that must be made. The first is the selection of the SSHAC Level at which the study will be conducted, and the second is the decision of whether the study will be a regional study or site-specific. Recommendations regarding these decisions are given below in Sections 3.2.1 and 3.2.2.

3.2.1 Selection of SSHAC Level

The first decision that must be made for a hazard study is the SSHAC level at which the project will be conducted. The attributes of SSHAC Levels 1 through 4 were discussed in the previous section. An important consideration in the selection process is whether or not there is an existing PSHA. If so, that study might be subject to revision, refinement, or replacement, depending on whether it is a regional or site-specific study and whether the previous study requires updating in light of new data, models, and methods that have become available from the time that the existing study was conducted. Section 4 of this NUREG provides the recommended methodology for assessing the need for updating an existing hazard study and the SSHAC Levels that should be used for the update, if it is required. In contrast, this section, regarding selection of a SSHAC level, will assume that an existing hazard study does not exist or that the existing study is found to be unsuitable for continued use.

The decision factors regarding the choice of SSHAC level are qualitative and subjective. These factors include the scope and the need for the hazard study and the risk profile of the facilities. The SSHAC guidance in NUREG/CR-6372 does not prescribe a formula for making this decision but identifies a number of factors to consider. The guidance in NUREG/CR-6372 (p. 24) suggests evaluating issues relative to several factors that underlie the need for the study, including

- the significance of the issue to the final results of the PSHA
- the issue's technical complexity and level of uncertainty
- the degree of technical contention about the issue in the technical community

NUREG/CR-6372 also identifies "decision factors" that include regulatory concern, available resources, and public perception. All of these factors play into a classic decision problem of balancing the costs associated with conducting a particular SSHAC level with the benefits of doing so. In such a decision process, the potential costs and benefits are first identified, and then the Sponsors assess the "value" of each cost and benefit (qualitatively or quantitatively) for the particular application being considered. Table 3-3 provides a summary of important attributes of projects conducted at the various SSHAC levels, based on experience. As discussed in Section 2.5, the most significant differences in most of the study attributes occur between SSHAC Levels 2 and 3, with much less difference between 1 and 2, or between 3 and 4. In addition, the largest differences in regulatory assurance lie between Level 1 or 2 studies versus Level 3 or 4 studies.

The features summarized in Table 3-3 are generic and not specific to any particular project location, facility type, or regulatory environment. Therefore, the second step in the decision process involves a consideration of the project-specific factors, such as

- safety significance of the facility (e.g., nuclear power plant, high-consequence dam, bridge, conventional building)
- technical complexity and uncertainties in hazard inputs
- regulatory oversight and requirements (e.g., quality assurance (QA) requirements, regulations and regulatory guidance in place, monitoring and audit)
- degree of public concern and oversight
- resource constraints (e.g., time and money)

These project-specific factors provide a basis for evaluating the relative value of the features identified in Table 3-3. For example, consider a study for a conventional building with limited public concern and oversight and constrained resources. In this case, the highest value would likely be assigned to the attributes of lower cost, shorter durations, and minimal management challenges. Lesser value would be accrued to transparency, regulatory assurance, and broader ownership of the hazard models and results. Conversely, consider a new nuclear power plant that is to be sited in an area of complex tectonics under heavy regulatory and public scrutiny. In this case, it is likely that the Sponsor of the hazard analysis would place high value on attributes such as participatory peer review, broad ownership, enhanced transparency, and higher levels of regulatory assurance.

Of course, many cases exist where the criteria are in conflict, and these will require a project-specific evaluation of the relative value of the various factors. An example is a study for a nuclear power plant sited in a country having very little regulatory oversight, high levels of public scrutiny, high levels of technical uncertainty, and severe resource limitations in terms of the available time to conduct the study. In this case, the Sponsor will need to assess the relative value of achieving an expedited schedule versus facing public opposition to the project or not achieving regulatory approval. These types of assessments of the relative value of various potentially conflicting objectives can be addressed systematically using tools advanced in the decision analysis community (e.g., Keeney, 1996).

In their considerations of the lessons learned from past hazard studies (Hanks et al., 2009, p.21) make the following recommendation:

> *"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."*

To the degree that such communication between the Sponsor and the regulator will clarify the positions of both parties relative to the decision factors discussed previously, this idea is endorsed. In the end, the decision regarding the SSHAC level rests with the project Sponsor, who must weigh his/her desire to minimize costs while maximizing benefits. Those studies that involve a broad Sponsor group benefit from having a range of perspectives brought to the decision process. Experience has shown that the SSHAC level decision made by a single Sponsor will require some level of explanation and defense, particularly within contentious and heavily regulated environments. The explanation will help those responsible for sponsoring the study understand what they are buying and those reviewing the study understand the factors that underlie the decision.

An example of this process that leads to the selection of a SSHAC level in support of regulatory decision-making is the recent response to the Fukushima Dai-ichi disaster. In response to the information requested in the 50.54(f) letter, the licensees of commercial nuclear power plants in the U.S. re-evaluated the seismic hazard at their sites consistent with present-day U.S. Nuclear Regulatory Commission (NRC) guidance. Accordingly, the licensees either relied on existing SSHAC Level 3 regional studies or conducted new site-specific Level 3 studies. Based on these actions, all nuclear power plants in the U.S. now have a SSHAC Level 3 study upon which decisions can be made regarding the seismic safety of the plants. As noted in NUREG–2117, the NRC makes no distinction between SSHAC Level 3 and 4 studies in terms of the regulatory assurance afforded by either level. As a result, in order to achieve the high levels of regulatory assurance needed for nuclear facilities (see Section 2.5) and to avoid some of the additional burdens associated with Level 4 studies (see Section 3.1), SSHAC Level 3 has gained considerable favor as the approach to conducting PSHA for nuclear facilities in the U.S. and in several other countries. Nevertheless, there may be situations in which a SSHAC Level 4 study is the most appropriate method to address the unique requirements or circumstances of a project.

With regard to new nuclear power plants, Regulatory Guide 1.208, “A Performance-Based Approach to Define the Site Specific Earthquake Ground Motion” (NRC, 2007), refers to the SSHAC process as providing an acceptable approach to assessing the seismic hazard at a site and defining seismic design criteria for new nuclear power plants. Likewise, ANSI/ANS-2.29-2008 refers to the SSHAC methodology as an acceptable approach to assessing seismic hazard for nuclear facilities in the U.S., and DOE–STD–1020–2012 (DOE, 2012b) endorses the use of the SSHAC approach for defining the seismic design of nuclear facilities owned and operated by the U.S. Department of Energy (DOE). Higher SSHAC levels are recommended for power reactors, although lower SSHAC levels may be justified for nuclear facilities having lower risk significance. A risk-informed methodology developed for the DOE for deciding on the appropriate SSHAC level to update an existing PSHA is given in Kammerer et al. (2017).

As discussed in Section 2.5, increased regulatory assurance is the primary benefit obtained by conducting a Level 3 or Level 4 study. However, it is very important to emphasize that adoption of a Level 3 or 4 process does not guarantee regulatory acceptance, even if the project fully conforms to the procedural requirements. On the other hand, it is reasonable to assume that adoption of lower SSHAC levels for safety-critical facilities will lead to increased review times by regulators and an increased burden on the part of sponsors to demonstrate that they have achieved all of the objectives of a SSHAC process.

3.2.2 Regional and Site-Specific Studies

Another decision factor at the outset of a SSHAC study is determining whether a regional or site-specific study is needed. A site-specific study is one that is done for a single site or facility at a particular location, while a regional study is one that is conducted over a geographically extended region that includes multiple sites. An example of a regional SSHAC Level 3 study was the central and eastern United States (CEUS) SSC study (NRC, 2012b), which included the entire CEUS east of the Rocky Mountains. This regional study was intended to provide an SSC model that could be used at multiple nuclear facility sites across the eastern half of the U.S.

Experience has shown that there are essentially two alternative methods for which the concept of a regional study has been implemented (with subtle variations within these two general approaches). In the first method, referred to herein as a phased regional study, a general SSC and/or GMC model is developed that is applicable for the entire study region. At a future date, site-specific refinements are made to this model to make it appropriate for site-specific use. An illustration of this process is given in Figure 3-6(a). The second method, herein referred to as an integrated regional study, incorporates a series of site-specific assessments that are conducted simultaneously within the regional study. In this integrated regional method, the SSC and GMC models share some common elements, such as the seismic source geometries and recurrence, but the details of the SSC and GMC models are constructed to include site-specific aspects [e.g., behavior of nearby faults, shear wave velocity and kappa[1] corrections to ground-motion prediction equations (GMPEs)]. An illustration of this process is given in Figure 3-6(b). The key difference between these two types of regional assessments is that the phased regional study uses general SSC and/or GMC models assuming that site-specific applications will be conducted at a later time. Presumably, these could be conducted under a lower level SSHAC process such as Level 2. The integrated regional model is developed for multiple sites in the region incorporating both regional and site-specific data, such that the model is immediately adaptable to all of the sites considered in the study region. An important additional feature of the integrated regional model is the incorporation of site-specific information that has traditionally been used for site response. In the integrated regional model approach, many aspects of the site response can therefore be included in the ground motion model. It may be possible for other sites to utilize much of the information developed by the integrated regional study at a future time, but that is not the primary purpose. Although both approaches provide an adequate way of incorporating available information and satisfying SSHAC goals, the choice of an integrated regional study or a phased regional study will depend on the needs of the Sponsor and status of existing SSHAC studies.

Naturally, the phased regional study, which results in general SSC and GMC models that are refined later (see discussion of refinement in Section 4), is the most efficient in terms of the initial duration and concentration of resources. However, if several sites are being considered, this regional study approach would likely also lead to the need for significant resources in terms of the time and costs associated with conducting multiple sequential site-specific Level 3 or 4 studies (Coppersmith and Bommer, 2012). Figure 3-6(a) illustrates how phased regional SSC and GMC models conducted at SSHAC Level 3 or 4 can be refined with site-specific SSHAC Level 2 studies conducted to incorporate local SSC and GMC information. The integrated regional study collects, evaluates, and incorporates site-specific information during the primary study and not as a later refinement; hence, the initial resource investment is greater, and the studies may take more time. However, because much of the SSC and GMC modeling is shared among the various sites being considered, it can also lead to considerable time and cost savings over the sequential site-specific SSHAC Level 3 or 4 studies at multiple sites (Coppersmith and Bommer, 2012). In the case where multiple nuclear facility sites in a region or country are being considered, there are many advantages of conducting regional SSC and GMC studies. These advantages include avoiding duplication of work on the earthquake catalogue, seismic source models, and candidate ground-motion models. Because many elements of the input to each site-specific PSHA would be commonly defined, each study can be expected to produce more stable results, and the bases for the hazard assessment are less likely to be challenged. Such consistency in the site-to-site models and hazard results can lead to efficiencies in the regulatory review process,

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[1]Kappa refers to the low strain, frequency-dependent diminution of ground motion amplitude that occurs in near-surface geologic materials (Anderson and Hough, 1984)

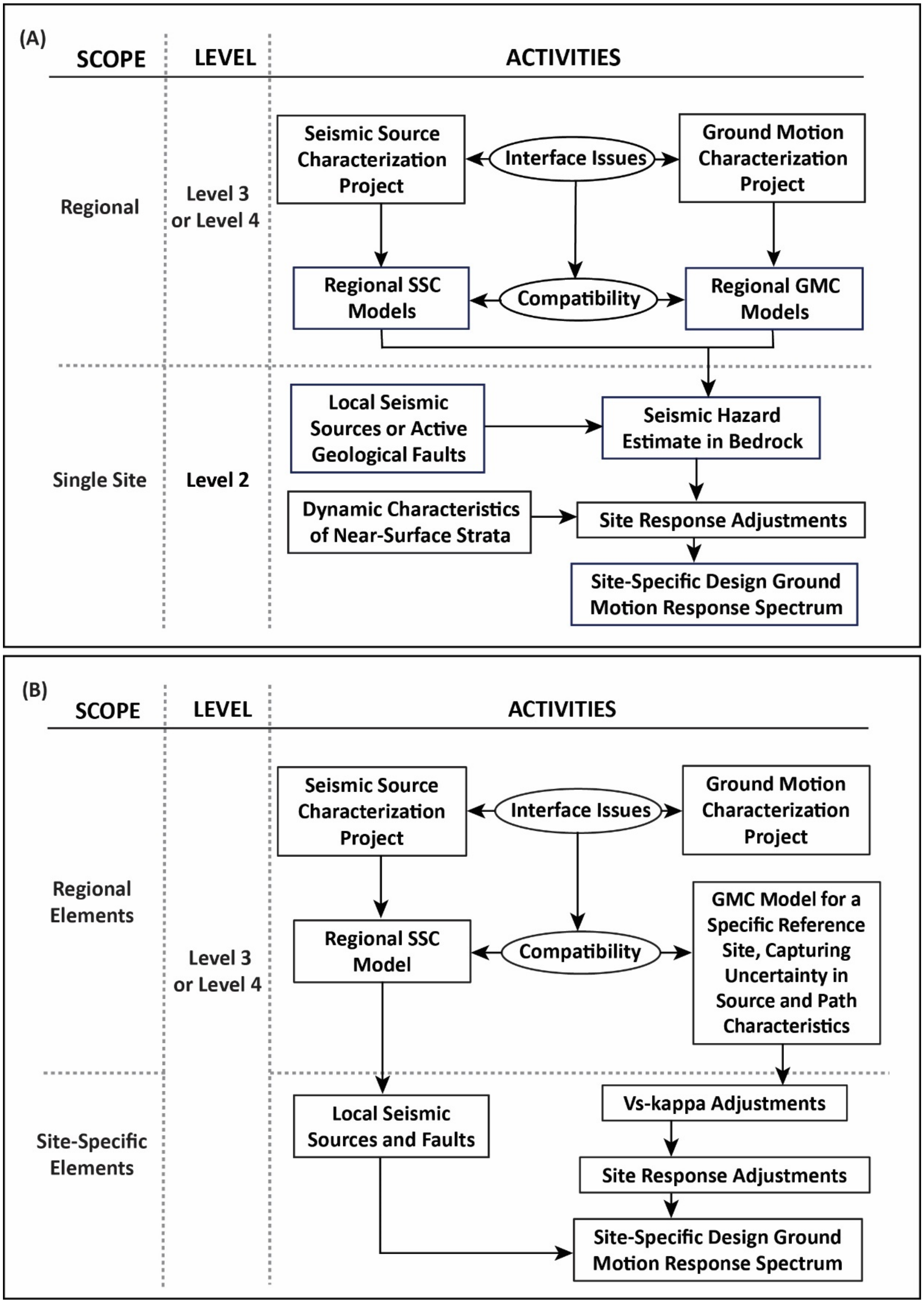

Figure 3-6 **Illustration of two types of regional SSHAC Level 3 or 4 studies. A phased regional study is illustrated in the first panel (A), and an integrated regional study is shown in the second panel (B).**

and potentially higher levels of regulatory assurance. In addition, better use can be made of the available resources, particularly the pool of expertise.

3.3 Development of Project Plan

The Project Plan is developed on behalf of the Sponsor of a SSHAC project and is the fundamental tool for documenting and communicating the specific elements and details of the SSHAC assessment process that will be used. It also provides a fundamental tool for the proper management and monitoring of a study to ensure that all procedural steps are taken and that they are conducted in a timely manner. Typically, the PM and the PTI develop the Project Plan so that roles and responsibilities of all project participants are defined, all programmatic and technical activities are properly and completely described, and the sequence and schedule for all activities and deliverables is defined. When the plan has been developed and approved by the Sponsor of the study, it should be considered to be "final" and subject to revision only in the unusual case of significant new information affecting the timing or resources required to conduct the study. When the PPRP members have been identified, it is recommended that the PPRP be provided with a copy of the Project Plan for their review. The goal of this review is to provide the PPRP with a detailed overview of the entire project and the approaches that will be taken to achieve the SSHAC goals, and to ensure that the PPRP agrees that the path set forth in the plan can be accomplished successfully. Likewise, the Project Plan should be provided to all participants as they are identified, as well as observers of the project such as regulators.

Acknowledging that project-specific applications may require additional information, the Project Plan should, at a minimum, include the following:

1. Introduction and Context of the Study

   This section should include a description of the context within which the study is being carried out, including the sponsors of the study, previous hazard studies and their applicability, and significant new data or developments leading to the need to conduct the study.

2. Objectives of the Study

   This section should include a description of the expected results of the study and the manner in which they will be used (e.g., design criteria, risk analyses). As applicable, the deliverables of the study should be described (e.g., types of ground-motion measures, annual frequencies of interest, or response periods of interest for the facility). The regulatory framework and the manner in which the study will be used to address applicable regulations and regulatory guidance should be discussed. If applicable, the discussion should also include a description of how the study will be used to address applicable public and programmatic concerns.

   A PSHA is always conducted for a specific purpose, ultimately linked to mitigation of earthquake risk to engineered structures or facilities. From the very outset of the project, at the planning phase, it is therefore strongly recommended to engage with the Sponsor to define the required deliverables. This will usually necessitate dialogue not only with managers from the sponsoring organizations but also with those who will make use of the output from the hazard calculations (see Section 3.3.1).

3. Selection of SSHAC Level

A description of the decision process for arriving at the use of a particular SSHAC Level should be provided. The discussion should include the decision criteria that were considered and the manner in which the criteria were evaluated. Due consideration should be given to the factors discussed above in Section 3.2.1, in addition to other project-specific considerations deemed to be important to the Sponsor. If applicable, consistency with regulatory guidance or requirements regarding the SSHAC Level should be summarized.

4. Project Organization

This section should define and describe the key participants in the project organizational structure including the positions, their functions, and the reporting hierarchy for the project. Section 2.6 of this NUREG provides examples of project organizational roles based on recent studies. Each of the functions should be described in terms of their roles and responsibilities within a SSHAC process, their scope of work, and the lines of communication that will be followed during the course of the project. The qualifications of the personnel selected to participate in the study should be summarized as well.

5. Project Activities

This section of the Project Plan describes the principal work activities that will compose the study. Task descriptions should be given for the essential elements of a SSHAC process. Depending on the SSHAC level, such elements should include

- description of the conditions under which the Project Plan would be updated
- as applicable, development of QA plans
- selection of project participants: PM, PTI, TI Leads (Level 3), or TFIs (Level 4), PPRP, TI Team members, Database Management team, hazard calculation team, and Specialty Contractors
- development of project-specific database, including the compilation and analysis of available data and plans for dissemination of the database to project participants
- new data collection and analysis activities (if planned) and description of their use in addressing technical issues
- description of plans for workshops, including their purpose, participants, timing, and expected products; includes the plans for the selection of Proponent and Resource Experts
- evaluation and integration activities, including expected working meetings, their focus, duration, and products
- plans for development of hazard input documents (HID) to provide input for preliminary feedback calculations as well as to transmit the final models to the Hazard Analyst

- hazard calculations and sensitivity analyses planned to provide feedback as well as arrive at the final hazard results.

- activities associated with developing a draft Project Report, planned review activities, and a final Project Report

- description of all planned activities for the PPRP, including the manner in which the PPRP will observe and review all key project activities during the course of the project, as well as review of the draft Project Report

6. Project Schedule

   This section should provide a discussion and depiction of the timing and duration of all project activities. It is also useful to display the relationships among the project activities (e.g., the ways that a given activity requires predecessor activities to be conducted and the successor activities that will use the results of each activity). The description of these activities will be found in the project activities section, but the purpose here is to show the overall flow, dependencies, and schedule of project activities.

7. Deliverables

   The Project Plan should describe deliverables in sufficient detail to provide confidence that the project will meet the objectives, and realistic cost and schedule estimates can be developed. This description will also provide a basis for users of the results of the study to understand exactly what they can expect the project to deliver.

3.3.1 Applications and Interfaces

Any site-specific PSHA is conducted for a specific purpose and application, whether related to the safety assessment of an existing facility or to provide (or confirm) the design basis for a new facility. Therefore, the project Sponsor commissioning the study should clearly agree with the PM and the PTI from the outset regarding the required outputs and deliverables derived from the PSHA. Examples of the potential deliverables for various applications of the seismic hazard results and the interfaces among the components of the PSHA are given in this section.

One of the most important specifications that should be established at the outset of a PSHA is the reference elevation at which the ground-shaking hazard is to be calculated, taking into account how the motions may be used in subsequent structural analyses and soil-structure interaction analyses (SSI). The goal is to develop final hazard curves that appropriately represent the uncertainty in the PSHA (source and ground motion characterization and site response).

In past practice, it has been common to specify the hazard at a reference rock horizon with specified geomechanical properties (e.g., shear wave velocity, density, and kappa) using GMPEs that do not separate the standard deviation into its component parts to remove the site-to-site component of the variability. Subsequently, the resulting motions are transferred to the target elevation (whether the ground surface or the base of a specific structure) using the results of the site response analyses. However, to avoid duplicating the variability in the reference rock motions and site amplification and to develop a complete distribution of final reference elevation hazard curves for subsequent seismic probabilistic risk analyses, an approach that incorporates the uncertainty in site amplification is needed. The development of site-specific hazard curves should utilize an approach that incorporates the site amplification and its uncertainty directly either through integration or convolution. These approaches for computing site hazard are described in detail in NUREG/CR-6728, “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines” (NRC, 2001). The explicit inclusion of site response as an integral element of the SSHAC process reduces the potential incompatibilities and inconsistencies between these two key parts of the PSHA. Figure 3-7 illustrates schematically how the rock GMPEs and site amplification functions (AFs) may be combined using a convolutional approach. Issues such as median motions, consistent with the target V_S-kappa conditions, single-station aleatory variability, and site-to-site variability, are all considered together within the context of the SSHAC process [see Rodriguez-Marek et al. (2014) and references therein.]

The Sponsor and the Sponsor’s engineers also need to specify very clearly their needs in terms of how the ground motions are characterized, including the specific definition of the horizontal component of motion. In this regard, there is no single correct definition that should always be adopted, because the important issue is that the definition is consistent with how the output from the PSHA will be used. The end-users need to be clear how the two orthogonal components from each accelerogram are treated in the fragility analyses or other applications, and then the output from the PSHA should be expressed according to the same convention (Baker and Cornell, 2006a). The most commonly used horizontal component definition in current ground-motion prediction equations is the geometric mean of the two horizontal components for each record or some variation of this definition. Empirical relationships can be used to transform spectral accelerations defined in this way to other component definitions (e.g., Beyer and Bommer, 2006; Watson-Lamprey and Boore, 2007).

Another engineering requirement that is best discussed at an early stage in a PSHA project is the damping ratios that may be required for the structural analyses. Predictive equations are invariably derived for spectral ordinates with 5 percent of critical damping. However, for many engineering applications, other values—both higher and lower than this nominal level—may be relevant. Response spectra for other damping ratios can be obtained by applying scaling factors to the 5- percent-damped acceleration ordinates, but these factors should be selected to reflect the influence of either magnitude and distance (Cameron and Green, 2007) or of duration (Stafford et al., 2008).

The engineering end users should also specify the range of oscillator frequencies at which the spectral accelerations are needed. Another very important parameter to define is the minimum magnitude to be considered in the PSHA integrations, M_{min}. The minimum magnitude is chosen on the basis of excluding contributions from frequent small-magnitude earthquakes that can increase the hazard of peak ground acceleration (PGA) and high-frequency spectral accelerations, but which produce ground motions having too little energy to be of engineering significance (Bommer and Crowley, 2017). The GMC subproject needs to be aware of this because the value may be smaller than the strict lower limit of applicability of the GMPE, in which case the GMC TI Team needs to consider the effects of the downward extrapolation of the predictive equations. Awareness of this issue may be heightened by the fact that some studies have shown that empirical GMPEs tend to over-predict ground-motion amplitudes at the lower magnitude limit of the dataset (Bommer et al., 2007; Atkinson and Morrison, 2009; Chiou et al., 2010). The development of the GMC model needs to be cognizant of all of these requirements. Because the GMC model will generally be constructed from existing GMPEs, albeit with extensive site-specific modifications, the SSC subproject needs to be aware of the variables that need to be defined for each ground-motion equation. This means that the style-of-faulting in each seismic source will generally need to be defined. Moreover, because most modern GMPEs use distance metrics defined relative to the extended fault rupture, even within area sources, the SSC model

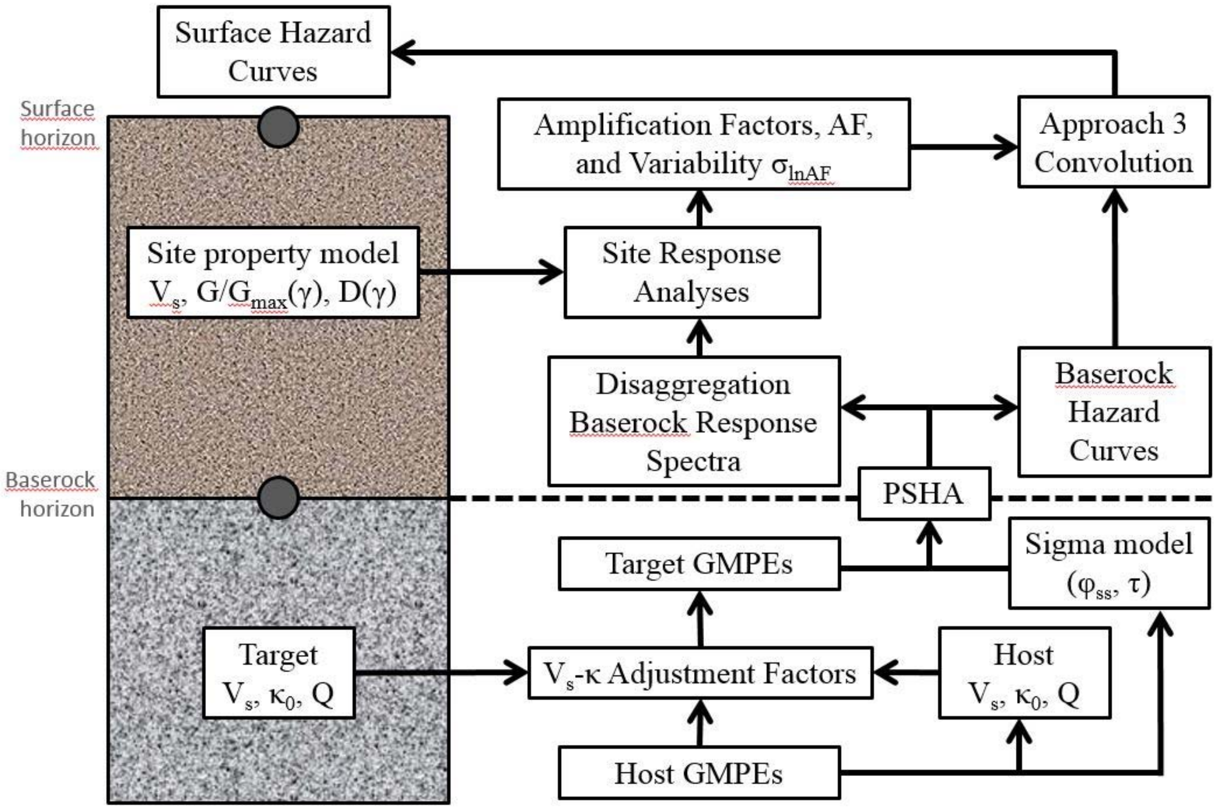

Figure 3-7 Schematic illustration of the incorporation of site response into PSHA following the Bazzurro and Cornell (2004a,b) approach, which is also referred to as Approach 3 in NUREG/CR-6728. Figure from Rodriguez-Marek et al. (2014). AFs refer to amplification functions.

will generally need to define focal depth distributions and the strike and dip of faults. The magnitude scale used is also an important interface between the SSC and GMC models; nearly all modern GMPEs use moment magnitude, **M**, hence the SSC model must also express recurrence rates in the same scale.

There are also features of the SSC model that need to be taken into account in the development of the GMC model. Other than the inclusion of different types of seismic sources—subduction interface, subduction in-slab, shallow crustal and deeper crustal—the clearest examples of SSC parameters that influence the development of the GMC model are the maximum magnitude (M_{max}) and the maximum distance over which the hazard integrations will be made to include all of the identified seismic sources.

Figure 3-8 provides a schematic illustration of how the key interface requirements arise within a site-specific PSHA, which serves to identify where the PTI needs to conduct early and sustained communication to ensure compatibility and consistency between the SSC and GMC sides of the analysis.

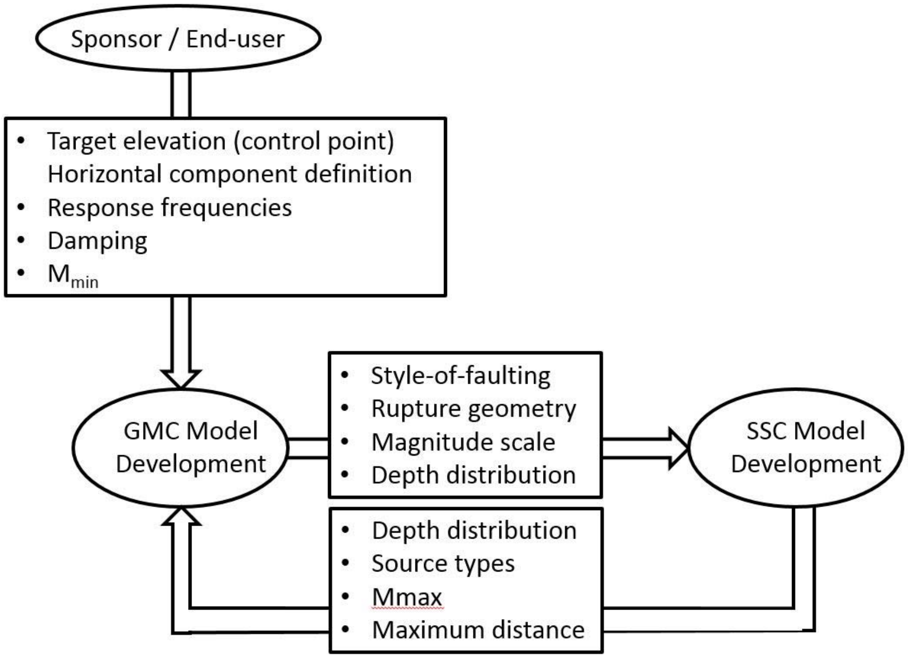

Figure 3-8 Schematic illustration of internal and external interfaces for a site-specific PSHA study.

3.3.2 Quality Assurance

When the outputs from a SSHAC hazard study are used in the design or assessment of a safety-critical facility or else underpin licensing actions for such a facility, adherence to appropriate QA requirements is indispensable. This section provides the context for how SSHAC studies fit within and contribute to successful QA programs. Indeed, a key motivation for the development of the SSHAC process was to bring structure and peer review to projects requiring expert judgment, and most of the applications of the SSHAC process have been conducted within the QA requirements for nuclear and critical facilities.

The successful application of QA processes relates to the manner in which a project is conducted, the quality controls that are applied to the inputs to the analysis, the assessments made, and the documentation of the results. Figure 3-9 shows in summary form the basic elements of a SSHAC process. The manner in which the SSHAC process can be used to address QA requirements relates to the (i) overall process, (ii) the data inputs to the process, (iii) the model-building and assessment activities, (iv) the hazard calculations, and (v) the documentation. Each of these aspects is discussed below with respect to the suggested approach to QA for a SSHAC project.

3.3.2.1 Overall SSHAC Process

Embedded in the PSHA process described in NUREG/CR-6372, NUREG–2117, in these guidelines, and in ANSI/ANS-2.29-2008 (American National Standard for Probabilistic Seismic Hazard Analysis) is the concept of “participatory peer review,” which is defined as both process and technical review of the PSHA, starting at an early stage and continuing through the life of a project. This participatory peer review is a fundamental element in ensuring the quality of the resulting PSHA product. Both ANSI/ANS-2.29-2008 and ANSI/ANS-2.27-2008

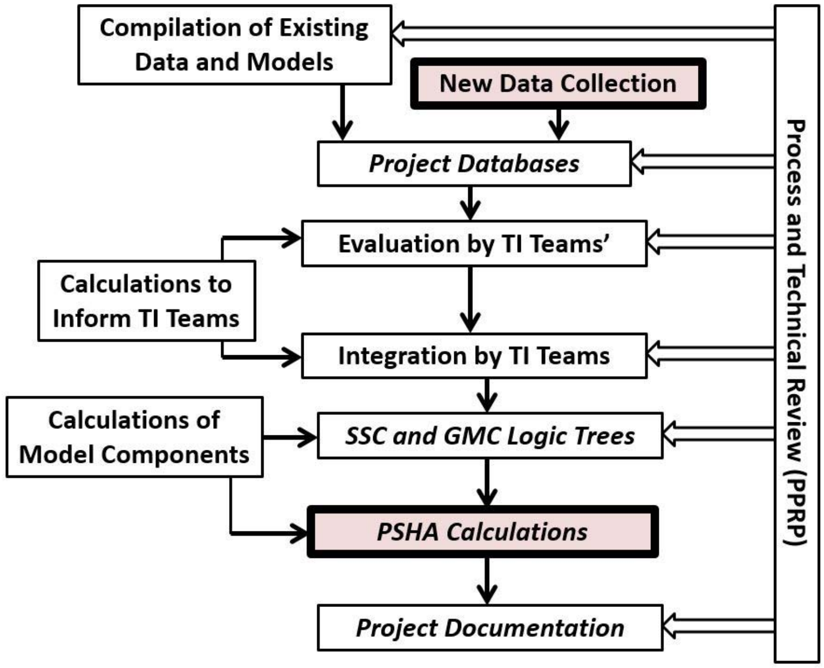

Figure 3-9 Key elements of a SSHAC hazard study and the role of the PPRP in providing at various stages. The two boxes highlighted are those where formal QA procedures must be applied. (adapted from Bommer et al., 2013).

(American National Standard–Criteria for Investigation of Nuclear Facility Sites for Seismic Hazard Assessments) were developed to be consistent with ANSI/ASME NQA-1-2008 Quality Assurance Requirements for Nuclear Facility Applications. Hence, following the guidance contained in NUREG/CR-6372, NUREG–2117, ANSI/ANS-2.29-2008, and ANSI/ANS-2.27-2008, will result in a study that satisfies the intent of national quality standards.

As noted many times in these guidelines, a fundamental component of the SSHAC process is the evaluation of the data, models, and methods that exist within the technical community. In the evaluation performed by the TI Team, the quality, relevance, technical basis, and uncertainties are assessed. Moreover, in the integration stage of the SSHAC process, the TI Teams build models that capture the center, body, and range of technically defensible interpretations. Therefore, it is the collective, informed judgment of the TI Team (via the process of evaluation and integration) and the concurrence of the PPRP (via the participatory peer review process), as well as adherence to the national standards described above (for the case of U.S. sites), that collectively lead to the assurance of quality in the process followed and in the products resulting from the SSHAC hazard assessment framework. In addition to the role of the PPRP in providing independent oversight of the process followed in the SSHAC study, assurance of quality also arises from the PPRP's technical review process to ensure that all assessments by the TI Team are technically defensible.

3.3.2.2 Data Inputs to the Process

As shown in Figure 3-9, the project database is comprised of two basic types of information: existing data and new data that are collected specifically for the project. The collection of new data for the project will require quality controls related to the field techniques being used (e.g., calibration of instruments; recording of raw data; documentation of field observations, checking of records, security protocols). These are typical QA requirements for field and laboratory data collection and lie outside of the SSHAC process. When the new data have been collected and are provided to the project database, the SSHAC process includes the consideration of the new data by the TI Teams—along with existing data. In this consideration, the TI Teams must be mindful of the quality controls utilized and any associated limitations in the use of the data that might be implied.

Within the SSHAC hazard assessment framework, the collection and evaluation of existing scientific information is performed with the aim of ascertaining the current state of knowledge regarding specific issues. The majority of existing information used in the conduct of a SSHAC PSHA will have been previously published in some fashion, usually within a peer review process. Thus, that information has already been reviewed and evaluated by the relevant technical community. Moreover, the data, models, and methods considered and used will also undergo what effectively constitutes peer review by the TI Team that is likely to be at least as rigorous as that conducted for journal publication. The systematic compilation of all pertinent information from the scientific literature (including specialized journals, technical reports, conference proceedings) or other relevant sources of information (e.g., databases or data sets, historical or archival documents) is a vital element in the conduct of a SSHAC PSHA study. Moreover, in some cases, nontraditional types of data that may be beneficial to the project may be available, such as unpublished project reports. It is important that such data not be dismissed without appropriate consideration, particularly in regions where data may be scarce.

In light of these ways in which information supporting the SSHAC study is evaluated prior to use in the PSHA, additional QA requirements are not needed for every data set considered during the SSHAC study. These conditions for how QA measures are applied in a SSHAC study arise because the SSHAC process itself provides a structured framework for reviewing and checking data and models evaluated by the TI Teams, both through the interactions of the TI Team as well as through the technical and process review by the PPRP. During the evaluation process, the evaluators are able to make an informed assessment of the quality of various datasets, whether or not those data were gathered within a formal quality program. In addition, because the set of information considered by the TI Team needs to be inclusive to capture a full range of data, models, and methods, a restriction should not be imposed regarding the use of data in cases where a formal QA program for the collection of field data outside of the project cannot be verified [e.g., if a quality control program cannot be verified for a U.S. Geological Survey (USGS) or university dataset]. Rather, the rejection of datasets in these cases could seriously diminish, instead of enhance, the process.

3.3.2.3 Model-Building and Assessment Process

During both the evaluation and integration phases of a SSHAC project, calculations or analyses may be conducted that provide insight to the TI Teams. In most SSHAC studies completed to date, hazard sensitivity calculations were conducted to help identify the hazard-sensitive issues as a way to help prioritize the subsequent data compilation process. Likewise, during the model-building integration process, various calculations may be requested by the TI Teams to assist them in determining the significance and relative impact of various technical assessments. For example, a Specialty Contractor may be asked to conduct calculations to exercise one or more models to see how the results or implications of those models might differ. Many calculations will be performed by TI Team members and Specialty Contractors throughout the project that inform the evaluation and integration processes being conducted by the TI Team, often using commercial off-the-shelf software, such as Microsoft® Excel or MatLab. Likewise, the

Hazard Analyst may conduct calculations of various model components (e.g., earthquake recurrence, median ground motion models) to provide insights into the relative importance of the components. While due diligence in checking all such calculations is clearly important, imposing formal QA requirements on such calculations is not necessary, because the results of these exploratory calculations and sensitivity analyses are all used by the TI Teams to provide insights, and none of them are used directly in the hazard calculations. Therefore, these calculations and analyses are just like any other data set or input that is considered by the TI Teams. In fact, formal QA requirements could actually demotivate exploratory analyses and investigations and stifle the evaluation and integration process unnecessarily. As such, as noted for input data in Section 3.3.2.2, there is no additional QA requirement for those analyses beyond the QA that governs the entire SSHAC process. That is, the evaluation and integration processes are conducted under the mindful watch of the PPRP, and the evaluation and integration processes are subject to complete documentation.

3.3.2.4 Hazard Calculations

Considering that the collection of new data is not a requirement of the SSHAC process and it is often conducted outside of that process, the only SSHAC-specific calculations for which formal QA will be required are the actual hazard calculations (Figure 3-9). This includes the software installation tests, validation, and verification, as well as clear and transparent procedures to check input and output files. Additional QA measures may be taken, such as spot checks by a second Hazard Analyst (possibly even using another PSHA code, provided due account is made for the inevitable differences arising from different approaches to the numerical integrations—see Thomas et al., 2010).

3.3.2.5 Documentation and Peer Review

As shown in Figure 3-9, all of the essential elements of a SSHAC process are subject to participatory peer review, and nowhere is the use of peer review to assure quality more important than in the development of the project documentation. The documentation should include not only a complete description of the evaluation and integration process followed, but also the complete description of the models built, the technical bases for the models, and the description and analysis of the hazard results derived. The PPRP's review of the project report results in written comments that the TI Teams addressed by revising the document. After the report is finalized and accepted by the PPRP, the PPRP issues a Closure Letter that states that the process followed in the project is consistent with SSHAC guidelines and that the technical assessments made are technically defensible. Such an endorsement by the PPRP, which follows their continual review of the project, from the time of its initiation, provides the assurance of quality that allows the results of the study to be used. Because the SSHAC process specifies a series of clear steps that must be followed for compliance with the chosen study Level, an effective mechanism to document continual PPRP review is for the PM and PPRP Chair to develop a checklist of the steps involving the PPRP. At the end of the project, the PPRP's concurrence that each step has been demonstrably and satisfactorily implemented would then provide confirmation that the process and technical review had been attained.

3.4 Selection of Project Participants

Given the roles that are essential to a SSHAC process (see Section 2.6) and mindful of the project-specific organization defined in the Project Plan, selection of project participants involves identifying and selecting candidates who will fulfill the specific roles required for the project. The PM is selected by the project sponsors and the selection of the PTI is made by the PM. In turn, TI Leads should be selected by the PM and the PTI in Level 3 and 4 studies. The TI Leads are responsible for selecting the TI Team members, with the concurrence of the PM and PTI. The chair of the PPRP is selected by the PM. Once selected, the PPRP chair and the PM are responsible for selecting the remaining members of the PPRP. All other project participants, including the Database Manager, Hazard Analyst, Specialty Contractors, Management Support Team, Resource Experts, and Proponent Experts are identified by the PM in consultation with the PTI and TI Leads.

It is useful to define a set of criteria against which candidates can be evaluated. These can start with general criteria, such as those shown in Figure 2-3, followed by specific criteria that relate to the project role being filled. As shown in Figure 2-3, which is based on experience on several SSHAC projects, four general criteria are worthy of consideration: (i) knowledge of PSHA, (ii) technical expertise in either SSC or GMC, (iii) the ability to provide an objective and impartial evaluation, and (iv) experience in previous SSHAC projects.

In addition to general selection criteria, the decisions regarding project participants can benefit from the identification of position-specific criteria that relate to the roles and responsibilities of the positions being filled. For example, as discussed in Section 2.6, the TI Lead and TFI roles typically entail facilitation and management experience, as well as technical expertise in the subject hazard area. The specific roles and responsibilities of the PPRP lead to the definition of a particular set of attributes that must be fulfilled for a candidate to be considered. Likewise, because the technical work that is performed by the TI Team is paramount to the success of the study, it is recommended that careful consideration be given to defining explicit selection criteria for a project based on the attributes given in Section 2.6. Because every SSHAC project is tailored to the specific site or region of interest, the selection criteria can also include experience and expertise in the geographic region or comparable locations.

Examples of specific selection criteria for members of a TI Team include the following:

- Earth scientist of high professional standing and widely recognized competence based on academic training and relevant experience. Tangible evidence of expertise, such as written documentation of research in refereed journals and reviewed reports is required.

- Understanding of the general problem area through experience collecting and analyzing research data for relevant earthquake studies in the region or similar tectonic environments.

- Availability and willingness to participate as a named TI Team member, including a commitment to devoting the necessary time and effort to the project and a willingness to explain and defend technical positions.

- Personal attributes that include strong communication and interpersonal skills, flexibility and impartiality, and the ability to simplify. Individuals will be asked specifically not to act as representatives of technical positions taken by their organizations but rather to provide their individual technical interpretations and assessments of uncertainties.

- Selection would contribute to a balanced team of experts with diverse areas of technical expertise, backgrounds, and organizational affiliations.

One advantage of establishing an explicit set of selection criteria—and informing the chosen individuals of those criteria—is that they provide a basis for evaluating the performance of the individuals during the course of the study and, if necessary, removing them from the study. For example, if selection criteria call for the willingness to commit the necessary time to the study and they are not willing or able to do so, grounds would exist to remove them from the study. Likewise, if they are not willing or able to provide independent assessments and play the role of an impartial participant, they should not remain in that role on the project.

It is recommended that a pool of candidates be identified based on general application of the criteria, followed by a selection based on a closer evaluation against the criteria. The typical number of participants fulfilling various roles is a function of the SSHAC Level and is discussed in Section 3.1. For example, the number of TI Team members in a Level 3 study is typically greater than five, and the number of PPRP members from four to seven. Based on experience, a five-member PPRP is effective.

3.5 Evaluation Process

As discussed in Section 2.3, the SSHAC process includes the evaluation process, during which data, models, and methods are compiled and evaluated by the TI Teams. This section describes the manner in which a project database is developed that becomes the subject of the consideration and evaluations, the dissemination of the database to the project participants, the collection of new data to add to the database, how the database evaluation process is documented, and the workshops that are conducted in Level 3 and 4 studies (or augmented Level 2 studies) as part of the Evaluation process. In this discussion of the Evaluation process, emphasis is given to SSHAC Level 3 and 4 processes but differences between the requirements for lower SSHAC Levels are noted.

3.5.1 Project Database

For the evaluation phase of a SSHAC project to be conducted properly, applicable data, models, and methods need to be evaluated by the TI Team. To do so requires the assembly of a project database that consists of the data to be evaluated. Having such a common database ensures that all members of the team (or teams, in the case of some Level 4 projects), will have access to the same data as they move into the construction of their models during the integration phase of the project. Also, because the TI Teams are expert evaluators of this information, they are able to make decisions regarding which data need to be compiled to address key technical issues, the quality and applicability of alternative datasets that exist within the technical community, and the degree of reliance that they will place on any given dataset to address the key issues of significance to their models.

As shown in Figure 3-4, although the development of the project database occurs from the beginning of the project, there are two key points in the project where the database provides important inputs to the deliberations of the TI Teams. The first is after Workshop #2 at approximately the beginning of the integration phase of the project. An Interim Database is made available to the TI Teams for use in the construction of the preliminary SSC and GMC models. At approximately the time of Workshop #3, prior to the finalization of the SSC and GMC models, the Final Database is made available to the TI Teams. Just as is the case for the other elements of the project, the project database will also be documented in the Project Report (see Section 3.10.2).

3.5.1.1 Compilation of Available Data

Compiling data for the project is critical to developing models that are based on the most complete and up-to-date information. For the purpose of SSHAC studies, data sources should include, as appropriate, available information from the following:

- professional literature
- data held in the public domain by groups such as government agencies
- private domain data developed as part of exploration activities or other projects
- available data in the academic sector and other research institutions
- site-specific data developed in the site vicinity (for site-specific studies)

Documenting this activity is important for demonstrating that efforts have been made to consider the range of views of the technical community. Data compilation is the shared responsibility of the TI Teams, who identify the data that they would like to be included in the project database, and the Database Management team, which is responsible for compiling the data and making it available and accessible to the project. Data compilation should begin at the time of project authorization, become more focused with the conduct of Workshops #1 and 2, and continue to the point that the final models are developed. This task begins with specification by the TI Teams of the data that they think they will need. The project database is augmented based on data needs identified at Workshop #1 on Significant Issues and Available Data (Section 3.5.4). Likewise, discussion of alternative models and methods in Workshop #2 by Proponent Experts will also lead to the identification of additional information to be added to the project database (Section 3.5.5). This augmentation continues during the course of the evaluation process and model development. Where appropriate, data should be placed in formats that allow them to be readily usable by the project participants. For example, mapped information can be entered as layers in a Geographic Information System (GIS) format system.

As the project progresses and assessments are made, the database management activity should include preparation of derivative maps and products that are directly applicable to the hazard analysis (e.g., seismicity maps). Additional analysis may also be necessary to provide the information and analyses that the evaluators need for their assessments. For example, maps of various geologic characteristics may be geo-referenced and superimposed at the request of the TI Teams. Likewise, spatially distributed data may be plotted to assist with interpretation. As part of the project database, a comprehensive bibliography of applicable literature should be compiled for the evaluators to use, as well as to provide documentation that the evaluators had knowledge of the literature at the time of their assessments. The documentation of the evaluation process is discussed further in Section 3.5.2.

3.5.1.2 Collection of New Data

A distinction is made here between data compilation and data collection. As discussed in Section 3.5.1.1, data compilation involves the assembly of all pertinent data that exist at the time a hazard analysis is conducted. Compiled data are entered into the project database and form the basis for the Evaluation and Integration processes. Data collection involves conducting new scientific studies beyond those that are available in the technical community. In most cases, new data collection activities for a SSHAC project are highly focused on issues of importance to the hazard analysis and are specifically designed to reduce uncertainties in the key inputs to the hazard analysis. Moreover, these studies are completed in a timeframe that allows for their use in the hazard study. Typically, new data collection activities are conducted by a combination of external contractors (e.g., those drilling boreholes and collecting shear wave velocity data) and members of the TI Teams (e.g., conducting Quaternary geologic investigations). In all cases, the studies conducted are those that have been identified and recommended by the TI Teams as having the potential to reduce uncertainties in key aspects of the SSC and GMC model inputs.

Although the SSHAC guidelines do not require that new data be collected, new data could significantly refine key uncertainties in the hazard inputs. An advantage of a well-structured SSHAC process is that it can be used to identify specific data-collection activities that have the highest potential to reduce the most hazard-significant uncertainties. One of the first steps in a SSHAC process is the identification of hazard-significant issues and the data that are available to address those issues (Section 3.5.4, Workshop #1). If significant data gaps exist, new focused data collection efforts can be considered. Geological data collection and analysis can include field studies, paleoseismic investigations, tectonic geomorphic mapping, geophysical studies, and dating of deposits and surfaces. Seismological investigations can include the collection of historical information related to pre-instrumental earthquakes, the collection and reprocessing of seismograms from the early instrumental era, relocation of earthquake hypocenters, the use of improved velocity models and advanced algorithms, and the installation of additional instruments. Strong-motion data collection and processing activities also can include instrumentation of the site or region (even weak-motion recordings from the site of interest can be of great value) and the geotechnical characterization of the site and recording stations as well as testing of predictive equations using local strong-motion datasets and intensity observations.

Such new data collection activities are important because the expansion of datasets can improve the uncertainty estimates. While new and higher quality data can lead to reductions in the uncertainty of a parameter or model, it is important to note that new data may instead reveal that the prior estimates of uncertainty were, in fact, too small. Thus, the inclusion of improved and expanded data in the analysis leads to a more robust understanding of the center, body, and range of technically defensible interpretations.

Because uncertainty will always be present to some degree, it is very important to capture in the assessment. The SSHAC process is designed to assist the analyst in capturing the state of knowledge and associated uncertainties regarding the seismic hazard at a given location at a given point in time. Therefore, multiple-expert assessment should only be used as a substitute for data collection for those cases where model parameters or other key values cannot be derived or measured from data collection within the time and budget resource constraints of a project.

Acknowledging the benefits of new data collection, a trade-off exists between the time and money resources required to conduct new data collection activities and the potential for uncertainty reduction. Situations will occur where pressures of budget and schedule preclude acquisition or collection of new data. Nonetheless, attention should be paid to the minimum data collection requirements specified in regulatory guidance such as Regulatory Guide 1.208 (NRC, 2007) and applicable standards (e.g., ANSI/ANS-2.27-2008).

Any new data collection activities should be identified early in the project, evaluated for their potential impact on the hazard results and associated uncertainties, and completed in a timely manner for use in the technical evaluations. Typically, this would mean that the activities should be completed prior to Workshop #3 on Feedback and certainly no later than the time that the models are finalized following Workshop #3.

The PTI should take the responsibility for identifying any new data collection activities in consultation with the PM, TI Team members, and possibly the PPRP. Of course, the Sponsor of the study ultimately makes the decision regarding whether or not such activities should be carried out because of the need for additional resources. If a decision is made to proceed, the PTI and applicable TFI/TI Leads should assume responsibility for completing the studies in a timely manner and for overseeing the incorporation of the results into the project database.

3.5.1.3 Data Dissemination

Given the likelihood that the SSHAC participants may be geographically distributed (especially for larger Level 3 and Level 4 studies), a key part of the database management activity is the dissemination of the database in an efficient and timely manner for use by all. Various alternatives exist for data dissemination, including secure project websites and on-request distribution. Recent projects have included the development and use of project websites as a means of making the project database available, hosting team webinars, and maintaining the project schedule. Larger database files, such as GIS map layers, are usually not amenable to distribution via a website due to their size, but the Database Manager can use the site for receiving requests for these datasets and make arrangements for transferring the files via secure File Transfer Protocol (FTP) sites. Regardless of the mechanism chosen, it is imperative that the TI Team members have ready access to the data for their evaluations and model building at any time and from any location. As will be discussed in Section 3.6.1, the real “work” the evaluators perform occurs between the workshops. Multiple “working meetings” are held so that the evaluator teams can review the data and make their assessments. For this to work efficiently, the Database Management team should interact with the TFI/TI Leads to develop a database structure and index that is appropriate and intuitive for the users. In addition, the Database team should be prepared to develop any derivative data products that are requested, such as combinations of GIS data layers or sorting of the data according to attributes the evaluators specified. Often, this will need to be conducted in “real-time” during the working meetings to inform the evaluation process.

3.5.2 Documentation of Evaluation Process

It is important for the reader of a project report, especially one reading the report some years after the project was completed, to understand fully what data were considered at the time of the study and how those data were used by the TI Teams in their evaluations. This includes the data that were made part of the project database and new data collected as part of the study. A summary of the project database should be included or appended to the project report, or reference should be made to a separate document (see Section 3.10.2). The database description should include the metadata that allow for an understanding of the specific elements of the database. In some cases, the project database will be considered a deliverable of the project and will be expected to be in a format for subsequent use and perhaps continued update by the project Sponsor(s). Release of the database will be project-specific and should be specified in the project contract terms.

It is important to document and inventory all data that were considered in the course of the project, including those data that were not used. For those data that were relied upon, it is important to also document the manner in which those data were used. A useful example of this type of documentation was developed as part of the CEUS-SSC project that involved the use of Data Summary and Data Evaluation tables (NRC, 2012b). The tables cite documentation of all data that were considered by the TI Team members in the evaluation, those data that were relied upon in the expert assessments, and the degree to which the data were relied on in the assessments. Other projects have used other approaches to document the data that were considered by the experts. For example, GMC projects, which use data, models, and methods very differently, may find it more appropriate to use other forms of documentation, such as “white papers" that summarize the data, models, and methods that pertain to a particular technical issue or approach. In any case, the documentation should describe the full suite of information available at the time of the study and should also detail the complete set of information that is used in developing the model along with its use and the degree to which it was relied upon.

3.5.3 Conduct of Workshops

Workshops play a vital role in SSHAC Level 3 and 4 processes and, when exercised, to augment a Level 2 study. Workshops are typically held in a venue that allows for participants and observers (typically 25 to 50 people). The room is configured to emphasize the participation of the TI Teams and other presenters (e.g., Resource and Proponent Experts) and to allow for the close observation by the PPRP. They provide opportunities for key interactions to occur; for models and interpretations to be presented, debated, and defended; and for Sponsors and reviewers to observe the progress being made on the study. As will be discussed next, however, they are not the place where models are developed and technical assessments are made. Those activities occur between the workshops.

The workshops are opportunities for outside participants to inform the TI Teams, for reporting the progress to date, and for identifying the issues still to be addressed. The workshops are also important because they allow for the process of assessing the range of technically defensible interpretations to be conducted formally and under observation. The workshops are typically 3 to 5 days long and usually divided between the SSC and GMC.

It is important that the best possible use be made of the available time. For this reason, the TI Leads should clearly brief the speakers on the scope and conduct of their presentation. The objective of this briefing is to ensure that the presentations clearly target the topic assigned and are focused on information that is relevant to the seismic hazard assessment. All of the presentations should be appropriate to the particular workshop and its associated theme. It is often useful for the TFI/TI Lead to provide the speakers with a list of questions or topics that the speaker is expected to address. These questions also help focus the speaker on aspects of the data, model, or method that the TI Teams need to understand and to help focus subsequent discussion.

The workshops also provide an appropriate opportunity for the technical leaders to remind the evaluators of the importance of being aware of expert judgment issues and the importance of avoiding these biases in their assessments (see Section 2.4). These issues may be raised at Workshop #1 so that the participants are aware from the start of the project; however, the time when they most need to be reinforced is Workshop #2, prior to the model-building process by the TI Teams.

The workshops provide the primary opportunity for the PPRP to observe and interact with the project participants. This leads to particular consideration of how to ensure that the PPRP engages most effectively at the workshops. All members of the PPRP should be present at all project workshops, but for practical reasons this may not always be possible. For this reason, a quorum may be established for the PPRP on each project, but with the proviso that at each SSC or GMC workshop, at least some of panel members who are experts in the respective areas should be present.

Although during the formal proceedings of Workshops #1 and #2 members of the PPRP act as observers and do not participate in discussions, it is important that they are given adequate opportunities to raise issues and pose questions to the evaluators in a timely fashion.

These opportunities can be created in a number of ways, including the following:

- opening the floor to observers to make comments at end of each day of the workshop

- holding informal debriefing sessions between the PPRP and key project participants (PM, TI Leads and PTI or TFIs and PTFI) after the close of each day of the workshop

- extended debriefing meeting between the PPRP and key project participants after the close of the workshop.

In many cases, discussion at the end of each session or in a daily debriefing have allowed issues to be addressed and resolved during the course of the workshop. Written reports from the PPRP to the PM should be provided after each workshop, and these provide the TI Teams with information to be taken into account as the work progresses. The TI Leads should respond in writing to the PPRP comments in order to document that the PPRP comments were clearly understood and to describe how the project or the TI Teams will address these comments.

Workshop #3 is important in that it provides the first opportunity for all participants, including the PPRP, to see the full preliminary hazard model (see Section 3.6.2). After the workshop, the PPRP's next task is reviewing the draft of the SSHAC report. It is problematic if serious technical challenges arise during the review of that document. However, there is greater risk of this occurring if the PPRP does not have ample opportunity to raise questions and concerns at Workshop #3. For this reason, it is recommended that at Workshop #3 the PPRP be relieved of their observer status and allowed to participate directly in discussions and ask questions regarding the technical justifications for the preliminary models developed by the TI Teams. In this way, all issues can be raised and thoroughly discussed before the TI Teams finalize the model and draft the SSHAC report. It is beneficial if the PPRP's questions and concerns are kept in mind while documenting the study. Likewise, as discussed in Section 3.8, a PPRP briefing is held after the finalization of the models but prior to the development of the draft project report. Experience shows that the efficiencies gained far outweigh the added costs because of the PPRP's improved understanding of the final model. It can also reduce questions and concerns being raised by the PPRP in their review of the draft project report.

Another point regarding the workshops concerns the independence and impartiality of the PPRP, particularly the perception of this objectivity by observers. Given the relatively small and close-knit nature of the specialist technical communities in the earth sciences, it is very likely that members of the PPRP and the technical staff on the project will know each other and may even be working together on other endeavors. Therefore, there should be no unrealistic expectations about separation and distance. Rather, all members of the panel should be vigilant about not being drawn into participating in the actual technical assessments and must refrain from using their role as a reviewer to improperly influence the outcome. To address this potential for reviewer bias, it may be wise to address outright any particular issues that may appear to contribute to conflict of interest at the outset of the project to provide transparency. The PPRP is fundamentally a review panel, and it is the responsibility of the chair of the panel to ensure that the interactions at the workshops maintain that function.

The ground rules for the workshops define the roles of all workshop participants, and they need to be established and presented at the beginning of each workshop so that the attendees understand and can fulfill their particular roles. The ground rules also need to be consistently enforced by the PTI, TI Leads, and PPRP Chair. Although additional workshops and gatherings (e.g., field trips) can be conducted for any particular project, a minimum of three workshops are required for Level 3 and 4 studies, and Sections 3.5.3, 3.5.4, and 3.5.5 discuss the required workshops and their focus.

3.5.4 Workshop #1—Significant Issues and Available Data

The hallmark of a SSHAC process is the interaction that occurs in a series of structured, facilitated workshops. Each workshop has a specific focus and goal, and each requires that particular work activities have been conducted prior to its occurrence, and certain work activities will occur following. For SSHAC Level 3 and 4 projects, a minimum of three workshops are held: Workshops #1 and #2 occur during the Evaluation process and Workshop #3 during the Integration process.

The goals of Workshop #1, “Significant Issues and Available Data,” are (i) to identify the technical issues of highest significance to the hazard analysis and (ii) to identify the available data and information that will be needed to address those issues. Because this is the first of a series of workshops, it is valuable to begin the workshop with a summary of the entire project and its objectives. This should include the expected deliverables and pertinent related information (e.g., the range of annual frequencies of exceedance of interest, the timeframe of interest, etc.).

Workshop #1 is the first opportunity for the TFI/TI Leads to establish the ground rules for all of the workshops, including a discussion of the potential for cognitive bias (see Section 2.5). The workshop should begin with a clear definition of the goals of the workshop, an explanation for the process that will be followed, and a definition of the roles of all those who attend.

Typically, those who attend the workshops include:

- Project Sponsor(s)
- Project Manager
- PPRP
- Project TI [Level 3 or 4]
- TI Teams, including the TI Leads/TFIs
- Database Manager
- Hazard Analyst
- Specialty Contractors, as appropriate
- Regulators
- Resource Experts (primarily Workshop #1)
- Proponent Experts (primarily Workshop #2)

First and foremost, the workshops are held to provide information to assist the TI Teams in their technical assessments. Therefore, it is essential that they are given ample opportunity to ask questions and to thoroughly understand what is being presented. All other workshop attendees are “observers,” except as their participation is required. For example, at Workshop #1, resource experts are asked to present and discuss their databases. Questions following each presentation should come from the TI Team members and, if time allows, from other Resource or Proponent Experts. The TI/TFI Leads are responsible for ensuring that the agenda is adhered to and all presentations are allowed to occur in an equitable manner. It is suggested that a short period of time to be set aside at the end of each day for any of the observers at the workshop, including the PPRP and regulators, to make statements or to pose questions.

The workshop ground rules should be repeated at the beginning of all subsequent workshops because the workshop attendees will change with each workshop.

Prior to Workshop #1, the TFI/TI Leads may conduct exploratory hazard studies and sensitivity studies to assist in identifying hazard-significant issues, based on available data. The sensitivity analyses should be presented and discussed at the workshop, and they can be supplemented with considerations of hazard sensitivity at other sites and the issues that have generally been shown to be important, based on experience. The purpose of identifying the hazard-significant issues first is to provide a basis for focusing and prioritizing the database compilation efforts. Experience has shown that technical experts are usually eager to discuss technical data, but they often require focus on the specific data that address the issues most important to a hazard analysis. This part of the workshop should end with a listing of the hazard-significant issues to be addressed and the types of data that can best address the issues.

The second part of Workshop #1 should focus on the data that are available to address the hazard-significant issues identified in the first part of the workshop. The discussions of the available data should be through a series of presentations by Resource Experts who have developed specific datasets. For example, the Resource Experts could discuss available seismicity catalogs, studies of historical earthquakes, regional and local geophysical data, geologic studies of tectonics, applicable ground-motion recordings, geotechnical site data, and the like. These Resource Experts should come from a wide range of disciplines within the technical community. The goal of this part of the workshop is to assist the TI Team members in identifying the data and information that should be made part of the project database and in understanding the attributes of the available datasets (e.g., the precision, weaknesses) to the extent possible. Therefore, it is important to instruct the Resource Experts to discuss not only the data but the accessibility of the data for use on the project. For example, are the data publicly available? How can they be accessed (as reports, publications, etc.)? The experts can also each be asked to provide their knowledge of additional available data—beyond that given in their presentations—which the project should also consider. It can be useful to request that the Resource Experts provide reference lists of data with which they are familiar as part of their presentations. During the course of the data identification process, the TI Teams may identify data gaps that can be filled with new data collection efforts within the time and resource constraints of the project. If data collection activities are contemplated or have been initiated at the time of the workshop, they should be described in detail at this workshop.

One concern that often emerges in the first workshop is the tendency for the Resource Experts to move from merely a presentation of available data into discussions of their interpretations of the data and the models that they have developed from them. In most Earth science problems, no clear-cut boundary exists between what is called "data" and what is called "interpretations." For example, seismic reflection "data" can mean the profiles devoid of any interpretation of reflectors or can include the interpretation of reflectors (e.g., faults, folds, or beds). The point here, from the standpoint of the SSHAC process, is that the forum for hearing and debating alternative interpretations of the data is Workshop #2 and that Proponent Experts will perform. So the TFI/TI Leads should attempt to limit the discussions at Workshop #1 to the available data, acknowledging that some discussion of data interpretations will inevitably occur.

Workshop #1 is typically structured such that the SSC and GMC TI Teams conduct their workshops separately but hold a common session with both teams to discuss topics of common interest. For example, the SSC workshop might be scheduled for a Monday through Wednesday, and the GMC workshop Wednesday through Friday. On Wednesday, a session can be attended by both TI Teams, which provides an important opportunity to discuss interface issues. For the joint session, topics such as the sensitivity analyses conducted to identify significant issues and data types important to both teams could be discussed (e.g., the earthquake catalog, types of seismic sources, and styles of faulting). In any case, it is imperative that communication occurs between the TI Teams—whether by conducting joint workshops or otherwise—to ensure consistency among the SSC and GMC subprojects.

As with all workshops, it is expected that the PPRP will issue written comments after the workshop that summarize their views of the degree to which the workshop accomplished the stated goals and consistency with the SSHAC process. The TI Leads will respond to the comments in writing, and they will become part of the project record.

3.5.5 Workshop #2—Alternative Models and Methods

The goals of Workshop #2, "Alternative Models and Methods," are (i) to present, discuss, and debate alternative models and methods pertaining to key technical issues; (ii) to identify and debate the technical bases for the alternatives and to discuss the associated uncertainties; and (iii) to provide a basis for the subsequent development of preliminary hazard models that consider these alternative viewpoints. The workshop also provides an opportunity to review the progress being made on the database development and to elicit additional input, as needed, regarding this activity.

Consistent with the evaluation phase of a SSHAC process during which the TI Teams evaluate data, models, and methods, Workshops #1 and #2 play important roles. A key attribute of Workshop #2 is the discussion and debate of the merits of alternative models and methods that pertain to key technical issues. Proponent Experts should present their models and methods in light of the technical support for them, given existing information. Presentations of alternative viewpoints on the same topic should be juxtaposed, if possible, and the TFI/TI Lead should facilitate discussion with a focus on implications of the inputs to the hazard analysis (not just on scientific viability) and on uncertainties (e.g., what conceptual models would capture the range of interpretations and the relative credibility of the alternatives). For example, Proponent Experts might speak to the technical support of their models to the location and size of a significant historical earthquake, or alternative methods for correcting GMPEs to take into account region-specific crustal properties. Because not all Proponent Experts advocating alternative viewpoints may be able to attend the workshop, the TFI/TI Leads should be sure that the models and methods of Proponent Experts not in attendance at the workshop are summarized and discussed. If feasible, the TFI/TI Lead should present those viewpoints at the workshop so that an opportunity exists to present, challenge, and defend them. This will help assure that all viewpoints are ultimately considered.

In the spirit of capturing the spectrum of thinking across the entire technical community, a goal of this workshop is to provide an effective forum for the exchange of ideas. More importantly for the SSHAC process, the workshop provides a unique opportunity for the TI Team to begin their consideration of the range of models and methods held by the larger technical community. Therefore, they should strive to not only understand the alternative interpretations, but also the degree to which each model or method is supported by the available data. The Proponent Experts should be asked to be prepared to discuss the uncertainties in their interpretations, the strengths and weaknesses in their arguments, and their view of the degree of support that their interpretations have within the larger technical community. It is often useful for presenters to be provided with a list of questions the TI Teams developed to focus the presentation on areas of interest to model development.

A role of the TFI/TI Leads should be to provide support, as needed, to Proponent Experts to ensure that interpretations are not judged on the basis of presentation skills. Proponent Experts should be encouraged to interact among themselves within the workshop, as facilitated by the TFI/TI Lead. For example, discussions of alternative models of the seismic potential of a particular fault or seismic zone might be presented and a facilitated discussion might occur with the TI Team regarding the future earthquake potential of the zone and the technical support for each model. Experience has shown that asking the Proponents to consider the views of others in the community can encourage useful discussion.

As with all workshops, it is expected that the PPRP will issue written comments after the workshop that summarize their views of the degree to which the workshop accomplished the stated goals and consistency with the SSHAC process. The TI Leads will respond to the comments in writing and they will become part of the project record.

3.6 Integration Process

As explained in Section 2.3, the second phase of a SSHAC process is the integration phase, which consists of building SSC and GMC models that form the basis of the PSHA calculations. This phase will include multiple working meetings, during which the TI Teams will make their assessments and construct their logic trees and other elements of the SSC and GMC models. Two rounds of model-building will occur: the first results in the preliminary models, which are presented and discussed in Workshop #3 in a SSHAC Level 3 or 4 process; the second results in the final models that ultimately provide the inputs to the final hazard calculations.

It can be stated with some confidence that very rarely will the evaluation phase identify a set of existing models that can provide all the input to the PSHA, requiring only that the experts select from among these models to populate the logic-tree branches and assign weights to these branches in the integration phase. For SSC projects, it is virtually never the case that, in the technical literature, sufficient and adequate seismic source models are available for the specific location under study, although pre-existing models of various source components may exist. So, in practice, any SSC project will build new models describing the location of seismic sources and their recurrence characteristics. For GMC projects, one might expect that the process may only involve selection of published GMPEs, but in practice this is unlikely to be the case. With the exception of a few geographical regions for which there are several GMPEs already published, GMC logic tree development will require bringing in models from other host regions and applying adjustments either to render the models more applicable to local conditions or simply to make the models compatible in terms of predictor variables. Therefore, even if the TI Teams begin with the intention of only using published prediction equations, these are likely to undergo transformations that—in effect—render them into new models. For low-seismicity regions, models will often be brought in from other regions because of the lack of an indigenous strong-motion database. If stochastic GMPEs are adopted from another stable region, such as Eastern North America, then consideration should be given to the benefit and drawbacks of adopting models extrapolated from weak-motion recordings in another region as compared to developing new models from local weak-motion recordings, if these are available.

In short, if the evaluation phase is likely to conclude that existing SSC and GMC models are insufficient to fully define the input to the PSHA logic tree, it should be recognized that the integration phase will involve building new models. There is an advantage in being aware of this from an early stage in the project. Specifically, the Project Plan should be developed to ensure that the TI Teams have sufficient time to independently and objectively evaluate all data, models, and methods that currently exist within the larger technical community and then develop new models as necessary to capture the center, body, and range of technically defensible interpretations. The TI Team members must fully assume the roles of technical integrators (and not proponents) in the development of new models. In a Level 3 project, in particular, members of the TI Teams are likely to work in subgroups to develop various components of models. The Team members must be given sufficient time to bring together these components into a coherent integrated distribution that is understood and endorsed by the entire team.

Although the workshops are a hallmark of a SSHAC Level 3 or 4 process, the bulk of the expert model development process is completed between the workshops. The integration or model development activity the TI Teams conducted includes the evaluation of available data; consideration of alternative data, models, and methods; and appropriate quantification of uncertainties. These types of technical evaluations are conducted in a closed setting using typical scientific assessment processes. It should be noted that the discussion in this section is based on a project that has only the three required workshops, but the information can be easily adjusted to accommodate additional workshops.

3.6.1 Model Development in Working Meetings

Much of the Evaluation and Integration the TI Team conducts is carried out in multiple "working meetings" (typically, at least three) of the team (Figure 3-4). This discussion refers specifically to Level 3 studies; Level 1 and 2 studies would simply include fewer TI Team members and perhaps fewer meetings. At the end of this section, the approach appropriate for Level 4 studies is given. Each working meeting usually lasts 3 to 5 days, and all TI Team members are expected to participate. Experience has shown that having one or two members of the PPRP present as observers can be valuable in allowing the PPRP to understand the assessments the teams made. It is important, however, that the PPRP maintain the role of observers at the working meetings so that separation between the team doing the assessments and the panel is never compromised. The TI Team should be apprised of the purpose of each meeting early in the planning process, thereby allowing ample preparations to be made by all team members so that they are able to participate constructively. The TI Lead convenes the working meeting for that particular technical topic (e.g., SSC or GMC), and the meeting is held in a conference room environment. It is important that ample real-time access to the project database be arranged to facilitate discussion. In addition to working meetings that include the physical presence of TI Team members in one place, it is expected that multiple conference calls and/or webinars will be conducted throughout the Evaluation, Integration, and Documentation processes. These teleconferences will assist in the organization of the team efforts, discussions of technical assessments, and management of issues related to the progress being made.

The first working meeting should review the purpose of the project, the context of the evaluations being made, time schedules, and deliverables. These topics may be discussed within the TI Team at the kickoff (launch) meeting, in the setting of a formal working meeting, or through a webinar. The TI Lead should reaffirm complete commitment of all team members to devote the required effort for successfully carrying out the project. This meeting also provides the opportunity to review methods for addressing uncertainties and to review the issues related to the use of expert judgment (e.g., see Section 2.4). At that meeting, the TI Team members should begin the identification of the hazard-significant issues and the databases that can be used to address those issues. The structure, format, and accessibility to the project database are other topics for discussion. This is also the opportunity to review and specify any new data-collection activities that will be conducted to supplement the available data. Finally, the team should identify the Resource Experts to be invited to Workshop #1 to present their databases. The meeting should be organized early enough to provide the PPRP the list of proposed experts for their review and to secure the participation of the Resource Experts, who typically have very full schedules.

Following Workshop #1, Significant Issues and Available Data, one or more working meetings should be held to prepare for Workshop #2, Alternative Models and Methods. This should include a review and discussion of the models and methods that have been proposed by the larger technical community and candidate Proponent Experts to be invited to present their interpretations at the workshop. The ongoing development of the project database should also be a topic of discussion.

Following Workshop #2 and prior to Workshop #3 (Feedback), multiple working meetings will be necessary to allow the TI Teams to develop complete SSC and GMC preliminary models that express the Teams' assessments and that can be used for purposes of sensitivity analyses to provide the necessary feedback to the TI Team. During these meetings, the project database will need to be available in formats the team finds most useful. For example, a Database Management team member should be present to respond to the Teams' requests to superimpose various GIS-based maps and three-dimensional data. TI Team members will also want to consider the credibility of alternative models and methods in light of the available data, including any data collected specifically for purposes of the project. The TI Lead should lead the discussions and work with the TI Team to develop an overall framework for the evaluations (often expressed as a master logic tree) and the detailed evaluations of the relative weights on alternatives and uncertainties in associated parameters.

To develop the feedback required for Workshop #3 (see Section 3.6.2), full preliminary models will need to be developed, including preliminary assessments of logic-tree branches and weights to quantify conceptual model and parameter uncertainties. The preliminary models will then be used for hazard calculations and sensitivity analyses that are specifically designed to provide information on the relative importance of various technical components of the preliminary model. For example, if two competing alternative models exist within the technical community and the TI Team concludes that both are technically defensible, the preliminary model should include the alternatives. The hazard feedback will illustrate the significance of the alternatives to the hazard results, both to the mean hazard result and the uncertainties. Additional feedback will be provided to the TI Teams from the PPRP, who will be encouraged to ask questions about the preliminary models and their technical bases. It should be emphasized to the TI Team that the preliminary model is developed for the purposes of evaluating sensitivities and identifying significant issues. The team should not become anchored on this model after considering feedback but should feel free to make whatever revisions are judged to be appropriate in subsequent parts of the project. If significant revisions are made, another round of feedback may be required.

Following Workshop #3, at which the preliminary results will be presented, one or more working meetings should be held to develop the final model. The results of the feedback provided at the workshop—both from the hazard calculations and from the PPRP questions and comments—provide a basis for prioritizing the efforts that will need to be made in the evaluation process. The prioritization will be towards those technical issues and inputs to which the hazard results are most sensitive and towards the uncertainties in the model that contribute most to the uncertainties in the hazard results. The work will be coordinated and facilitated by the TI Lead, who will also monitor its progress. Issues of concern related to the progress being made or to interface issues between various components of the project (e.g., between SSC and GMC) will be reported to the PTI, who will be responsible for seeking solutions. During the model-building process, the TI Team may divide the work among subgroups to expedite the evaluation process. However, the full team should thoroughly review, understand, and endorse the decisions made by any subset of the team because the entire team will be expected to assume ownership of the final model. Upon completion of the final model, the TI Team will hold a briefing with the PPRP (see Section 3.8) to summarize all elements of the final models and their technical justification. Following the PPRP Briefing, the project will move into the documentation phase. One or more working meetings and multiple conference calls/webinars may be useful to establish the outline for the project report, to agree upon writing assignments, and to monitor the progress of the report-writing effort.

The model development activities for a SSHAC Level 4 process are very similar to those of a Level 3 in their content, sequence, and relationship to the intervening workshops. However, the structure and participants at the working meetings are different. Each Level 4 working meeting is attended by the TFI and an individual expert (or expert team, if a team is being used). Each expert develops their own preliminary and final models. The suite of models the experts developed is then integrated by the TFI. This differs from a Level 3 assessment in which the TI Team works in a group to develop the preliminary and final models. The TFI is responsible for ensuring that all the experts have access to the project databases. The TFI serves the same function as the TI Lead in ensuring a common understanding of the issues associated with the use of expert judgment, assisting the experts on methods of quantifying uncertainties, facilitating the discussions, and ensuring that all of the model components have been addressed. Because only the expert (or expert team) is doing the evaluations in each working meeting, each meeting includes the TFI and each individual expert. The TFI attends each working meeting with each expert and each working meeting typically lasts two to three days per expert. The TFI must work to ensure that the same information is disseminated across all experts on the panel, and any issues that arise of general concern to the entire expert panel must be addressed and resolved across the entire panel. For example, if a pertinent question is raised by one expert and the answer to that question would benefit all of the experts on the panel, that information should be shared with all experts. Clearly, because the number of working meetings in a Level 4 study is greater than that for Level 3, the meetings must be carefully planned and expeditiously scheduled to avoid protracting the time needed between workshops and to finalize and document the final report.

3.6.2 Workshop #3—Feedback

As discussed in Section 3.6.1, following Workshop #2, the TI Teams develop their preliminary models. Based on these models, preliminary calculations and sensitivity analyses are conducted. The goal of Workshop #3, feedback, is to present and discuss the preliminary models and calculations in a forum that provides the opportunity for feedback to the evaluators. Feedback is given in the form of hazard results and sensitivity analyses to shed light on the most important technical issues. Feedback is also provided at this workshop by participation of the PPRP and allowing them to ask questions regarding the technical justification for the preliminary SSC and GMC models. The feedback provided at this workshop will ensure that no significant issues have been overlooked and will allow the evaluators to understand the relative importance of their models, uncertainties, and assessments of weights. This information will provide a basis for prioritizing the subsequent finalization of the models following the workshop.

Workshop #3 consists of two parts: (i) the evaluators presenting their preliminary models with particular emphasis on the manner in which alternative Technically Defensible Interpretations and uncertainties have been incorporated and (ii) sensitivity analyses and hazard calculations that provide insight into the preliminary models. In the discussions of the preliminary models, the technical bases for the assessments and weights should be described to allow for a discussion of the implications and constraints provided by the available data. This part of the workshop differs somewhat between a Level 3 and a Level 4 study. In a Level 3 study, the entire TI Team will have been involved in the development of the preliminary model, and it is not expected that individual members of the team will question aspects of the model. Rather, the PPRP will be expected to question and probe aspects of the preliminary model to understand the manner in which the views of the larger technical community have been considered and the range of Technically Defensible Interpretations included. In a Level 4 study, each expert (or expert team) will present their preliminary model and should discuss and defend it under questioning of colleagues on the panel. Again, the questions should probe how each expert considered the views of the larger community and the manner in which their preliminary model represents current knowledge and uncertainties. If the model input distributions the evaluator experts developed are narrow, with little overlap among the other experts' distributions, this should spark some discussion regarding the bases for the assessments so that it is clear what is causing the differences. However, there is no requirement that any expert's assessment be changed as a result of the feedback discussions.

In the second part of the workshop, the presentation of the sensitivity analyses and preliminary hazard calculations provide a means of focusing the discussions on those issues having the greatest hazard significance, including the largest contributors to the hazard uncertainty. In turn, this will serve to focus the assessments performed after the workshop on those technical issues of most importance to the hazard results. Section 3.7, "Preliminary hazard calculations," discusses the types of sensitivity analyses and hazard calculations that should be considered. It is important to include not only hazard calculations and associated sensitivity analyses but also sensitivity analyses on particular elements of the models that will provide insight into the models themselves. For example, the effect of various components (branches of the logic tree) of the SSC model on the assessments of maximum earthquake magnitudes and earthquake recurrence rates could be examined. Likewise, the relative contribution that the epistemic uncertainty and aleatory variability in a particular element of the model has to an intermediate output can be explored. It should be noted that these feedback calculations are not intended to provide a basis for artificially truncating or otherwise limiting the models developed by the evaluators. Rather, they are intended to provide a basis for prioritizing the activities associated with developing the final models.

Developing and using feedback during the Integration (model-building) process is an important characteristic of a SSHAC process. In large regional studies where there are large numbers of assessments and possibly complex components to the models, the project may benefit from more than one feedback cycle. Multiple feedback cycles may be particularly beneficial in large regional studies.

The PPRP will issue written comments after the workshop to summarize their views regarding whether the workshop accomplished the stated goals and consistency with the SSHAC process. The TI Leads will respond to the comments in writing, and the responses will become part of the project record.

3.6.3 Hazard Input Documents

The hazard input document (HID) is the vehicle for summarizing the results of the technical evaluations made in the SSHAC process and transmitting the information relevant to the quantitative model to the hazard analysts for calculation. The concept of an HID resulted from the need to have a documented mechanism to ensure that the expert models have been faithfully and accurately transmitted to the calculation team. The HID is a succinct summary of what is in the logic tree for the preliminary and final models. It gives seismic source geometries, nodes, and branches that represent the alternative models and parameters, and weights on the tree but does not provide any discussion or justification for the values. This is because such information is not relevant to the hazard calculations. The HID summarizes the relevant instructions and parameter inputs that are needed for the calculations. For example, alternative geometries may be depicted in an illustration with reference to a data file that specifies the geometric coordinates. The HID will contain other types of data files, such as those that describe continuous distributions. As another example, the data file containing the results of two-dimensional smoothing of spatial rate density can be explained to ensure that the proper discretization is used and that the spatial distribution is properly accounted for. The HID should be complete and clear enough to ensure that the hazard analyst does not have to interpret any ambiguous information.

To ensure that the technical models developed from the SSHAC process are accurately transmitted to the hazard analyst, it is recommended that the TI Team members review the HID and endorse its accuracy prior to its delivery to the hazard analyst. One advantage of the HID is that it also provides an accurate input to third-party "spot-checks" of the calculation procedure. A well-constructed HID facilitates an efficient review by regulators, especially when the regulator performs confirmatory analyses. The HID has been shown to be an effective mechanism for providing an auditable document that ensures the accurate transfer of the SSC and GMC models to the hazard analyst.

3.6.4 Avoiding and Handling Excessively Large Logic Trees

As has been stated, the fundamental objective of a SSHAC hazard study is to capture the center, body, and range of technically defensible interpretations for each element of the SSC and GMC models. The ultimate aim is thus to capture the best estimate of the mean seismic hazard at the site and the associated range of uncertainty, based on currently available data. The tool most widely used in PSHA to incorporate epistemic uncertainties into the PSHA is the logic tree (e.g., Kulkarni et al., 1984). In a logic tree, there is a node for each element of the SSC and GMC models, and branches are assigned at each node that carry alternative models or alternative parameter values. Each branch is assigned a weight that reflects the relative degree of confidence of the TI Team in each model or parameter value. Because these weights are subsequently treated as probabilities when the mean hazard is used, it is important that they should sum to unity at each node.

When the full logic tree has been assembled, hazard calculations are performed for all possible combinations of branches, each leading to a separate hazard curve. The weight or probability associated with each hazard curve is obtained from the product of all the individual branch weights. The final results will generally be presented in the form of mean hazard curve and associated fractiles, including the median; the calculation of all these curves involves estimating the weighted statistics of the annual exceedance frequencies at each level of acceleration. Calculation of the mean hazard is relatively straightforward, but correct determination of the fractiles is more onerous in terms of computational effort.

With several nodes included for the influence of key elements of the SSC and GMC models, and several branches at each node, the total number of branch combinations in a logic tree can grow rapidly. In a SSHAC Level 4 study, very large logic trees are almost unavoidable because each member of the expert panels for SSC and GMC is charged with developing their own logic tree. The individual logic trees are then combined—generally with equal weights, although the SSHAC guidelines do allow for the TFI to use other approaches (NUREG/CR-6372)—into a single logic tree. The resulting logic tree will tend to be very large unless all of the individual logic trees have identical structure and differ only in the branch weights, which is very unlikely. In the PEGASOS project, which was a Level 4 PSHA for nuclear power plant sites in Switzerland, the final number of logic-tree branch combinations was 10^{26}. In a Level 3 study, where the TI Team is required to develop a single logic tree for SSC and GMC, this problem of combining multiple logic trees is automatically avoided. The same also applies for Level 1 and 2 studies.

The TI Teams should develop SSC and GMC logic trees that reflect the current state of knowledge, including the full range of epistemic uncertainty. It is not advisable for the TI Teams to make assumptions regarding branches or nodes that may be neglected on the basis of having little or no influence on the hazard estimates unless this has been checked through sensitivity analyses across the relevant range of response frequencies. Moreover, caution should be applied because nodes or branches found to exert small influence on the hazard results when considered in isolation may be found to have a noticeable effect when considered in combination.

Giving due consideration to all variables in the SSC and GMC models and to the range of epistemic uncertainty associated with each of these, it will frequently be the case that the final large trees will have very large numbers of possible branch combinations. Such large logic trees may present two challenges, the first being that a very complex logic tree structure potentially leads to more possibilities for errors in the implementation of the SSC and GMC models in the PSHA code. However, the most appropriate response to this is to apply as many checks as possible—as required by the QA procedures—and also to ensure that the schedule provides sufficient time for the Hazard Analyst to implement the models carefully and with all appropriate checks applied. The second challenge that may arise from a large and complex logic tree is that the run time required to execute the full hazard calculations may become very long. For the final hazard calculations, this may not be a major problem provided that the schedule allows sufficient time for the PSHA runs to be completed, but during the course of the project, the run times may limit the number of sensitivity analyses that can be run, and this limits the insights that the TI Teams and the PPRP may obtain about the implications of the preliminary models.

The ideal solution for such a situation is to access greater computational power and to make use of parallel processors or other facilities that enable the calculations to be run without any modification of the logic tree. In some projects, simplifications of the logic trees have been implemented by running the hazard calculations through procedures such as “pruning” (removing branches having little influence on the hazard estimates and redistributing their weight to the other branches) and “pinching” (merging branches that have similar effects). While such pragmatic approaches have been needed in some cases, these procedures can potentially undermine the important principle of full intellectual ownership of the SSC and GMC models by the TI Teams. Therefore, such practices are discouraged and should be avoided, to the extent practicable. If the logic trees need to be reduced, the TI Teams should be asked to propose how this should be accomplished. During this discourse, the TI Team may request sensitivity analyses to determine the relative influence of different branches and branch combinations.

In the context of this discussion, it is important to emphasize that a large logic tree with many branches does not necessarily and automatically correspond to effective capture of the center, body, and range of technically defensible interpretations. Although there will be multiple nodes corresponding to model features, such as seismic source boundaries, recurrence parameters and M_{max}, median ground-motion predictions and ground-motion variability, the purpose of the logic trees is actually very simple: the SSC logic tree represents the potential distribution of locations and annual recurrence rates for earthquakes of different magnitudes, and the GMC logic tree represents the potential distributions of ground-motion amplitudes at the site because of each of these earthquakes. In recent years, this insight has prompted different approaches to the construction of logic trees for PSHA (e.g., Bommer, 2012). For example, it has been recognized that assigning weights to large numbers of published GMPEs does not necessarily result in a broad distribution of the resulting ground-motion amplitudes and indeed, the relationship between weights on alternative models and the resulting distribution of accelerations is generally obscure, unless advanced visualization tools are employed (e.g., Scherbaum et al., 2010). To make the relationship between branch weights and the resulting ground-motion distributions more transparent, several projects have adopted approaches based on constructing the GMC logic tree by populating the branches with scaled and adjusted versions of a single "backbone" model (Atkinson et al., 2014).

In a similar way, even if the original logic-tree structure is complex, it can always be re-sampled to a number of equivalent models that capture the same distributions in terms of earthquake activity rates and ground-motion amplitudes. An example of developing such equivalent branches for an SSC model has been presented by Stromeyer and Grünthal (2015). For any element of the logic tree, standard techniques (e.g., Miller and Rice, 1983) may be applied to obtain an equivalent discrete distribution. There are potential pitfalls in such approaches, one being that it cannot be guaranteed that the hazard fractiles will be faithfully reproduced with such equivalent distributions without performing at least one set of calculations with the full logic tree. Additionally, if the resampling involves merging nodes—for example, median GMPE predictions and associated V_S-kappa adjustments—then the individual influence of the nodes can no longer be explored through sensitivity analyses or disaggregation of the hazard.

A final consideration in this context is that if computational demand does become an issue in a PSHA project, then modification and simplification of the SSC and GMC logic trees may not be the only option worthy of consideration. Some aspects of the PSHA integrations over defined distributions of random variables may be unnecessary in sources remote from the site under study. For example, in a source zone with a closest approach to the site of several tens of kilometers, it may be that integrating over focal depth distributions and randomizing the generation of virtual fault ruptures to calculate the source-to-site distances are both redundant. Sensitivity analyses should be performed before making any deviation from full integration over all distributions, but if such analyses show that the impact of the additional computational effort is negligible, then it would be more advisable to simplify the calculations to speed up the PSHA run times rather than to modify the logic tree, if this is the only purpose of making such adjustments.

3.7 Preliminary Hazard Calculations and Sensitivity Analysis

As discussed in Section 2.3, feedback is an important feature of a SSHAC process, and much of it comes from the hazard calculations developed from preliminary models. After the TI Teams have developed their preliminary models, feedback is developed in preparation for Workshop #3 by the Hazard Analyst that includes preliminary hazard calculations and sensitivity analyses based on those models. The sensitivity analyses are requested by the TI Teams and should be designed to show the importance of all elements of the preliminary model, including all branches of the logic tree and their associated weights. This often means that the sensitivity shown is not only in terms of the importance to the calculated hazard but also to intermediate results such as recurrence rates.

Figures 3-10 through 3-15 show examples of different types of sensitivity analyses used for feedback. At the hazard level, sensitivity can be displayed in a number of established and useful ways. Most common are hazard curves showing the mean contributions from various seismic sources as a function of the ground motion measure of interest (Figures 3-10 and 3-11). Such plots provide a means of focusing on those sources that have a significant hazard contribution.

Deaggregation plots (Figure 3-12) show the contribution of different distances and magnitudes to the mean hazard. Also useful are sensitivity plots of mean hazard curves that display the hazard

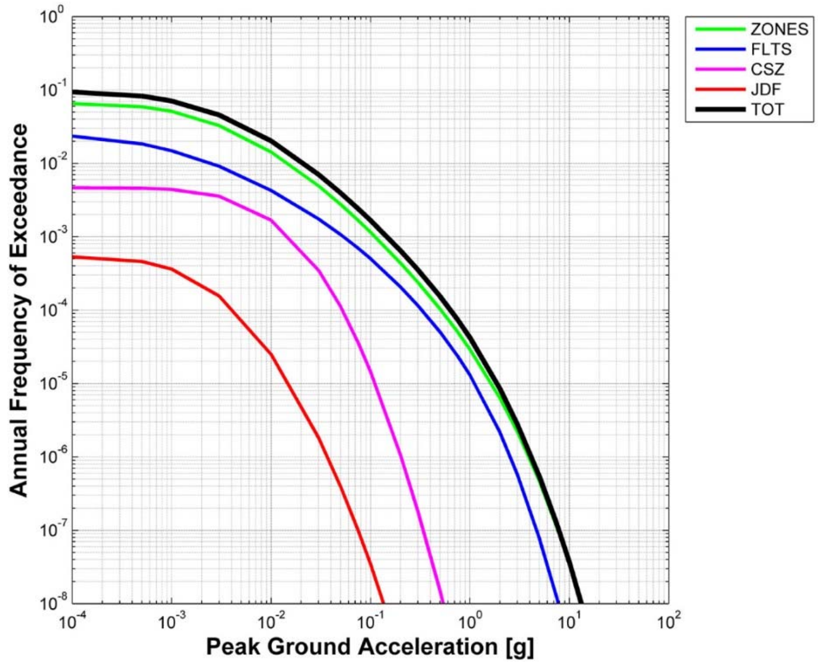

Figure 3-10 Example of seismic hazard feedback showing the relative contributions of various types of seismic sources to the peak ground acceleration hazard at a site of interest. The total hazard is shown by the black hazard curve.

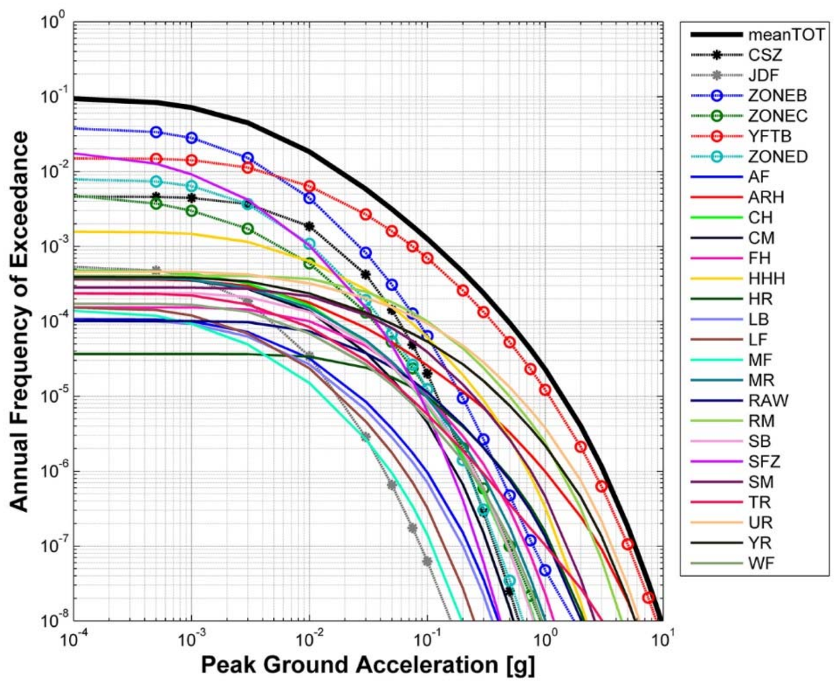

Figure 3-11 Example of seismic hazard feedback showing the relative contributions to the peak ground acceleration hazard of all seismic sources in an SSC model. Such plots can provide an indication of the dominant contributors to the hazard at annual frequencies of exceedance of interest.

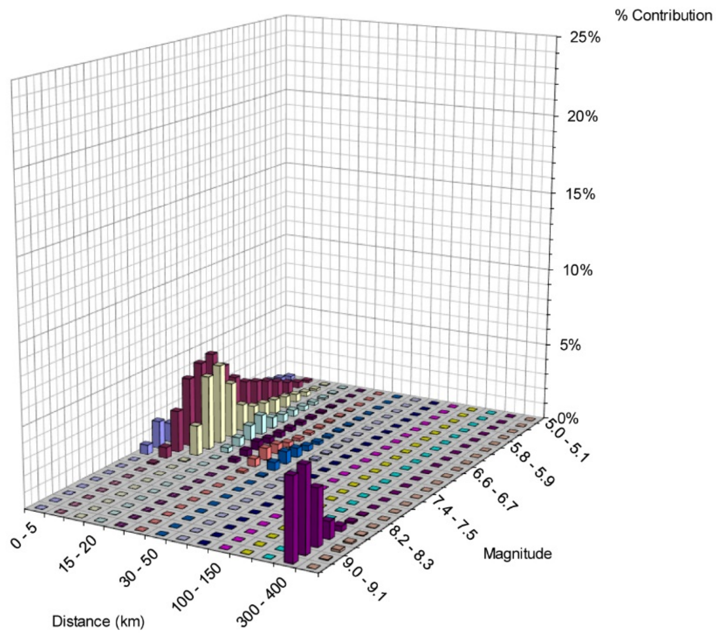

Figure 3-12 **Example of seismic hazard feedback showing a deaggregation plot for the magnitude and distance contributions to the hazard at 1.0 second spectral accelerations at an annual frequency of exceedance of 10^{-4}. Such plots can be compared to the magnitude and distance contributions at other structural periods and other annual frequencies of exceedance.**

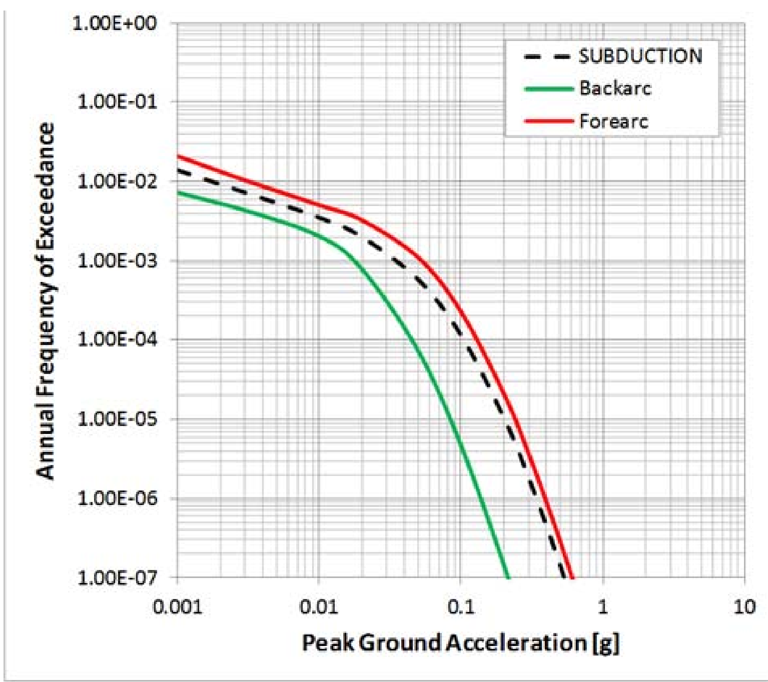

Figure 3-13 **Example of seismic hazard feedback showing the effect of alternative branches of a GMC logic tree. Shown are the hazard curves resulting from use of either a backarc or a forearc GMPE. The dashed line is the weighted combination of both branches of the logic tree.**

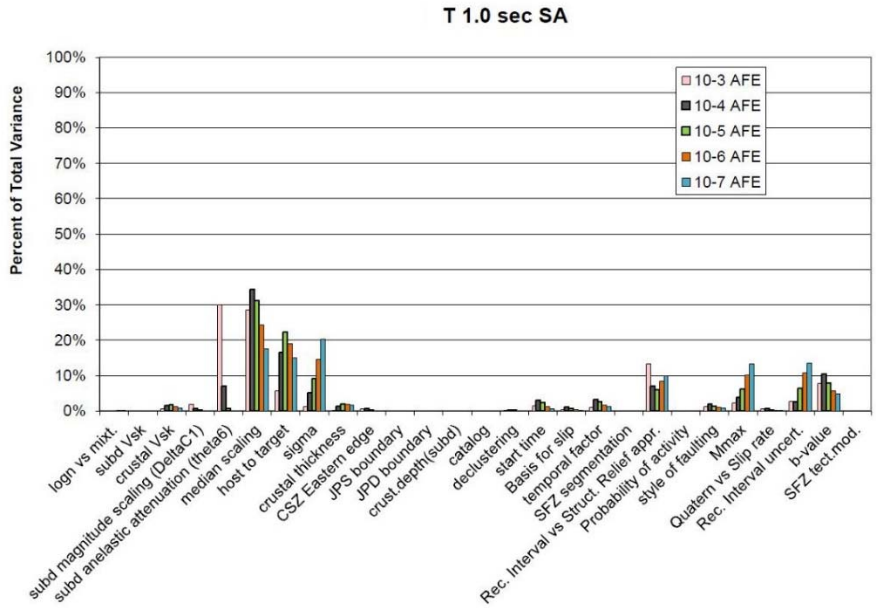

Figure 3-14 Example of seismic hazard feedback showing the percent contribution that various elements of the GMC and SSC logic trees make to the total variance in the hazard distribution. Variance contribution histogram at the 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, and 10^{-7} annual frequencies of exceedance for the T 1.0-sec spectral acceleration. These types of plots provide insight into the largest contributors to the uncertainties in the seismic hazard.

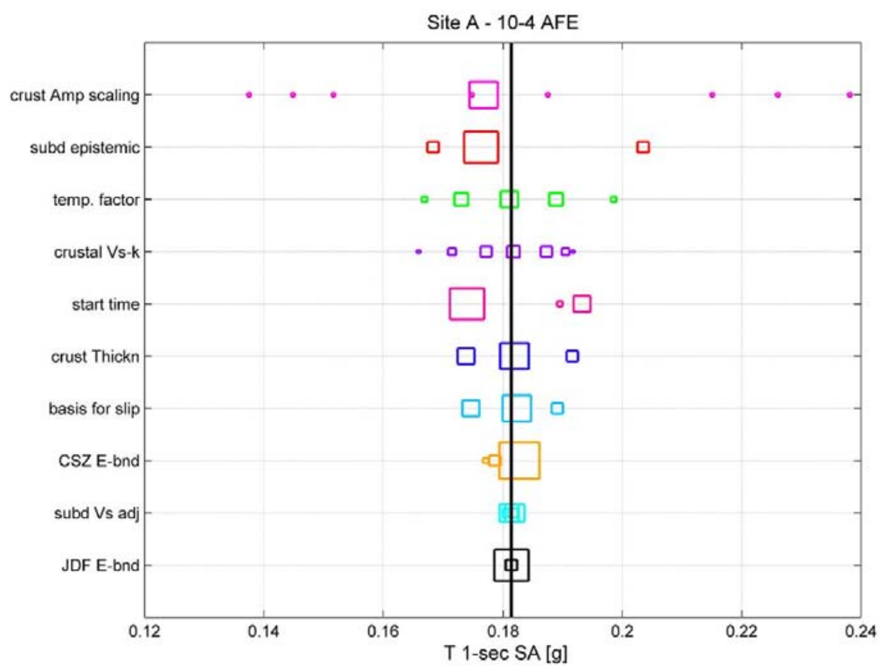

Figure 3-15 Example tornado plot for T 1.0-sec spectral acceleration at AFE of 10^{-4}. The size of the symbols is proportional to the logic-tree weight assigned to each branch.

results conditional on particular branches of the logic tree (Figure 3-13). Given the importance of quantifying uncertainties, one way to assess the relative importance of the uncertainties in various input parameters to the uncertainty in the hazard is shown in Figure 3-14. This plot shows the percent contribution that the uncertainty in specific elements of the SSC and GMC logic tree makes to the uncertainty in the hazard. Other approaches, such as tornado plots (Figure 3-15), also portray the relative contributions of input uncertainties to the total hazard uncertainty.

In summary, feedback is needed so that the TI Team members can make hazard-informed decisions, and they can refine their models to focus on those elements that contribute to the hazard. One possible downside to providing quantitative hazard feedback is that it can allow unintentional biases to occur. To minimize the potential for bias and maintain the unfettered and unobstructed perspectives of the evaluators, it is recommended that the sensitivity analyses developed early in the project for Workshop #1 present hazard results in the form of relative contributions or sensitivities, normalized so that the actual hazard estimates are not shown. This provides the same valuable feedback information but discourages biases early in the project. For sensitivity analyses developed based on the preliminary models for Workshop #3, it is recommended that actual hazard results be shown because this can provide additional information the evaluators needed to finalize their models.

3.8 PPRP Briefing

After Workshop #3, during which the PPRP plays an active role in the interrogation of the preliminary SSC and GMC models, the TI Teams focus their attention on finalizing their models in the light of the feedback received. Although this is a busy time for the TI Team, the PPRP does not have many opportunities to observe the proceedings during this time. Typically, at least one working meeting is held to assist with the finalization of the models, and one or two PPRP members can be present to observe that meeting. Otherwise, the PPRP will not have knowledge of how the models were finalized—nor the supporting technical bases—until the Panel receives the draft project report. It is, therefore, recommended that after the SSC and GMC models have been finalized, but before the project report has been written, that a PPRP Briefing be held with the TI Leads (and possibly also other TI Team members) to review all of the elements of the final models and the associated technical justifications. The PPRP Briefing can be several days in duration, with the TI Leads presenting the final models and the PPRP asking questions about the bases for the branches and weights in the logic trees, as well as the technical assessments that led to the final TI Team decisions. The goal of the briefing is to inform the PPRP sufficiently such that they are prepared when they receive the draft project report to understand the final models. Experience has shown that this can help expedite the PPRP review and minimize the number of review comments on the report. The briefing can also provide an opportunity for the PPRP to inform the TI Teams about the issues that need to be explained in greater detail in the documentation prior to the development of the project report.

3.9 Final Hazard Calculations

Based on consideration of the data and feedback provided throughout the project, the TI Teams will develop their final models, the models will be documented in the final HID (which must be completed prior to the PPRP Briefing), and final hazard calculations may or may not be conducted as part of the SSHAC study. Instances where this would not be included are (i) in regional studies and (ii) when site response and site response data need to be governed by their own QA requirements. To ensure that the final model is “locked down” and that no changes will be made during the report preparation phase of the project, it is suggested that the development and delivery of the HID by the TI Leads to the Hazard Analyst mark the official end of the model finalization effort. The products from the final hazard calculations should include all of the visualizations (e.g., plots and figures) and outputs that are needed for the subsequent use. In addition to the hazard outputs, a series of sensitivity analyses should be conducted—similar to those conducted for purposes of feedback—to provide a basis for understanding the dominant contributors to the hazard results and to the associated uncertainties.

3.10 Documentation

The project documentation is the fundamental basis for the reader to understand (i) what process was used in the hazard analysis; (ii) what data were available and used in the evaluation process; (iii) how the data, models, and methods of the larger technical community were considered; (iv) the elements of the models and their technical bases; (v) how the models capture the center, body, and range of technically defensible interpretations; and (vi) the hazard results and instructions for their use. The draft report is subject to PPRP review, with the goal of producing clear, complete, and transparent documentation showing the study has achieved all SSHAC goals.

3.10.1 Process Used

A principal finding of NUREG/CR-6732 was that the process followed in a hazard analysis can have a significant impact on the hazard results. Accordingly, this NUREG is intended to provide guidance on elements of a process that can help provide stable hazard results if conducted in the manner recommended. It is, therefore, important that the project report provide a detailed description and explanation for the process conducted and a discussion of how the process followed the guidance in this NUREG. A description and basis should be given for any deviations from the process outlined in this NUREG. An explanation should be given for the selection of the SSHAC Level and why it was deemed appropriate for the project. The discussion should also describe the participant roles and responsibilities, organizational structure, evaluation and integration activities, workshops, schedules, and the participatory peer review.

3.10.2 Data Considered

It is important for the reader of a project report, especially one reading the report some years after the project was completed, to understand fully what data, models, and methods were considered during the evaluation phase of the study and how those data were used by the TI Teams in their model-building efforts during the integration phase of the project. This includes the data that were made part of the project database and new data collected as part of the study. As discussed in Section 3.5.2, “Documentation of Evaluation Process,” a summary of the project database should be included or appended to the project report, or reference should be made to the database as a separate document. This can include a description of the project database, as well as other documents such as topical white papers developed by the TI Teams. In particular, the documentation should describe the full suite of information available at the time of the study and should also detail the complete set of information that was used in developing the models, along with its use and the degree to which it was relied upon.

3.10.3 Elements of the Models

The technical discussion of the elements of the expert models and their technical bases is the backbone of the report. Each element of the models (i.e., the logic-tree branches and weights) should be discussed in detail, including all models, parameters, and uncertainties. The discussion should include all data, models, and methods that were considered. This discussion should account for those that were excluded because the TI Team determined that they were not credible enough to be included in the final model (i.e., those that are given zero weight). A key part of the model documentation process is the assessment of how the final model is believed to capture the center, body, and range of technically defensible interpretations.

The documentation process will differ somewhat for the various SSHAC Level studies. The discussion of the model for Levels 1 to 3 studies will be the final model developed by the TI Team. In a Level 4 study, each expert should prepare a report that summarizes all elements of their individual models, along with the technical basis for all model components. It is recommended that the TFI provide the expert panel an outline to use in documentation to increase the likelihood that all necessary topics are covered and that the expert reports are consistent in format. These individual expert reports should be appended to the final project report. The TFI should prepare a summary in the main body of the report that details the process followed, assessments made by all of the evaluator experts, and conclusions regarding common elements across the expert assessments or differences, as appropriate. The report should also discuss the methodology used to aggregate the expert assessments and the associated justifications.

3.10.4 Hazard Results and Instructions for their Use

The project report should include a thorough documentation of the hazard results, sensitivity analyses that provide information on the dominant contributors to the hazard, and instructions for the use of the hazard results for the anticipated users. The latter may include any caveats or limitations to the use of the results. For example, some hazard results may be limited to certain annual frequencies of interest or geographical limits to their applicability. As discussed in Section 3.3, "Development of Project Plan," the specific hazard deliverables for the project should be identified at the outset of the project and included in the Project Plan. This will ensure that the expectations of the sponsors will be met in terms of the delivery of hazard products for subsequent use.

The SSHAC guidelines describe how the hazard output should be presented and documented. The basic outputs required from a PSHA study are also specified in Regulatory Guide 1.208 (NRC, 2007). At a minimum, a site-specific PSHA should provide the following representations of the ground-shaking hazard:

- hazard curves for each of the required ground-motion parameters, including the mean and several fractiles (5, 15, 50, 85 and 95 percent) over a wide range of annual frequencies of exceedance
- curves showing the contribution of individual seismic sources to the mean hazard for a range of response frequencies
- uniform hazard spectra at specified annual exceedance frequencies, which will generally include 10^{-4} and 10^{-5}
- deaggregation of the mean hazard at selected response frequencies and annual exceedance frequencies to identify the contributions from different bins of magnitude and distance
- results of sensitivity analyses showing contributions to the variance in the hazard curves (i.e., epistemic uncertainty) from different sources of uncertainty

Other representations of the hazard and design ground motions that may be required—such as conditional mean spectra (Baker and Cornell, 2006b) and acceleration time-histories—can all be obtained from post-processing of the above information. A very important issue to define *a priori* is the lowest annual frequency of exceedance for which ground motions may be required. With modern computing capacities, it is a relatively straightforward task to extend the calculations to lower exceedance frequencies, whereas considerable logistical difficulties can arise if the need for these only comes to light after the project is completed. Extrapolation of calculated hazard curves is not an acceptable approach, so the lower limit should be carefully considered before the hazard calculations commence. Whereas for design of nuclear power plants the annual frequencies of exceedance of interest will generally be in the range from 10^{-4} to 10^{-5} (e.g., NRC, 2007), hazard estimates may be required as low as 10^{-8} for a complete probabilistic risk analysis (PRA). Extending PSHA to such low annual exceedance frequencies is much more involved than a simple extrapolation of routine hazard models because it will influence the models considered. It is also important to avoid misunderstanding that such PSHA is not an extrapolation to some distant time in the future but rather to the likelihood of the events within the present tectonic setting. This confusion is sometimes increased by referring to such low annual frequencies as return periods; for example, as the "one-million-year ground motion."

In many cases, project-specific instructions may be needed to provide for subsequent users of the hazard results. Such may include any caveats or conditions necessary for subsequent use for design or risk analyses. It is not uncommon for hazard results to be provided for specific reference rock conditions that generally apply to the location of interest, but instructions may be needed for applying the hazard results at any specific site that may have different site conditions than the reference. For example, the hazard results may apply to a reference condition known to exist at some depth below the surface, and instructions can be provided describing how the hazard input to a site profile that extends to the surface should be made. As another example, instructions may be provided to users of the hazard results regarding recommendations for developing additional hazard products for design, such as time histories. Given the potential for ambiguity and misinterpretation, it is important that such instructions be developed and reviewed within the SSHAC framework.

3.10.5 Document Review

When the draft project report has been completed, it is subject to PPRP review and, if applicable, the Sponsors and other groups. Because the PPRP undertook a participatory review throughout the project, they will have a working familiarity with all aspects of the project. Thus, they will be in a strong position to comment on the degree to which the documentation has sufficiently and completely represented the project execution. It is suggested that the PM provide the PPRP with a set of review criteria with which to review the report. As with their review throughout the course of the project, the PPRP review should entail both technical and process aspects. Example review criteria are the following:

Technical

- Have all data, models, and methods considered in the assessment been identified and documented?

- Have all elements of the model been defined in sufficient detail?

- Have the model elements and expressions of uncertainty (e.g., logic-tree branches and their weights) been technically justified?

Process

- Has the choice of SSHAC Level been explained?
- Have all of the essential steps of a SSHAC process been followed and documented?
- Is the evaluation process sufficiently justified, including documented evidence that the data, models, and methods of the larger technical community have been considered?
- Has the integration process been sufficiently documented such that the center, body, and range of technically defensible interpretations are well justified?

Other reviewers, such as the Sponsors, may have other review criteria specific to the project and the intended use of the results.

3.10.6 Peer Review Documentation

As discussed in Sections 2.5.8, 2.5.9, and elsewhere, the participatory peer review role is an important component of SSHAC projects. The selection of the PPRP should occur early in the process (Section 3.4, "Selection of Project Participants") and the PPRP should provide its review and feedback periodically following key points in the project. This should include written comments following all workshops, review of the Draft Project Report, and other decision points indicated by the PTI and PM.

The PPRP's review of the Draft Project Report is a major work activity, and the written comments the PPRP provided should be provided to the project team to assist in the finalization of the report. The goal of the PPRP review of the Draft Project Report is to improve the completeness and clarity of the documentation. Experience has shown that it is useful for the PPRP to prioritize its comments into those requiring consideration by the project team and those comments that are more editorial or optional suggestions for improving the report. For the PPRP to understand how comments have been addressed, it is recommended that the project team provide written responses to each PPRP comment duly noting changes that have been made to the report or explaining why no changes were made in light of the comment.

After the project report has been revised and PPRP comments have been responded to in writing, the PPRP is provided with another opportunity to review the document. Typically, a single round of PPRP review comments is sufficient to allow the PPRP to conclude that the project documentation is adequate. However, if another round of review and revision is necessary to assure PPRP acceptance, then that should be completed.

At the conclusion of the project and after completion of the final report, the PPRP should provide its final comments in a PPRP Closure Letter, which is written on behalf of the Panel and delivered to the PM. These final comments should include: (i) a brief description of the PPRP's review activities during the course of the project; (ii) the PPRP's final assessment of whether or not the project was found to be consistent with the SSHAC process; (iii) whether the technical assessments represented by the final models capture the center, body, and range of technically defensible interpretations; and (iv) whether the documentation is adequate and complete.
The PPRP Closure Letter should be delivered along with the Final Project Report to the project Sponsor(s).

4 UPDATING: REPLACING, REVISING, AND REFINING PROBABILISTIC HAZARD ASSESSMENTS

As discussed throughout this document, a goal of a Senior Seismic Hazard Analysis Committee (SSHAC) process is to capture the center, body, and range of technically defensible interpretations (CBR of TDIs). Implicit in a SSHAC study is that it represents a snapshot in time because the study is based on the information available when the study was conducted. With the passage of time, new information could trigger the need to update an existing hazard study. These changes might be the gathering and analysis of new hazard-significant data, new models proposed by the larger technical community, or new methods for analyzing or interpreting data. In some regulatory environments, an evaluation to determine whether an update is needed is required periodically [e.g., U.S. Department of Energy (DOE) Order 420.1C] (DOE, 2012a).

In anticipation of the potential need to update existing hazard studies, this section describes the procedures for determining whether an update is needed and what the nature of the update should be to maintain the SSHAC standard of the original study. The elements that compose the framework for evaluating an existing site-specific study or an existing regional study are discussed in the next subsections. In this context, the term “update” refers to this overall process of evaluating an existing study and any of specific actions that take place as a result of the evaluation. This section significantly clarifies and expands the discussion in Section 6 of NUREG–2117 and should be used in lieu of that document.

4.1 The Need and the Purpose

Current U.S. Nuclear Regulatory Commission (NRC) regulations require a site-specific hazard analysis for the design or safety review of a nuclear power plant or a nuclear power reactor. These site-specific hazard analyses could be a single site study, such as the existing Probabilistic Seismic Hazard Analyses (PSHAs) for the three operating nuclear power plants in the Western U.S., or they could be a site-specific study that draws upon a larger regional study, as is the case for the remaining operating nuclear power plants in the Central and Eastern U.S. Site-specific or regional hazard analyses are conducted to provide a technical basis for licensing actions (e.g., new nuclear facilities, safety reviews of an existing facility, or evaluation reviews to determine the viability of existing hazard studies), including those that might address requirements for periodic reviews of existing hazard studies. Regulatory drivers for such studies include Title 10 of the *Code of Federal Regulations* (CFR) 50, Appendices A and S; 10 CFR 52; 10 CFR 63; 10 CFR 70; 10 CFR 72; 10 CFR 100.23; and NRC Regulatory Guides 1.208 and 3.73. These regulations and guidance require that high-quality hazard studies be conducted for purposes of design and design review. For seismic hazard assessments, the SSHAC guidelines have been specifically referred to as an acceptable approach for addressing seismic hazards probabilistically [e.g., Regulatory Guide 1.208 and the 50.54(f) letter].

For DOE nuclear facilities, the requirements related to natural phenomena hazards are governed by DOE Order 420.1C (DOE, 2012a), which requires that all natural phenomena hazards assessments be evaluated at least every 10 years, to ensure that the existing studies are still applicable. The Order refers to the Standard DOE–STD–1020–2012 (DOE, 2012b) for the methodology to evaluate existing hazard studies. Consistent with the graded approach given in DOE (2012b), methodologies have been proposed by Kammerer et al., (2017) and Payne et al. (2017) to scale the requirements for updating based on the risk significance of facilities (ASCE-43-05 and ANSI/ANS-2.26-2004). Because of the risk significance, the requirements for nuclear power reactors are the most rigorous, and the discussion in this section assumes that the PSHA being considered for updating would be used for such facilities.

As previously noted, new information may come to light or events may occur that prompt a re-evaluation of existing hazard studies to determine whether an update is needed. In other cases, even if a periodic update is not required, significant time may have passed since a study was conducted such that it is prudent to reconsider the continued viability of the study.

4.2 Existing Study Evaluation

The process of updating begins with an evaluation of the existing PSHA, as illustrated in Figure 4-1 for a site-specific study and Figure 4-2 for a regional PSHA. The basic process is the same for the existing study evaluation, but there are important differences in the updating options (Section 4.3). The existing study evaluation process is described first. In the diagrams, decision points are indicated by the diamond-shaped boxes.

As shown in Figures 4-1 and 4-2, it is assumed that either a site-specific or regional PSHA is needed. If a SSHAC Level 3 or 4 study does not exist, then the proper action is to conduct such a study. If such a study does exist, then the existing study is subject to an Existing Study Evaluation to determine if it is still valid. This evaluation consists of two steps. The first step is to conduct a SSHAC Level 1 study using available information, including any applicable new data, models, and methods that became available since the original SSHAC study was completed. Conducting a SSHAC Level 1 study will provide all of the information that is needed to conduct an Existing Study Evaluation; in addition, it will ensure that it is performed in a comprehensive and consistent manner, will be properly documented, and will benefit from the assurance afforded by a peer review process required of such studies, all to ensure that the updating process remains within the SSHAC framework.

The second step is a comparison of the existing PSHA with the inputs and results of the SSHAC Level 1 study. Specifically, six decision factors are identified to determine whether an update is needed and what type of update is needed. These factors are:

1. Changes in data, models, or methods: This decision factor requires that all relevant new and updated data, models, and methods be identified, compiled, and evaluated to assess how currently available information differs from the information that was evaluated as part of the original PSHA. Because the SSHAC process requires that data, models, and methods be identified, evaluated, and documented, the identification of changes from the time that the existing PSHA was conducted can be readily defined.

2. Changes in inputs to the hazard analysis: This factor considers whether or not changes in data, models, and methods identified in the previous decision factor would lead to changes in the principal inputs to the hazard analysis, which are the seismic source characterization (SSC) and/or ground motion characterization (GMC) models in a PSHA. The evaluation should include consideration of the manner in which aleatory and epistemic uncertainties have been addressed in those models, and whether or not the SSC and GMC models continue to adequately represent the center, body, and range of technically defensible interpretations.

3. Changes in mean hazard results: This factor involves a comparison of the original hazard results with results from the SSHAC Level 1 study (from the first step of the Existing Study

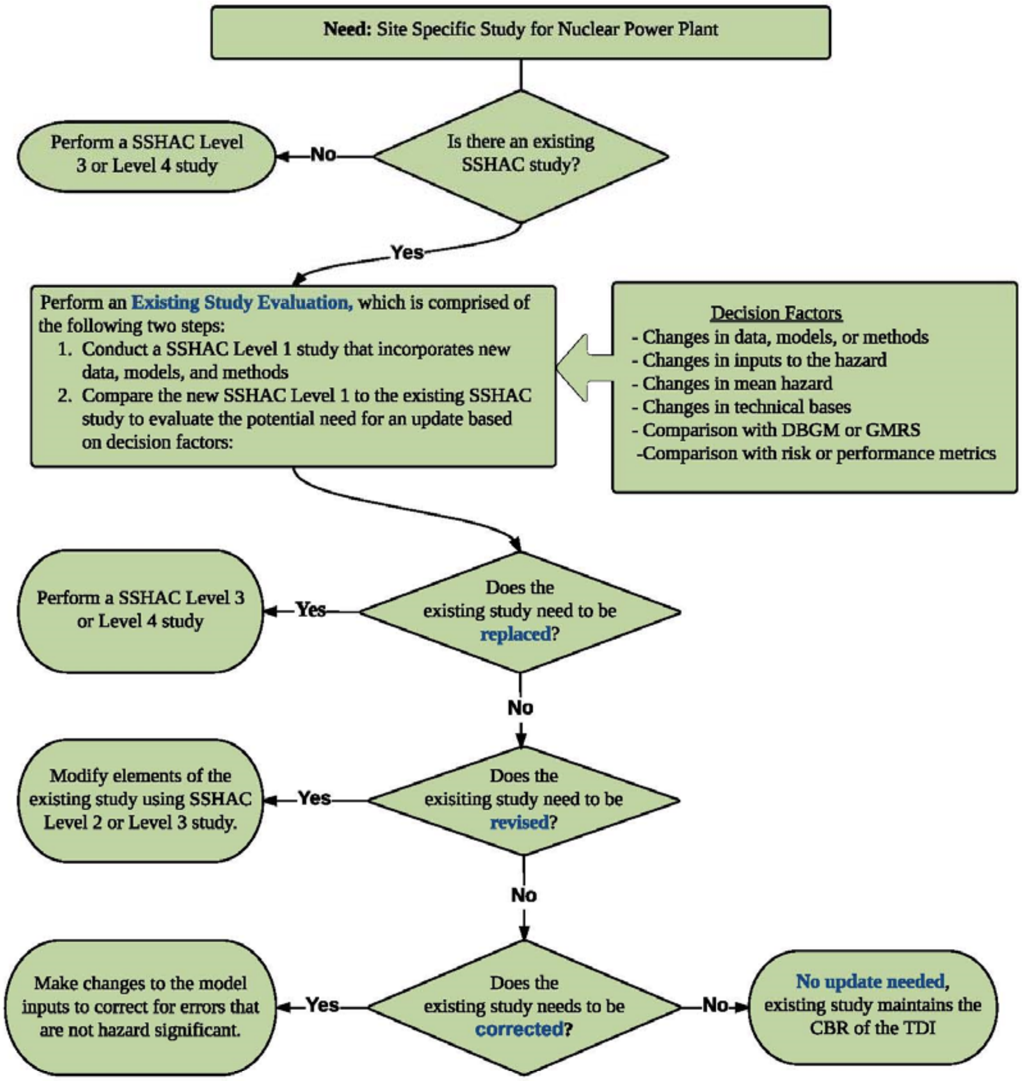

Figure 4-1 Flowchart illustrating the steps to evaluate the need for updating an existing site-specific PSHA.

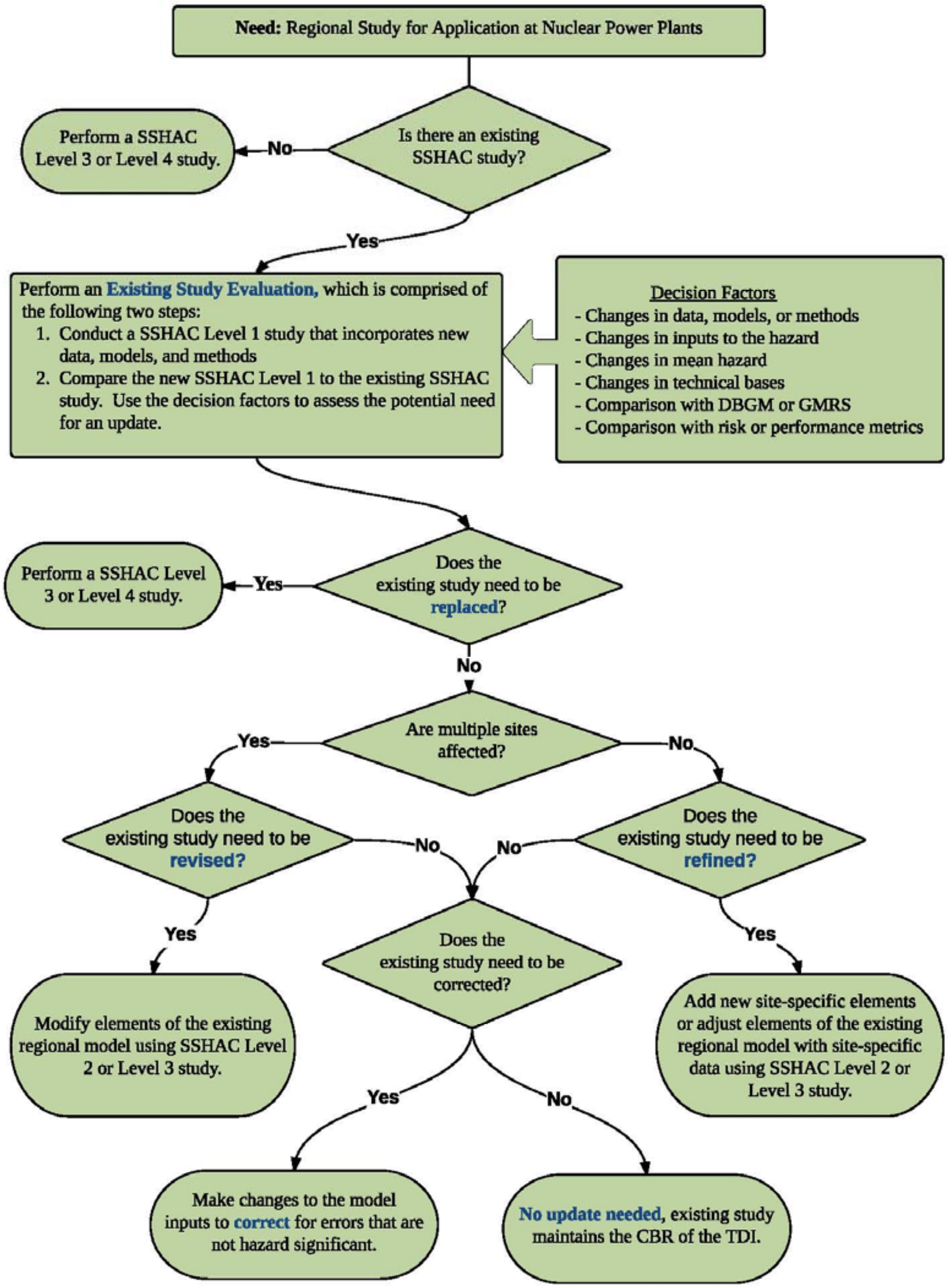

Figure 4-2 Flowchart illustrating the steps to evaluate the need for updating an existing regional PSHA.

Evaluation) to determine whether there are significant changes to the calculated hazard. This assumes that the new data, models, and methods, as well as the associated changes in the inputs to the hazard model, have been accounted for and are then used to calculate hazard at the site of interest. Typically, comparisons of seismic hazard at nuclear power plants are performed using the mean hazard at annual frequencies of exceedance (AFE) of 10^{-4} to 10^{-5}.

4. <u>Changes in the technical bases</u>: This factor includes an evaluation of whether the technical bases for the hazard have changed, even if the calculated hazard does not indicate a significant change. The technical bases include the technical arguments and justifications for the hazard inputs and the associated treatment of uncertainties.

5. <u>Comparisons of calculated mean hazard with current design bases</u>: This factor includes a comparison between the calculated mean hazard from the SSHAC Level 1 study and the design basis that exists for the facility. For seismic hazard, the basis for comparison could be the Ground Motion Response Spectrum (GMRS), as defined in NRC Regulatory Guide 1.208 (NRC, 2007) or the "design response spectra" (DRS) in ASCE/SEI-43-05. As described in RG 1.208, the GMRS for new nuclear power plant designs is developed based on a uniform hazard response spectrum (UHS) at AFE of 10^{-4} to 10^{-5} coupled with "design factors" from ASCE/SEI-43-05 that account for the slope of the hazard curve at those AFE of interest. In addition, the GMRS has been used by NRC licensees as a risk-informed screening measure for the post-Fukushima evaluation of all of the nuclear power plants in the United States (NRC, 2012a). For DOE nuclear facilities, the basis for comparison could be the UHS at the hazard exceedance probability specified for the Seismic Design Category for the facility of interest, as given in DOE–STD–1020–2012 (DOE, 2012b).

6. <u>Comparisons of risk or performance to target goals</u>: This factor extends the hazard comparisons described previously to consider whether the new calculated hazard would result in calculated risk that would exceed target performance or risk objectives, such as those given in ASCE/SEI-43-05 and RG 1.174. Because the goal of evaluating the adequacy of an existing hazard analysis is to contribute to safety, the incorporation of risk information into the existing study evaluation process is beneficial. This decision factor is included in anticipation of ongoing efforts to include risk information and in light of insights that may be gained from the ongoing risk analyses at many nuclear power plants in the United States. In any case, the choice of risk objectives and criteria should be determined and agreed upon, preferably at the start of the overall existing study evaluation process, by facility owners and regulators

As shown in Figures 4-1 and 4-2, the existing study evaluation process will result in a decision that an update to the existing PSHA is needed or that no update is needed. If no update is needed, then the existing hazard study can be considered adequate for continued use. If it is decided that an update is needed, then various options exist, as discussed next in Section 4.3.

4.3 Updating Options

Within the updating process depicted in the flowcharts, there are five specific outcomes:

1. <u>Replace</u>: To completely set aside an existing hazard study and to develop a new study that will serve as the replacement to the previous study. Because the goal is to have a

PSHA that can be used for critical nuclear facilities, the new study should be conducted using SSHAC Level 3 or 4 processes.

2. Revise: To modify one or more components of an existing SSHAC study. Revisions incorporate new information that only affects these specific components. For example, if over the course of time since the original SSHAC study was completed, the only significant new information is the addition earthquakes to the earthquake catalog, then a revision to that component of the original SSHAC SSC model may be appropriate. If the Existing Study Evaluation leads to the conclusion that the updated catalog has a significant impact on the existing hazard (based on the decision factors), then only that component of the existing SSHAC Level 3 SSC model would need to be revised. Revisions can be conducted using SSHAC Level 2 or 3 processes.

3. Refine: To adapt an existing regional study to incorporate site-specific information. Thus, in the context of the updating process described here, a refinement only applies to the adaptation of a regional model to a specific site. Refinements can be conducted using SSHAC Level 2 or 3 processes.

4. Correct: To rectify a nontechnical error in the existing documentation. A correction does not require the use of a SSHAC process. However, the correction should be documented transparently.

5. No Update Needed: To continue using the existing SSHAC study because it maintains the center, body, and range of technically defensible interpretations.

The decision regarding whether to replace, revise, refine, or correct should be made with respect to the Existing Study Evaluation discussed above. During the course of applying those decision factors, the degree to which new data, models, and methods would lead to changes in the inputs to the hazard and to the hazard results themselves will have been assessed. Further, the evaluation will indicate how many elements of the existing model are no longer technically defensible and the significance of the differences between the existing model and a hazard model that incorporates the new information. For example, the evaluation may indicate that only a limited number of elements of the hazard-input models, such as the maximum magnitude estimates for one or two seismic sources or the estimates of site kappa for ground motion models, require modification in light of the new information. Another example might be new methods that have come to light regarding the manner by which various instrumental magnitudes in an earthquake catalog should be converted to moment magnitudes, or the manner by which uncertainties in the conversions should be propagated into the recurrence estimates for seismic source zones.

If the number of elements of the hazard model requiring modification is substantial, and/or the significance of the modifications to the calculated hazard and to the technical defensibility of the study is large, then the decision to replace the existing study in its entirety should be made and the new study should be conducted, at a minimum, as a SSHAC Level 3 study. The high levels of regulatory assurance that accompany Level 3 studies will mean that the new hazard analysis will be technically defensible and will likely remain stable for a significant period of time.

If a limited number of elements of the SSC or GMC models are affected and other elements of the models continue to be technically defensible, then the decision to revise the existing study may be made. Depending on the significance of the modifications to the calculated hazard and/or to the defensibility of the technical bases for the revisions, the revision may be conducted as a SSHAC

Level 2 study (for revisions that are limited in number and relatively minor in significance) or a Level 3 study (for revisions that involve multiple elements of the model and have relatively larger significance). In either case, the SSHAC process followed can be limited in scope to only those elements of the hazard analysis that require modification, assuming that consideration has been given to how updating a particular element of the model will affect other elements.

For application of a regional SSHAC study to a specific site, it may be necessary to refine the regional study to account for site-specific conditions. Examples of this include adding in the site-specific V_S-Kappa corrections to a regional GMC model or adding details to the geometric parameters used to model proximal fault sources to add granularity to the SSC model. In these cases, the decision to refine the existing study may be made, and the elements of the refinement process would likely be derived from a SSHAC Level 2 or 3 study designed to capture the center, body, and range of technically defensible interpretations related to the specific topic needed for the site-specific refinement.

As shown in Figure 4-2, there are some slightly different considerations to be made in the updating decision process for a regional PSHA. After the decision has been made that the existing regional study does not need to be replaced, a decision is needed regarding whether or not multiple sites are affected based on the Existing Study Evaluation. If only a single site would be affected, then a refinement may suffice, as described above. However, if multiple sites would be affected, then a revision to the regional study would be recommended and it should be conducted using a SSHAC Level 2 or 3 process.

In applying the Existing Study Evaluation that leads to any of the five outcomes described above, there is considerable expert judgment that is required in making the assessment of whether or not the new information or new calculated results are significantly different from those derived from the existing PSHA. There are no explicit rules for making those significance determinations. However, by beginning with the SSHAC Level 1 study and thoroughly documenting the entire evaluation process, this Existing Study Evaluation provides an objective and transparent basis for decision making. Having this documentation in the record will benefit later evaluations as additional information becomes available.

5 SUMMARY

This section summarizes and highlights some of the key conclusions and recommendations made throughout this document. The reader is encouraged to refer to the full text to provide the appropriate context for the points made in this section.

- Most importantly, the five key features that distinguish all Senior Seismic Hazard Analysis Committee (SSHAC) studies are:

  — Clearly defined roles for all participants, including the responsibilities and attributes associated with each role.

  — Objective evaluation of all available data, models, and methods that could be relevant to the characterization of the hazard at the site.

  — Integration of the outcome of the evaluation process into models that reflect both the best estimate of each element of the hazard input with the current state of knowledge and the associated uncertainty. This distribution is referred to as the center, body, and range of technically defensible interpretations (commonly referred to as the CBR of TDI).

  — Documentation of the study with sufficient detail to identify all of the data, models, and methods considered in the evaluation, and justify in detail the technical interpretations that support the hazard input models.

  — Independent participatory peer review to confirm that the SSHAC process was followed appropriately and the technical assessments are justified.

- This document contains guidance for conducting expert assessments through the SSHAC process. This document builds on the framework described in the prior NUREGs (NUREG/CR-6372, “Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts” (NRC, 1997); and NUREG–2117, “Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies, (NRC, 2012c) and incorporates lessons learned from conducting recent SSHAC studies. This document does not invalidate the prior guidance documents or the studies conducted accordingly; however, the intent of this NUREG is to provide the most current standalone guidance. While the prior NUREGs contain useful concepts and historical context, this document should be used for conducting future SSHAC studies.

- The current document: strengthens the implementation framework for Level 3 studies based on recent experience; provides guidance on the essential attributes of Level 1 and 2 studies (missing from the earlier SSHAC documents); and develops a revised and more rigorous framework for decision making regarding the updating of existing SSHAC studies. Based on actual project applications, the conceptual underpinnings of the SSHAC guidelines in NUREG/CR-6372 remain strong.

- Due to large uncertainties in our understanding and models of earthquake processes and the lack of empirical data to eliminate this uncertainty, expert judgments are always required in seismic hazard analyses. The SSHAC process represents a formal, structured approach for incorporating the judgments of experts. Drawing on the field of decision analysis, a wealth of studies have been conducted, and can be utilized, regarding the use of experts to make estimates of uncertain quantities. There are several known cognitive biases that can plague expert assessments; most are not deliberate or intentional, but they must be countered. Experience on several SSHAC projects has shown that this can be accomplished successfully.

- The SSHAC guidelines in NUREG/CR-6372 defined four levels of SSHAC hazard studies, increasing in complexity from Level 1 to Level 4. The five key features of a SSHAC process noted previously are required at all SSHAC levels. The core objective of developing a hazard estimate that reflects the center, body, and range of technically defensible interpretations is the same at every study level. However, with the increased number of participants and greater interaction among the various experts, including the peer reviewers, the likelihood of effectively capturing the center, body, and range of technically defensible interpretations increases with study level. The higher study levels provide increased regulatory assurance. Therefore, one of the main criteria in selecting the SSHAC Level for a hazard study is the degree to which regulatory assurance is required (see Section 3.2.1).

- Because of the large number of participants and more focused interactions among the experts, Level 3 and Level 4 studies should be viewed as alternative ways of achieving the same degree of regulatory assurance.

- The essence of the SSHAC process is the structured interaction among experts to achieve a well-documented hazard study that captures the center, body, and range of technically defensible interpretations. Central to the success of the process, therefore, is clear definition of the different roles within a project and of the responsibilities that each role entails. This document defines the main roles and their relationships in the project structure for various SSHAC Levels, including attributes that are required for an individual to be able to contribute effectively in their role within a SSHAC process. These attributes are among the key criteria for selection of project participants because the SSHAC process is based on the assumption that the experts in each role possess the required knowledge, experience, and skill sets.

- Based on experience in the application of numerous SSHAC projects over the past two decades, flowcharts depicting the sequence of key features of projects conducted at each of the SSHAC Levels are presented. Level 3 and 4 studies include the most participants and workshops that allow observers to follow the proceedings.

- For all SSHAC Levels, the Evaluation, Integration, and Documentation phases of the project are present; the technical assessments are made by TI Teams (or individual experts, in the case of a Level 4 project); and the peer review is conducted as a continuous process throughout the project by the Participatory Peer Review Panel (PPRP). The attributes of each SSHAC Level are described, including the numbers of participants, transparency, regulatory assurance, cost, and duration.

- Specifications are provided in this document regarding the requirements for SSHAC Level 1 and Level 2 studies, which are more demanding than the requirements previously assumed in many applications in the absence of such detailed guidance. These specific minimum requirements emphasize the fact that all SSHAC studies have merit and are clearly distinguished from non-SSHAC studies.

- The largest increment in level of effort from one SSHAC level to another exists between Levels 2 and 3. This document provides suggestions to span the gap between Level 2 and Level 3 studies through the inclusion of specific options that would strengthen a Level 2 study in order to increase the degree of regulatory assurance without necessarily fully adopting all of the requirements of a Level 3 study.

- The document includes new guidance regarding procedures for determining whether an updated SSHAC study is needed and what the nature of the update needs to be to maintain the pedigree of the original study. The definitions and terms for these procedures have been clarified. The elements that compose the framework for evaluating an existing site-specific or regional study are given.

This intent of this NUREG is to carry forth the principles originally formulated in previous NRC guidance, while capturing the most current thinking regarding the SSHAC process. This information and guidance is presented with the assumption that further advances will be made in the future.

6 REFERENCES

Anderson, J.G. and S.E. Hough. "A Model for the Shape of the Fourier Amplitude Spectrum of Acceleration at High Frequencies." *Bulletin of the Seismological Society of America*. Vol. 74. pp. 1,969–1,993. 1984.

ANSI/ANS. "Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design." ANSI/ANS-2.26-2004; R2010. La Grange Park, Illinois: American National Standards Institute/American Nuclear Society. 2004 (Reaffirmed 2010).

_____. "Probabilistic Seismic Hazard Analysis." ANSI/ANS-2.29-2008. La Grange Park, Illinois: American National Standards Institute/American Nuclear Society. 2008.

_____. "Probabilistic Seismic Hazard Analysis." ANSI/ANS-2.27-2008. La Grange Park, Illinois: American National Standards Institute/American Nuclear Society. 2008.

APS. "Seismic Source Characterization for the Palo Verde Nuclear Generating Station, SSHAC Level 3." Arizona Public Service. 2015. <http://www.nrc.gov/docs/ML1507/ML15076A073.pdf>

ASCE/SEI 43-05. "Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities." *Structural Engineering Institute of the American Society of Civil Engineers*. 2005.

Atkinson, G.M. and M. Morrison. "Regional Variability in Ground Motion Amplitudes Along the West Coast of North America." *Bulletin of the Seismological Society of America.* Vol. 99. pp. 2,393–2,409. 2009.

Atkinson, G.M., J.J. Bommer, and N.A. Abrahamson. "Alternative Approaches to Modeling Epistemic Uncertainty in Ground Motion in Probabilistic Seismic-Hazard Analysis." *Seismological Research Letters*. Vol 85, No 6. pp. 1,141–1,144. 2014.

Baker, J.W. and C.A. Cornell. "Which Spectral Acceleration Are You Using?" *Earthquake Spectra*. Vol. 22, No 2. pp, 293–312. 2006a.

Baker, J.W. and C.A. Cornell. "Spectral Shape, Epsilon and Record Selection." *Earthquake Engineering and Structural Dynamics*. Vol. 35. pp. 1,077–1,095. 2006b.

Bazzurro, P. and C.A. Cornell. "Ground-Motion Amplification in Nonlinear Soil Sites With Uncertain Properties." *Bulletin of the Seismological Society of America*. Vol. 94. pp. 2,090–2,109. 2004a.

Bazzurro, P. and C.A. Cornell. "Nonlinear Soil-Site Effects in Probabilistic Seismic Hazard Analysis." *Bulletin of the Seismological Society of America*. Vol. 94. pp. 2,110–2,123. 2004b.

BC Hydro. "Probabilistic Seismic Hazard Analysis (PSHA) Model. Volume 2: Seismic Source Characterization (SSC) Model." Report No. E658. Vol. 2. WPR-3030. Vancouver, British Columbia: BC Hydro Engineering. 2012.

Beyer, K. and J.J. Bommer. "Relationships Between Median Values and Between Aleatory Variabilities for Different Definitions of the Horizontal Component of Motion." *Bulletin of the Seismological Society of America*. Vol. 96. pp. 1,512–1,522. 2006.

Bommer, J.J. "Challenges of Building Logic-Trees for Probabilistic Seismic Hazard Analysis." *Earthquake Spectra*. Vol. 28, No. 4. pp. 1,723–1,735. 2012.

Bommer, J.J. and H. Crowley. "The Purpose and Definition of the Minimum Magnitude Limit in PSHA Calculations." *Seismological Research Letters*. Vol. 88, No. 4, pp. 1097-1106. DOI: 10.1785/0220170015. 2017.

Bommer J.J., M. Papaspiliou, and W. Price. *Earthquake response spectra for seismic design of nuclear power plants in the UK*. ISSN: 0029-5493. Elsevier Science SA. pp. 968–977. 2011.

Bommer, J.J., K.J. Coppersmith, R.T. Coppersmith, K.L. Hanson, A. Mangongolo, J. Neveling, E.M. Rathje, A. Rodriguez-Marek, F. Scherbaum, R. Shelembe, P.J. Stafford, and F.O. Strasser. "A SSHAC Level 3 Probabilistic Seismic Hazard Analysis for a New-Build Nuclear Site in South Africa." *Earthquake Spectra*. Vol. 31, No. 2. pp. 661–698. 2015.

Bommer, J.J., F.O. Strasser, M. Pagani, and D. Monelli. "Quality Assurance for Logic-Tree Implementation in Probabilistic Seismic Hazard Analysis for Nuclear Applications: A Practical Example." *Seismological Research Letters*. Vol. 86, No. 6. pp. 938–945. 2013.

Bommer J.J., P.J. Stafford, J.E. Alarcon, and S. Akkar. "The Influence of Magnitude Range on Empirical Ground-Motion Prediction." *Bulletin of the Seismological Society of America.* Vol. 97, No. 6. pp. 2,152–2,170. 2007.

Cameron, W.I. and I. Green. "Damping Correction Factors for Horizontal Ground-Motion Response Spectra." *Bulletin of the Seismological Society of America*. Vol. 97. pp. 934–960. 2007.

Chiou, B., R.R. Youngs, N. Abrahamson, and K. Addo. "Ground-Motion Attenuation Model for Small-to-Moderate Shallow Crustal Earthquakes in California and its Implications on Regionalization of Ground-Motion Prediction Models." *Earthquake Spectra*. Vol. 26. pp. 907–926. 2010.

Code of Federal Regulations. "General Design Criteria for Nuclear Power Plants." Title 10—Appendix A—Nuclear Regulatory Commission, to Part 50. Washington, DC: U.S. Government Printing Office. 2012.

_____. "Earthquake Engineering Criteria for Nuclear Power Plants." Title 10—Appendix S—Nuclear Regulatory Commission, to Part 50. Washington, DC: U.S. Government Printing Office. 2012

_____. "Licenses, Certifications, and Approval for Nuclear Power Plants." Title 10—Nuclear Regulatory Commission, to Part 52. Washington, DC: U.S. Government Printing Office. 1989.

_____. "Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain." Title 10—Nuclear Regulatory Commission, to Part 63. Washington, DC: U.S. Government Printing Office. 2001.

_____. "Domestic Licensing of Special Nuclear Material." Title 10—Nuclear Regulatory Commission, to Part 70. Washington, DC: U.S. Government Printing Office. 2000.

_____. "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste." Title 10—Nuclear Regulatory Commission, to Part 72. Washington, DC: U.S. Government Printing Office. 1988.

_____. "Reactor Site Criteria." Title 10—Nuclear Regulatory Commission, to Part 100. Washington, DC: U.S. Government Printing Office. 2015.

Coppersmith, K.J. and J.J. Bommer. "Use of the SSHAC Methodology Within Regulated Environments: Cost-Effective Application for Seismic Characterization at Multiple Sites." *Nuclear Engineering and Design*. Vol. 245. pp 233–240. 2012.

DOE. "Facility Safety." DOE Order 420.1C. Washington, DC: U.S. Department of Energy. 2012a.

_____. "DOE Standard, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities." DOE-STD-1020-2012. Washington, DC: U.S. Department of Energy. 2012b.

GeoPentech. "Southwestern United States Ground Motion Characterization SSHAC Level 3–Technical Report." Rev. 2. March, 2015. <http://www.pge.com/en/safety/systemworks/dcpp/sshac/index.page>

Hanks T.C., N.A. Abrahamson, D.M. Boore, K.J. Coppersmith, and N.E. Knepprath. "Implementation of the SSHAC Guidelines for Level 3 and 4 PSHAs—Experience Gained From Actual Applications." USGS Open-File Report 2009-1093. 66p. 2009.

Kahneman, D., P. Slovic, A. Tversky, eds. *Judgment Under Uncertainty: Heuristics and Biases*. Cambridge, United Kingdom: Cambridge University Press. pp. 3–20. 1982.

Kammerer, A., Coppersmith, K., Coleman, J., Payne, S., Chokshi, N., and Budnitz, R.J. "Development and application of the seismic hazard periodic reevaluation methodology for meeting DOE Order 420.1C at Idaho National Laboratory." Transactions of the 24th Conference on Structural Mechanics in Reactor Technology SMiRT-24, BEXCO, Busan, Korea. 2017.

Keeney, R.L. "Value-Focused Thinking: A Path to Creative Decisionmaking." Cambridge, Massachusetts: *Harvard University Press.* 432 p. 1996.

Kulkarni, R.B., R.R. Youngs, and K.J. Coppersmith. "Assessment of Confidence Intervals for Results of Seismic Hazard Analysis." Proceedings of the Eight World Conference on Earthquake Engineering, San Francisco, California: Vol 1. pp. 263–270. 1984.

Miller, A.C. and T.R. Rice. "Discrete Approximations of Probability Distributions." *Management Science*. Vol. 29, No.3. pp. 352–362. 1983.

NRC. "Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendation 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-Ichi Accident." Washington, DC: U.S. Nuclear Regulatory Commission. 2012a.

_____. NUREG–2115, "Central and Eastern United States Seismic Source Characterization for Nuclear Facilities." Washington DC: U.S. Nuclear Regulatory Commission. 2012b.

_____. NUREG-2117, “Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies.” Rev. 1. Washington, DC: U.S. Nuclear Regulatory Commission. 2012c.

_____. “A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion.” Regulatory Guide 1.208. Washington DC: U.S. Nuclear Regulatory Commission. 2007.

_____. NUREG/CR-6728, “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-Consistent Ground Motion Spectra Guidelines.” Washington, DC: U.S. Nuclear Regulatory Commission. 2001.

_____. NUREG/CR 6372, “Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts.” Washington, DC: U.S. Nuclear Regulatory Commission. 1997.

_____. NUREG–1563, “Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program.” Washington, DC: U.S. Nuclear Regulatory Commission. 1996.

O’Hagan, A., C.E. Buck, A. Daneshkhah, J.R. Eiser, P.H. Garthwaite, D.J. Jenkinson, J.E. Oakley and T. Rakow. *Uncertain judgments: Eliciting experts’ probabilities.* Chichester, West Sussex, England: John Wiley & Sons. 321 pp. 2006.

Payne, S., Coppersmith, K., Coppersmith, R., Montaldo-Falero, V., Youngs, R., Rodriguez-Marek, A., and Silva, W. “Assessing the need for an update of a probabilistic seismic hazard analysis using a SSHAC Level 1 study and the Seismic Hazard Periodic Reevaluation Methodology.” Nuclear Engineering and Design, v. 323, p. 103-119. 2017.

PG&E. “Seismic Source Characterization for the Diablo Canyon Power Plan, San Luis Obispo County, California.” Report of the Result of a SSHAC Level 3 Study. Pacific Gas and Electric Company. 2015. <http://www.pge.com/en/safety/systemworks/dcpp/sshac/index.page>

PNNL. “Hanford Sitewide Probabilistic Seismic Hazard Analysis.” PNNL-23361. Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830, Pacific Northwest National Laboratory. Richland, Washington: Pacific Northwest National Laboratory. 2014. <http://www.hanford.gov/page.cfm/OfficialDocuments/HSPSHA>

Rodriguez-Marek, A., E.M. Rathje, J.J. Bommer, F. Scherbaum, and P.J. Stafford. “Application of Single-Station Sigma and Site Response Characterization in a Probabilistic Seismic Hazard Analysis for a New Nuclear Site.” *Bulletin of the Seismological Society of America*. Vol. 104, No.4. pp. 1,601–1,619. 2014.

Scherbaum, F., N.M. Kuehn, M. Ohrnberger and A. Koehler. “Exploring the Proximity of Ground-Motion Models Using High-Dimensional Visualization Techniques.” *Earthquake Spectra*. Vol. 26. pp. 1,117–1,138. 2010.

Stafford, P., R. Mendis, and J.J. Bommer. “Dependence of Damping Correction Factors for Response Spectra on Duration and Number of Cycles.” *ASCE Journal of Structural Engineering*. Vol. 134, No. 8. pp. 1,364–1,373. 2008.

Stromeyer, D. and G. Grünthal. "Capturing the Uncertainty of Seismic Activity Rates in Probabilistic Seismic-Hazard Assessments. *Bulletin of the Seismological Society of America*. Vol. 105, No.2A. pp. 580–589. 2015.

Thomas, P., I. Wong, and N. Abrahamson. "Verification of Probabilistic Seismic Hazard Analysis Computer Programs." PEER Report 2010/106. UC Berkeley, California: Pacific Earthquake Engineering Research Center, 2010.

Tversky, A. and D. Kahneman. "Judgments Under Uncertainty: Heuristics and Biases." *Science*. Vol. 185, No. 4157. pp 1,124–1,131. 1974.

Watson-Lamprey, J.A. and D.M. Boore. "Beyond Sa_{GMRotI}: Conversion to Sa_{arb}, Sa_{SN}, and Sa_{MaxRot}." *Bulletin of the Seismological Society of America*. Vol. 97, No.5. pp. 1,111–1,524. 2007.

APPENDIX A

DEVELOPMENT PROCESS FOR THIS NUREG

APPENDIX A DEVELOPMENT PROCESS FOR THIS NUREG

A.1 Background

As noted throughout this NUREG, the Senior Seismic Hazard Analysis committee (SSHAC) process set forth in the NUREG/CR-6372 was motivated by the need for a methodological framework that could be reliably applied and would lead to increased consistency in the hazard results obtained from different studies. The development and application of this framework was designed to provide enhanced regulatory assurance. NUREG–2117 was published in 2012 by the U.S. Nuclear Regulatory Commission (NRC) to expand on and clarify the guidelines in NUREG/CR-6372, particularly for Level 3 and Level 4 studies, and to capture some of the experience gained in the intervening years. Numerous additional studies since that time (see Table 1-1 of this document) have continued to build the experience of SSHAC practitioners and lend practical wisdom that could further improve the NUREG–2117 guidelines. The NRC staff determined that any update to NUREG–2117 would, in the spirit of the SSHAC process, benefit from robust engagement of the technical community.

A.2 Process

To accomplish this update, a SSHAC NUREG–2117 Updating Group (SNUG, or working group) was assembled to seek input from those who have been directly involved in the SSHAC process and who could provide first-hand "lessons learned" experiences. The core working group consisted of one NRC staff member, two staff from the Center for Nuclear Waste Regulatory Analyses, and two consultants, with considerable input from other NRC staff and oversight by an NRC Project Manager. The SNUG gathered information from various practitioners and stakeholders with the objective of considering a range of perspectives on key topics (see Table A–1 for a list of participants). The topics were chosen by the working group based on the perceived needs arising from implementation of SSHAC processes in several projects. The perspectives provided a firm basis for enhancing and augmenting the implementation guidelines. While the team requested input and opinions from many involved in recent SSHAC studies, this process was not, in itself, considered a SSHAC study.

Information gathering for this update was completed in four phases, with each phase focusing on a particular topic. These topics were (i) criteria for evaluating the need for an update of an existing hazard study; (ii) specification of SSHAC Level 1 and Level 2 Processes; (iii) detailed guidance for Level 3 and Level 4 Processes; and (iv) use of SSHAC for non-seismic hazard and risk assessments. For each topic, the working group selected possible participants and developed a list of interview questions for discussion. The potential participants were contacted via email to request their participation and provided a copy of the interview questions along with any needed background materials, such as portions of previously published NUREG documents. Individual phone interviews were then scheduled with each of the willing participants, who volunteered their time and input for inclusion in the NUREG update. The approximately one-hour phone interviews generally included a brief explanation of the overall NUREG update topics, an opportunity for the participant to provide general comments, and then a discussion of the participant's responses to the interview questions. A few interviewees chose to provide their input in writing, either in addition to or instead of an interview. When input was gathered from the group of participants, summaries of each of the responses to the questions were assembled and used to develop an agenda for a group discussion. Finally, for each topic, the working group then hosted a group discussion in Walnut Creek, California, that also was accessible via webinar for remote participants.

Table A–1 List of participants in SSHAC practitioner interviews	
Name	**Affiliation**
Walter Arabasz*	University of Utah
Michelle Bensi*	NRC
Julian Bommer	Imperial College London
Bob Bryce*	Pacific Northwest National Lab
Nilesh Chokshi	Independent consultant
Carola DiAlessandro*	GeoPentech
Fernando Ferrante	NRC
Emily Gibson*	Defense Nuclear Facilities Safety Board
Kathryn Hanson*	KLHanson Consulting
Brittain Hill	NRC
Annie Kammerer*	Kammerer Consulting
Joseph Kanney	NRC
Keith Kelson	U.S. Army Corps of Engineers
Jeff Kimball	Rizzo Associates, Inc.
Richard Lee	Los Alamos National Laboratory
Bill Lettis*	Lettis Consultants
Scott Lindvall	Lettis Consultants
Marty McCann*	Jack R. Benjamin & Associates, Inc.
Steve McDuffie	Department of Energy
Cliff Munson*	NRC
Richard Quittmeyer	Rizzo Associates, Inc.
John Richards	EPRI
Larry Salomone*	Independent consultant
Woody Savage	Independent Consultant
Dogan Seber	NRC
Carl Stepp*	Independent Consultant
Steve Thompson*	Lettis Consultants
*Also attended a group meeting/webinar	

Following each of the topical group meetings, the working group assembled key points of agreement, lessons learned, or examples of interest to include in this document. It is important to note that while each of the interviewees provided valuable input, there was not always agreement on all points. The group meeting (webinar) provided an opportunity for these differing views to be debated and for multiple viewpoints to be heard. The outcomes of these discussions were incorporated throughout this document by the working group. We deeply appreciate the generous sharing of the participants' time, wisdom, and experience to make this document more robust and to more accurately reflect recent SSHAC experience.

A.3 Topic 1: "Updating Criteria"

The first topic that the working group addressed was "Updating Criteria," or the criteria and process for updating an existing hazard study, as discussed in Chapter 6 of NUREG–2117. Among the goals was to better define the criteria and approach for "accepting, refining, or replacing" an existing study, and consider other aspects of this topic, such as whether the option of "revise" should be included; how often and by what mechanism existing studies should be evaluated relative to new data, models, and methods; how to define and determine the threshold for significant differences due to new information; and how local refinements relate to regional and site-specific studies.

The following questions were developed for the interviews:

1. How should existing hazard studies be evaluated relative to new data, models, and methods? How should these evaluations be documented?

2. What approaches should be used to assess whether changes in hazard inputs or to calculated hazard are significant? Are quantitative definitions of “significant” useful? If so, what metric is best to quantify “significant?”

3. Are the alternatives for evaluating an existing probabilistic seismic hazard analysis (PSHA) given in NUREG–2117 (accept, refine, replace) adequate? Are there other appropriate actions to consider?

4. Should a local “refinement” of a regional study be considered an update to the regional study; in the sense that a comparison is made between the hazard from the regional study and the hazard from the refined study? Are comparisons with the U.S. National Hazard map useful?

5. Are periodic updates to hazard studies necessary (for example, every 10 years)? As an alternative, are periodic reviews on the need to update sufficient? If so, how should these periodic reviews be implemented?

6. How do your responses to the above questions relate to the SSHAC Level of existing hazard studies and the SSHAC level of the update?

7. Should the guidelines for updating hazard studies be tied to the risk profile of the facilities for which the hazard is under review? For example, require periodic updates for highest risk category facilities (i.e., nuclear power plants) but suggest less stringent periodic or as-needed updates for facilities with lower risk profiles (spent fuel storage facilities and fuel cycle facilities)?

The interviews were conducted between June 8, 2015 and July 8, 2015. The group meeting was held on July 14, 2015. Approximately 13 practitioners participated or provided input to this topical discussion through the interviews and at the group meeting.

Several key messages were agreed on by the working group and presented in the group discussion. These key points included (i) the need for a SSHAC “brand,” a structured and controlled process for evaluation within a framework that is peer reviewed and documented; (ii) clarification that “updating” starts with an evaluation step that should be controlled by the SSHAC process; (iii) all decision points within this evaluation and update process should have some level of SSHAC for control and to maintain the pedigree of the original studies; (iv) the framework of evaluation and updating indicates the need for tracking and centralized version control of regional models; and (v) the updated NUREG needs to make careful use of well-defined terms.

A.4 Topic 2: “Level 1 and Level 2 Process”

The second topic that the working group addressed was “Level 1 and Level 2 Processes.” The guidance in NUREG–2117 focused on Level 3 and Level 4 studies almost exclusively. However, in addition to the Level 2 “refinements” that are currently being conducted at U.S. nuclear power plants, it is likely that current Level 3 studies (including the Central and Eastern U.S. Seismic

Source Characterization Model and the Next Generation Attenuation-East Model) will be updated in the future using a Level 2 process. Also, Level 1 studies are being used to screen existing studies or provide insights into the hazard significance of new technical data, models, and methods. Therefore, the working group determined that further guidance and specification of the essential steps in SSHAC Levels 1 and 2 processes was useful to include in this document.

The following questions were developed for the interviews:

1. All SSHAC studies have the same goals of conducting and documenting the evaluation and integration phases of the project, as defined in NUREG–2117. What is the minimum set of steps or attributes that would qualify a study to be considered a SSHAC Level 1 or 2 project? Does the focus of the study change what elements are required? For example, would there be differences for a study conducted for all elements of a hazard analysis (e.g., a replacement) versus a study conducted to address one or two key issues (e.g., a revision, refinement, or correction)?

2. What are the ways that the technical integration team demonstrates and documents that they have identified and evaluated all data, models, and methods during the evaluation stage?

3. What are the differences between SSHAC Levels 1 and 2, and between Levels 2 and 3, in terms of the products developed, costs, schedule, and regulatory assurance? Are there ways to reduce the large increment between the costs and benefits of Level 2 and Level 3 studies?

4. Workshops in Level 3 and 4 studies are designed to demonstrate that a comprehensive evaluation and integration process has been followed. However, workshops involve considerable time and resources. Should one or more workshops be encouraged as part of Level 2 studies? If so, how should those studies be designated (e.g., "enhanced" Level 2; 2+; 2a,b,c)?

5. What is the role of the probabilistic seismic hazard analysis (PPRP) in Level 1 and 2 studies, including when and how they interact with the project teams, and what written products are expected from them? What are the pros and cons of a participatory process versus a late-stage review?

The interviews were held between August 18, 2015 and September 4, 2015. The group discussion and webinar was held on September 10, 2015. Because less experience exists for the Level 1 and Level 2 processes, a smaller group participated than for the first topic (6 participants).

Several key outcomes were again identified by the working group: (i) regardless of the level of the study, there is a need for a SSHAC "brand," a structured and controlled process for evaluation within a framework that is peer reviewed and documented; (ii) the SSHAC process is designed to provide regulatory assurance, and higher SSHAC study levels are indicative of more rigorous reviews and can, therefore, contribute to increased regulatory assurance; (iii) clear and transparent documentation is key and should include technical justification for all elements of the final assessment or model, as well as data, models, and methods that were considered during the evaluation but not incorporated; (iv) aspects of updating criteria, as discussed in the first topic, provide context for where Level 1 and Level 2 processes may be used; and (v) Table 4-2 in NUREG–2117 should be updated; but there is an important distinction between "attributes" and "minimum requirements" for Level 1 and Level 2 processes.

The topic of Level 2 "options" was one of the major areas of discussion at the group meeting, in part because of the potential benefits and pitfalls of including multiple Level 2 designations in the guidelines. Participants generally agreed that there is a need to decrease the large step increment between Level 2 and Level 3, and that providing "options" serves the intended purpose of increasing the value of Level 2 studies. Participant opinion varied regarding whether the addition of options should receive new terminology. The outcome of the discussion was that because the need for options (and which options are useful) is highly dependent on the type and complexity of the study topic, there is no need to have a specific designation for Level 2 studies that include additional options.

A.5 Topic 3: "Level 3 and Level 4 Processes"

The third topic addressed by the working group was updates to guidelines for how to conduct Level 3 and Level 4 studies. Most recent studies have been SSHAC Level 3 studies, so there were significant lessons learned from these recent experiences that provided additional insights regarding how the guidance can be improved or augmented.

Because of the breadth of experience and input anticipated, the questions developed for this topic area were more comprehensive than for the other topics. They are as follows:

1. Role of PPRP. Current guidance calls for written comments from the PPRP following each workshop and detailed comments of the draft project report. In addition, the PPRP is only actively engaged with the Technical Integrator (TI) Team(s) during Workshop #3, "Feedback."

    a. Are there other project activities in which the PPRP should be included (e.g., work plan, working team meetings, or briefings), and what should the nature of their participation be (e.g., listening, reviewing, or active engagement)?

    b. Current guidance is ambiguous as to whether the PPRP can intervene mid-process to terminate a SSHAC study that is significantly off track or inadequate, and will not be able to comply with the SSHAC guidelines. Should the NUREG include more direct guidance for these types of situations? At what point in the project can this assessment be made?

    c. Are there additional PPRP milestones (briefings, reviews, or correspondences) that would improve the effectiveness of the PPRP and add to the regulatory assurance their reviews provide? If so, when in the project should they be developed?

2. Relative Timing of Workshop 3 and Development of the Final Models. According to current guidance, Workshop #3, "Feedback," is devoted to a presentation of the preliminary models the TI Teams developed, verbal feedback in the form of questions regarding the models from the PPRP, and hazard feedback based on sensitivity analyses conducted using the preliminary models. The TI Teams then use the feedback from the workshop to finalize the preliminary models that were the subject of the workshop.

    a. Based on your experience, how effective has the process been in allowing the PPRP to challenge the TI teams with respect to the technical defensibility of their preliminary models and the degree to which those models capture the center, body, and range of technically defensible interpretations? What can improve?

b. How mature should the preliminary models be to have meaningful interactions with the PPRP and to have meaningful hazard sensitivity analyses that provide the basis for developing the final models?

c. Some recent SSHAC Level 3 projects have held a post-Workshop 3 briefing between the TI Teams and the PPRP at the time that the final models have been developed, but prior to the final hazard calculations and development of the draft report. What are the benefits and pitfalls of this type of briefing? Are there other interactions, meetings, or briefings, or even workshops that can be used to show the PPRP (or the regulators) elements of the final models prior to the final hazard calculations and report writing?

3. Coordination between the Seismic Source and Ground Motion Characterization Models. Many of the recent SSHAC Level 3 studies have had separate seismic source characterization (SSC) and ground motion characterization (GMC) components.

    a. In what ways should the seismic source characterizations and ground motion characterization efforts be coordinated to develop reliable hazard sensitivity models needed to guide the TI Teams?

    b. When the SSC and GMC studies are performed in parallel, but distinct from each other [e.g., the recent Diablo Canyon Power Plant (DCPP) and Pablo Verde Nuclear Generating Station (PVNGS) SSC studies performed in parallel with the South Western United States (SWUS) GMC study], how much and what kind of interaction is needed among the various project leads, TI Teams, and PPRPs?

4. Role of Project Manager (PM). The current discussion of the role of the PM in NUREG–2117 identifies some key administrative tasks, but experience has shown that the PM usually fulfills additional responsibilities.

    a. What is the role of the PM in such activities as developing the Project Plan, selection of key project participants, point of contact with the PPRP, implementation of quality assurance (QA) requirements, interfacing with the project sponsors, and addressing challenges to the project schedule and budget?

    b. What recommendations would you make for the types of experience and attributes for the PM of the SSHAC Level 3 or 4 project?

    c. What advice would you give for methods or activities to ensure a close working relationship between the PM and the technical participants throughout the course of the project?

5. Flexibility for Workshops 1 and 2. Give us your opinion on whether you think we can add flexibility to the NUREG guidance to allow Workshops 1 and 2 to be integrated, swapped, or combined?

Other Implementation Advice. Based on your experience, is there any other advice or recommendations that you would like to provide regarding the implementation of SSHAC Level 3 or 4 studies? Are there specific areas of the guidance that should be more explicit, or allow greater flexibility?

The interviews for this topic were held between November 10, 2015 and December 18, 2015. There were nine participants for this topic. The group meeting and webinar was held on December 17, 2015.

Important input was received with regard to roles and interactions of the PPRP; roles, responsibilities, and characteristics of the PM; and purpose and flexibility of formal workshops and working meetings. Because of the broad nature of the questions and the type of input that was received, the group discussion focused on topics, such as roles of participants, rather than the enumerated questions.

Interviewees provided many insights regarding the presence and participation of the PPRP in working meetings. Most interviewees felt that PPRP presence at working meetings was useful and beneficial. Specifically, they noted that: (i) seeing the development process at the working meetings is key for PPRP members so that they understand the thought process and aspects considered; (ii) it is important to maintain separation between the TI Team and PPRP, specifically if a member of the PPRP is "wearing different hats" as an expert as well as a panel member; and (iii) the PPRP should have selective attendance at the working meetings, and whereas not all members need to attend every meeting, participation could be based on areas of expertise. Areas of differing opinion among the interviewees included (i) how "active" a participatory role should or could be in the working meetings; (ii) whether formal or informal working meetings were recommended; and (iii) methods of documentation of PPRP participation (though all interviewees recommended some form of documentation and sharing of information).

The group discussion also focused on the role and characteristics of the PM. Most respondents emphasized the critical communication role between the PM and project teams, sponsors, and stakeholders, as well as early communication of conditions that will impact cost, schedule, or technical aspects of the project to minimize disruptions to the project. The PM also has the responsibility to ensure that all project goals are reached, including the positive endorsement from PPRP. Most respondents felt that the PM should be involved in development of the Project Plan and selection of PPRP, although opinions about the measure of involvement ranged from a consultative role to a decision-making role in terms of selection of project participants.

Based on lessons learned, a number of important attributes of the PM were noted; specifically, that while it was important that the PM be technically knowledgeable, it was not necessary (and potentially not beneficial) to be a technical expert. However, some measure of technical expertise is needed to minimize the opportunity for miscommunication among the teams and stakeholders. The characteristics suggested by interviewees included demonstrated experience in managing large, complicated projects; strategic thinking; good risk management and resource prioritization skills; a strong understanding of the SSHAC process and QA requirements; and good interpersonal skills.

Interviewees also provided comments on the timing and potential for flexibility among the workshops. The general consensus was to keep the structure of the workshops but have some flexibility with the content. For example, it may be possible to have some experts and proponent models at Workshop #1, or have resource experts at Workshop #2, especially if there is ongoing data collection. However, it is still necessary to consider when to cut off new data collection. The data needs to be driven by the models, and it is important to have these discussions early on so that data collection is properly focused.

There was also general consensus that models need to be relatively mature prior to Workshop #3 for the sensitivity analysis to be meaningful. This process can be improved by proper planning and scheduling, as well as proper conveyance of information to the PPRP prior to Workshop #3. Some interviewees also endorsed a pre-Workshop 3 briefing, but there was not a consensus on this due to cost implications.

Both benefits and drawbacks of a post-Workshop 3 briefing were identified. Drawbacks included cost and perceived lack of benefit to sponsors. The benefits identified were the ability for the PPRP to review a more complete model prior to reviewing the reports, opportunity for vetting of potential issues, providing early information to regulators, and an opportunity for the PPRP to see how issues were addressed. With or without a final model briefing, the PPRP needs to clearly understand the final decisions, elements, and revisions from the draft model. To improve the guidance regarding workshops, the team and interviewees agreed that providing the completed hazard input document (HID) can serve as evidence that the model is relatively complete.

The final topic of discussion was coordination between the GMC and SSC efforts. The interviewees all agreed that coordination between the two efforts is important to ensure consistency and avoid disconnects. Several respondents felt that "cross-pollination" of team members among the two teams was helpful in ensuring that information was effectively conveyed and there is consistency among the assumptions and framing. Clear documentation was also noted as key. Additionally, interviewees emphasized the need for careful scheduling so that the tracks are complementary.

A.6 Topic 4: "Use of SSHAC for Non-Seismic Hazard and Risk Assessments"

The fourth and final topic the working group addressed was the use of SSHAC for non-seismic hazard assessments. Due largely to the history of the development of SSHAC guidance, applications of the approach have been focused primarily on the assessment of vibratory ground motion hazards. However, the attributes that define the inputs to a seismic hazard analysis, including large uncertainties, limited observational data, the need for expert judgment, and high safety significance also characterize other natural hazards. Indeed, the goals of the SSHAC process are ideal for capturing many of these uncertainties in a structured, transparent, and well-documented manner such that the final hazard assessment should capture the center, body, and range of technically defensible interpretations. Such hazards include volcanic, flooding, tsunami, wind loading, and so on.

Because of the wide variety of potential non-seismic analyses, the interview questions encouraged more free-form responses than previous interviews. The questions developed for this topic were:

1. For those who have SSHAC experience:

    a. Describe your experience using SSHAC for a non-seismic evaluation.

    b. What was the purpose of your project (i.e., the regulatory and technical purpose of the project)? How well-defined was your objective/output going into this?

    c. Where did you find the guidance helpful; where was it too ambiguous or difficult to apply to non-seismic issues?

    d. How does application for a non-seismic compare to seismic? (for those that have completed both)

    e. Did this SSHAC achieve the SSHAC objectives through a transparent and robust process of integration and evaluation?

2. For those who have not used SSHAC:

    a. Describe your hazard assessment.

    b. What was the purpose of your project (i.e., the regulatory and technical purpose of the project)? How well-defined was your objective/output going into this?

    c. How do you see SSHAC applying to this process?

    d. What are potential advantages or disadvantages, from your point of view?

3. For all:

    a. Are there specific recommendations that you would make for updating NUREG–2117 in this regard?

    b. Are there alternatives to the SSHAC process that are better suited to non-seismic hazards?

Participants were interviewed between February 9, 2016 and February 24, 2016. The group meeting and webinar was held on February 25, 2016. Input was received from eight participants.

There were several important points of discussion in this topic. The group of participants generally agreed that SSHAC is a "tried and true" process that results in well-considered, robust conclusions, and that the structure and use of peer review included in SSHAC can be useful for non-seismic hazard analyses, with adaptation. Aspects such as documentation, roles and responsibilities, and process may not need large changes for use in non-seismic applications. However, most of the participants expressed that seismic hazard analyses are more mature than most other hazard analyses (e.g., flooding, volcanic, or high wind). They noted that analyzing these non-seismic hazards is perceived by practitioners as more complex and less understood, in that both the inputs and outputs are less clearly defined in comparison to the well-established seismic hazard framework. Having a more mature framework for seismic hazard analyses has led to common understandings and expectations among the seismic experts, which helps constrain and focus the SSHAC process. Similar constraints do not currently exist for non-seismic hazards. For example, some interviewees pointed out that the inputs (initiating events) may not already be well defined, the types of data needed may not be known, and assumptions about process may not be agreed on. The group concluded that a robust framework (event sequence) is needed that accounts for the basic elements and interactions of the process under consideration, and this model should include a clear definition of what the results will be and how the results will be used in the risk assessment. The group also agreed that early interaction with end users is needed to help determine the scope of the analysis and the appropriate form of the output.

The participants agreed that several questions could be helpful to formulate non-seismic assessments. These questions are (i) What is the output? How will it be used? (ii) What are the attributes of the process that need to be developed? (iii) What are the initiating events or inputs? Are they already well defined, and if not, how can they be defined? (iv) How are the various events or processes in the analysis related and interfaced? (v) What data are needed? (vi) What are the assumptions? and (vii) What aspects of the analysis can be decided with no discussion (i.e., those aspects with no judgment component); which would need a side discussion (research); and which aspects would need to be decided as part of the SSHAC?

Ultimately, because it was well-recognized among the interviewees and the working group members that non-seismic hazard analyses are currently less mature than seismic hazard analyses, additional practical experience is needed in the application of non-seismic hazards probabilistically before guidelines can address how to conduct these studies effectively within a SSHAC framework.

A.7 Conclusion

To develop this update to NUREG–2117, we sought to take full advantage of the extensive expertise throughout the community of SSHAC practitioners by incorporating lessons learned from first-hand experiences. Our interview and workshop process, although not in itself a SSHAC study, allowed various viewpoints to be considered, debated, and integrated into this update. We are grateful for all of the input received, especially to those who graciously donated their time to participate in the interviews and topical discussions.

As noted in Section 1, there is no presumption that documenting today’s best advice regarding SSHAC implementation guidance should or will put an end to the evolutionary process that has characterized the past 20-plus years. On the contrary, the information and guidance provided in this document assumes that further advances will continue to be made in the future, and that experience will lend itself to further refinements and updates to these guidelines.

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11. ABSTRACT (200 words or less)

This document contains guidance for conducting expert assessments through the structured process that is referred to as the Senior Seismic Hazard Analysis Committee (or SSHAC) process. It serves as an update to the original SSHAC guidance in NUREG/CR-6372, “Recommendation for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and the Use of Experts” (NRC, 1997) and the implementation guidance provided in NUREG–2117, “Practical Implementation Guidelines for SSHAC Level 3 and 4 (NRC, 2012c). This document builds on the framework described in the prior NUREGs and incorporates lessons learned from conducting recent SSHAC studies. This document does not invalidate the prior guidance documents or the studies conducted accordingly; however, the intent of this NUREG is to provide the most current standalone guidance. While the prior NUREGs contain useful concepts and historical context, this document should be used for conducting future SSHAC studies.

Specifically, this document: (i) clarifies terminology and key concepts that are essential for all SSHAC studies; (ii) strengthens the implementation framework for Level 3 studies, based on extensive recent experience; (iii) provides guidance on the attributes of Level 1 and 2 studies; and (iv) presents a revised and more rigorous framework for decision-making regarding the updating of existing SSHAC studies. These updated guidelines describe an acceptable framework to implement the recommendations in Regulatory Guide 1.208 (NRC, 2007) with respect to performing a probabilistic seismic hazard analysis study.

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