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LESSONS LEARNED FROM APPLICATION OF THE NUREG-2117 GUIDELINES FOR SSHAC LEVEL 3 PROBABILISTIC SEISMIC HAZARD STUDIES FOR NUCLEAR SITES

Julian J Bommer[1], and Kevin J Coppersmith[2]

[1] Professor, Dept. of Civil Engineering, Imperial College London, UK (j.bommer@imperial.ac.uk)
[2] President, Coppersmith Consulting Inc., Walnut Creek, CA, USA

ABSTRACT

In 2012 the US Nuclear Regulatory Commission published guidelines for the implementation of SSHAC Level 3 and 4 hazard assessments that took account of 15 years of experience since the issue of the original SSHAC report in 1997. The guidelines in NUREG-2117 have been implemented in a number of current or recently completed projects. These projects show that the procedures work well in practice and that SSHAC Level 3 projects can be planned in such a way that they can be confidently completed on schedule and within budget. Optimal arrangements in terms of project planning, structure, management, and sequencing of the components of a SSHAC Level 3 study are suggested. One of the key lessons learned is that the Level 3 process has the capacity to be considerably more efficient, but no less effective, than the Level 4 process. Misunderstandings regarding the requirements for, and the value of, Level 1 and 2 studies are dispelled. SSHAC Level 3 processes incorporate significant procedural and technical peer review, thus making them compliant with quality assurance processes for nuclear facilities. There is also a common misconception that intermediate SSHAC Levels exist, whereas there are only the four unique levels and every study can only be classified into one of these categories.

INTRODUCTION

Seismic hazard assessment for nuclear facilities is increasingly performed using probabilistic approaches since these have the facility to take account of the inherent randomness in earthquake processes, such as the location of future events and the resulting level of ground motions at a specified location. A probabilistic seismic hazard analysis (PSHA) considers all possible earthquake scenarios that could affect a site and calculates the rate at which different levels of acceleration could be exceeded at the site. The presentation of the output in terms of a relationship between levels of ground motion and their associated probabilities means that PSHA can provide the input required for risk-informed decision making and performance-based design.

The basic input for a PSHA are Seismic Source Characterization (SSC) and Ground Motion Characterization (GMC) models, the first specifying the locations and average rates of recurrence of earthquakes of different magnitudes and the latter the expected levels of ground motion at the site due to earthquakes of various magnitudes located at a range of distances from the site. Typically, a unique SSC or GMC model cannot be defined for a given study because the available data allow multiple interpretations in terms of implications for future earthquakes, all of which may be technically defensible. Moreover, there will be scenarios considered in the PSHA integrations—such as large magnitude earthquakes at very short distances—which are not represented in the available databases and therefore require extrapolations from the data. The existence of multiple alternatives for components of the SSC and GMC models reflects epistemic uncertainty, which results from our lack of knowledge both about earthquake processes in general and about earthquake characteristics in the specific region under study. The quantification of epistemic uncertainty requires expert judgment and in order to ensure that all such uncertainties are identified and quantified in the SSC and GMC models, it has become common practice to involve multiple experts in making these assessments.

Two landmark PSHA studies that employed multiple expert assessments were conducted in the 1980s by the Electric Power Research Institute (EPRI, 1989) and Lawrence Livermore National Laboratory (LLNL; Bernreuter et al., 1989) for nuclear power plants in Central and Eastern United States. Divergence among the assessments by individual experts within each study was very large, and the mean hazard estimates from the two studies showed great differences. This prompted EPRI, the US Department of Energy (DOE) and the US Nuclear Regulatory Commission (NRC) to convene the Senior Seismic Hazard Analysis Committee (SSHAC) to explore the reasons behind these differences. In their report, which became known as the 'SSHAC Guidelines', Budnitz et al. (1997) made the following observation: "*In the course of our review, we concluded that many of the major potential pitfalls in executing a successful PSHA are procedural rather than technical in character. ..... This conclusion, in turn, explains our heavy emphasis on procedural guidance.*" The main outcome of the SSHAC study was guidelines for conducting a PSHA with a particular emphasis on how epistemic uncertainty could be assessed. Four levels of SSHAC study were defined, increasing in complexity from Level 1 to Level 4, with Levels 3 and 4 always requiring the participation of multiple experts to make the assessments.

Just as the SSHAC guidelines themselves were the outcome of lessons learned from the review of the experience of the EPRI and LNLL seismic hazard studies, the SSHAC guidelines have been reviewed in the light of experience gained from applications (e.g., Hanks et al., 2009). In turn, the lessons learned led to the development of detailed implementation guidance given in NUREG-2117 *Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies* (USNRC, 2012b). The original SSHAC guidelines were quite high-level, generalized, and based on limited project experience. They devoted a great deal of attention to Level 4 studies, which were viewed at the time as being the most rigorous option, and a key contribution of NUREG-2117 was to provide detailed guidelines for both Level 3 and 4 studies. In this regard, NUREG-2117 in particular reflected lessons learned from the SSHAC Level 3 project *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities* (CEUS-SSC; USNRC, 2012a). This paper continues this practice of recording lessons learned from applications of the SSHAC process, with particular emphasis on Level 3 studies and experience from a number of site-specific PSHAs conducted following the NUREG-2117 recommendations. The paper also briefly considers the other three SSHAC study levels and some common misconceptions regarding their application.

SSHAC LEVEL 3 STUDIES

The SSHAC Level 3 process has been adopted for two major site-specific PSHA studies in recent years, the Thyspunt new-build site in South Africa (Bommer et al., 2013) and the Hanford site in Eastern Washington (Coppersmith et al., 2013), the latter study encompassing DOE facilities on the Hanford site and the co-located Columbia Generating Station nuclear power plant. The lessons learned that are presented herein are derived primarily from the experience of the authors in those two studies, but also from roles played within other SSHAC Level 3 studies, including some of those initiated in response to the NRC 50.54(f) letter issued one year after the Fukushima accident in Japan and requiring all US nuclear power plant operators to re-assess the seismic hazard at their sites. As well as direct involvement in many of these studies, the authors have also been informed by discussions with participants in and reviewers of other SSHAC Level 3 studies, primarily in the United States.

The key conclusion that is drawn is that the SSHAC Level 3 process, as specified by the implementation guidelines in NUREG-2117, works well and provides an efficient but effective approach to meeting the SSHAC goal of capturing the center, the body, and the range of technically-defensible interpretations of the available data, methods and models relevant to the characterization of seismic hazard at a site. The experience gained in implementing the SSHAC Level 3 framework in very different environments has demonstrated that such projects can be planned, scoped, and managed in such a way that they can be completed on schedule and on budget, and that the duration and cost of these studies fall within relatively narrow ranges with surprisingly little variation globally. Some of the lessons and insights gained from the experience of these implementations are presented in the following sections.

Project Structure and Organization

A key feature of the SSHAC Level 3 process is the clear definition of roles for all participants and specific responsibilities assigned to these roles. Consequently, the success of a SSHAC Level 3 process can depend to an appreciable degree on the appropriate selection of participants to occupy the different positions within the project and ensuring that individuals conduct themselves in strict accordance with the requirements of their assigned roles. The different roles, and their inter-relationships, are illustrated in Figure 1.

In addition to providing the resources to conduct the study, the project sponsor defines the specific deliverables required to meet the engineering and regulatory requirements. The Project Management role is one that takes responsibility for the contractual, quality assurance, and administrative management aspects of the project. Close communication between the Project Manager, the Sponsor, and the Project Technical Integrator (PTI) is vital to ensuring that all project milestones are being met and any problems or threats to the success of the project are handled in a timely manner.

The core of the project is the Technical Integration (TI) Team, which is usually organized as two separate teams to develop the SSC and GMC models. The TI Teams are responsible for evaluating all existing data, methods and models with regards to their inherent quality and their potential applicability to the region and site under study. Towards this end, the TI Teams benefit from input from Specialty Contractors engaged to gather particular datasets or perform specific analyses, and from the presentation of datasets by Resource Experts and of models by Proponent Experts. The TI Team must collectively assume responsibility for the final models constructed through the integration process that follows from the evaluation.

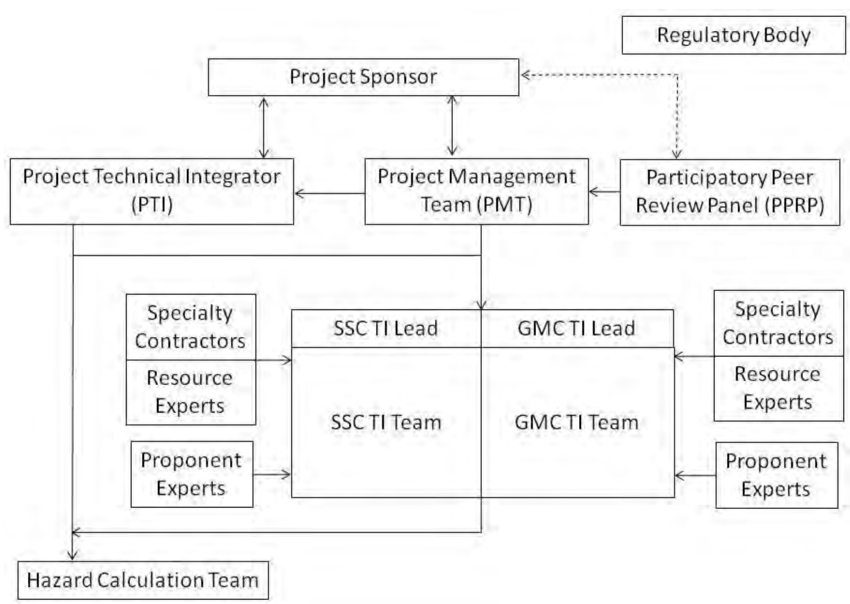

Figure 1. Organizational structure of a SSHAC Level 3 project (modified from USNRC, 2012b).

After the TI Team, the most important element of the project is the Participatory Peer Review Panel (PPRP), which is discussed in more detail in a later sub-section. Selecting the members of the TI Team and the PPRP is vitally important, and must ensure that they have adequate technical knowledge and experience of the SSHAC process, are willing to conduct themselves in an impartial and objective fashion, and are available to commit the necessary time and effort for the duration of the project. Figure 2 illustrates the different selection criteria that should be considered when assembling the project teams, and the degree to which each criterion needs to be met by different groups or individuals.

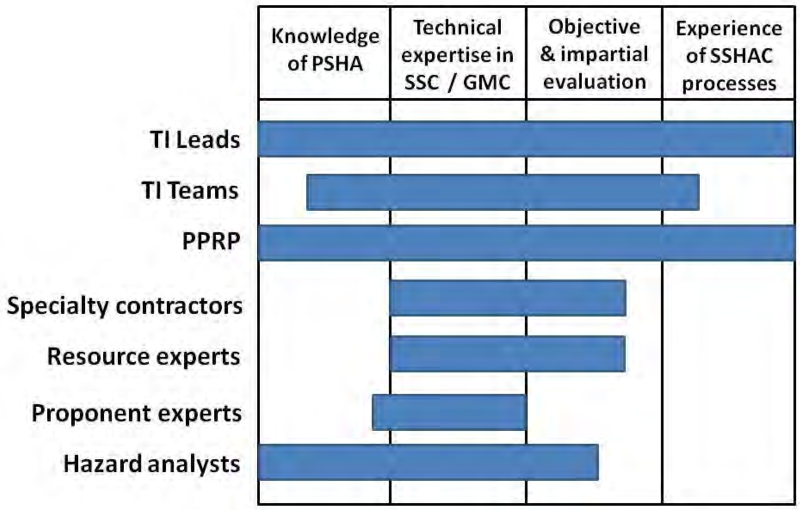

Figure 2. Selection criteria for participants in a SSHAC Level 3 project; the length of the bar within a given column reflects the degree to which that criterion must be met by each role.

In terms of the size of the TI Teams, there are no hard and fast rules but there should be sufficient number of members to not only cover all technical areas but also ensure that adequate technical challenge and defense will take place among the evaluators. The SSC TI Team will often be slightly larger than the GMC Team since it must comprise both geologists and seismologists, and also because there is generally a great deal more data to be evaluated for the SSC model. If possible, broad technical areas—for example, earthquake catalog development or site response analysis—should fall within the technical expertise of more than a single team member to ensure sufficient scrutiny and challenge within the team. The total duration of these projects is on the order of two-and-a-half years, so there is a good chance that one or more participants, due to health or other reasons, will exit at some point prior to completion, and the structure of the project should include a degree of redundancy to absorb such eventualities. This also applies to the PPRP, which for a full site-specific PSHA should not have fewer than five members.

The global pool of experts in SSC and GMC model development that can match the requirements indicated in Figure 2 is small, and given how many participants are required for a SSHAC Level 3 study (Figure 1), there could be great challenges in populating project teams in coming years (Bommer, 2012). With this in mind, NUREG-2117 specifically recommends involving young scientists and engineers in these projects so that they may gain experience and thus expand the pool of expertise. Adoption of this recommendation has generally proved successful because any lack of experience on the part of younger participants is balanced by the enthusiasm and energy they can bring to the work. To minimize the total number of experts required, any country or region with multiple sites to characterize in terms of seismic hazard can find considerable benefit in first developing regional SSC and GMC models through a SSHAC Level 3 project, followed by conducting multiple site-specific refinement studies (Coppersmith and Bommer, 2012).

As recommended in NUREG-2117, the PTI is the technical leader of the project and has overall responsibility for ensuring that all interface issues are addressed, not only between the SSC and GMC models but also between both models and the hazard calculations. The PTI is also the technical interface with the project sponsor, working alongside the Project Manager to address technical issues that arise throughout the project and ensuring that the output from the PSHA meets the engineering needs of the sponsor. It has been found that if the Project Manager is the sole point of contact with the sponsor on all issues, this places a heavy burden on that person with regard to understanding and communicating the technical issues on top of the already onerous administrative burden of coordinating the project overall.

Experience has shown that having the PTI and Project Manager interface with the sponsor jointly, with clear distinction of their respectively technical and managerial responsibilities, is conducive to more effective communication and smoother operation of the project. The PTI may also be one the two TI Leads, and this has been the case in both the Thyspunt and Hanford projects. This arrangement brings advantages in terms of familiarity with the details of the project and reduces the number of lines of communication, but it should be noted that it results in a very significant workload for that individual. The alternative arrangement of a PTI separate from the TI Leads might be preferable in some circumstances, but the PTI would then need to be prepared to attend some, if not all, of the TI Team Working Meetings and be in continuous communication with the TI Leads.

Project Budget and Schedule

One of the most important lessons learned from the experience of the Thyspunt and Hanford SSHAC Level 3 PSHA studies is that with good planning and strong management it is possible to bring these projects to their conclusion on schedule. This is important since it enables sponsors to meet regulatory schedule commitments. Keys to success include realistic and detailed budgeting and scheduling of all activities. SSHAC Level 3 and 4 projects involve a large number of people over significant periods of time and, as a result, entail significant labor costs. Experience has shown that careful manpower loading can be accomplished for all key project activities based on the required steps enumerated in NUREG-2117. Experience has also shown that project budgets must be realistic and adequate such that they can be properly monitored and managed throughout the course of the project without the need for scope changes or budget augmentations. The project schedule included within an overall Project Plan must be realistic, allowing sufficient time for all tasks to be carried out without comprising quality, and the key project events should be fixed in the diaries of all participants from the outset of the project. The main activities in a SSHAC Level 3 PSHA are illustrated in Figure 3, in which time runs from the top of the page. The project is built around three formal Workshops (see next section) and their position within the schedule determines the timing of most other elements. In addition to the Workshops, it has been found that four Working Meetings (WMs) of each TI Team are also required. These are less structured than the Workshops (WSs) but are centered around key decisions being made by TI Team members. In addition, *ad hoc* interactions among TI Team members will occur through smaller meetings, conference calls and other communication channels throughout the entire project duration. The first WM should occur between WS1 and WS2, and the second two in the space between WS2 and WS3, when the preliminary SSC and GMC models are developed. The final WM is scheduled after WS3 and serves as the opportunity for the TI Teams to finalize their models in the light of feedback obtained at the third and final Workshop.

There is great benefit in fixing the dates and locations of all three WSs and all four WMs from the very beginning of the project, and to embed these within the Project Plan. This enables all participants to block the dates in their schedules and ensure that they will be available. The early scheduling also helps with securing the participant of Resource and Proponent Experts in WS1 and WS2. This is not to say that there can be no flexibility, and changes may need to be made with no impact on the final delivery date, but fixing dates early ensures the proper level of commitment by all project participants.

In terms of timing, there must be a significant gap between WS2 and WS3, during which two WMs will take place and the TI Teams will develop preliminary models. Time needs to be allowed for extensive hazard sensitivity calculations to be executed using these preliminary models. However, it is also important to leave adequate time after WS3 for the models to be finalized, the definitive hazard calculations to be run and checked, and for the project to the documented. In view of these considerations, it is advisable to conduct WS1 early on in the project—within the first two or three months—and then hold WS2 sufficiently early (a few months later) to avoid bottlenecks downstream. Table 1 offers some suggestions for timings, based on an assumed 30-month project duration.

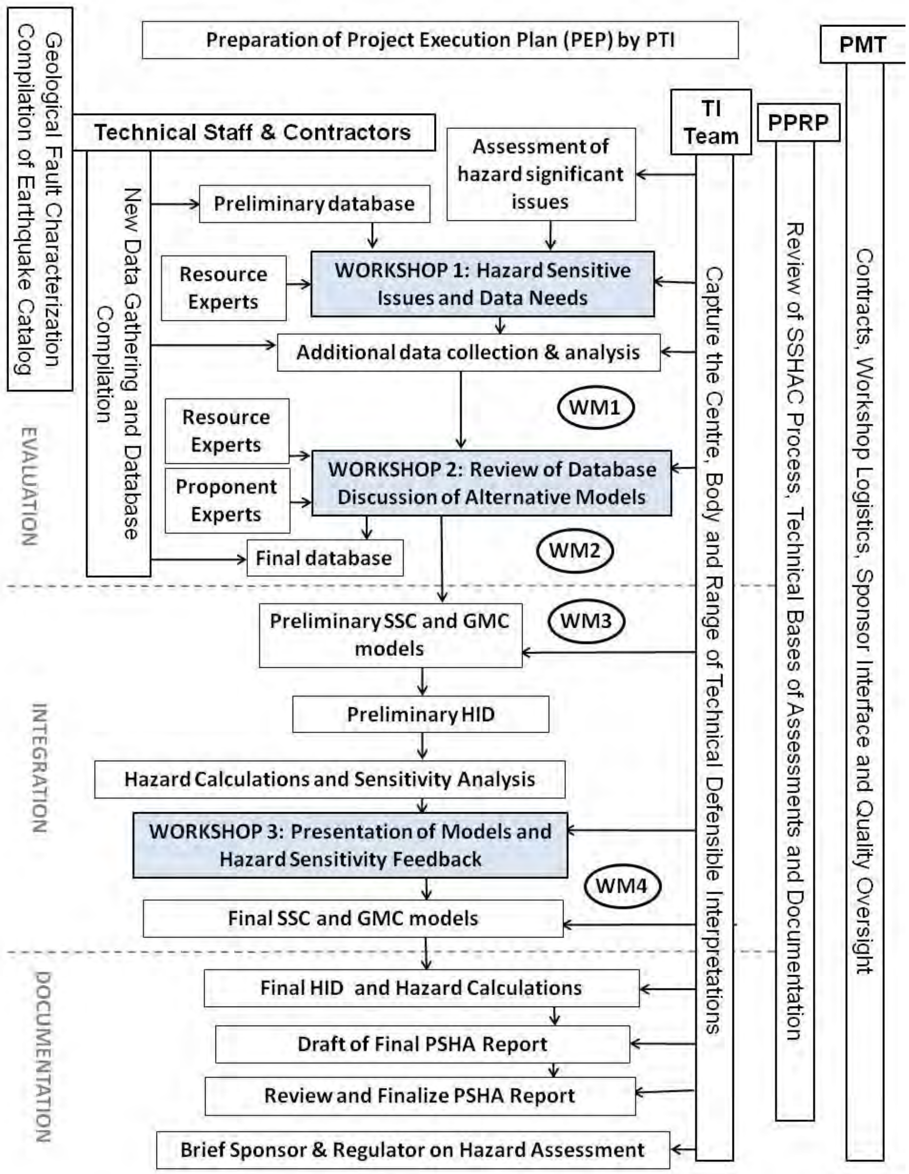

Figure 3. Flowchart for a SSHAC Level 3 project, with time running from the top to the bottom of the page (modified from USNRC, 2012b);WM is Working Meeting.

The SSHAC process requires that all available data relevant to the seismic characterization of a site be compiled in the early stages of the project and made available to all project participants. Although there is no obligation to collect new data, if sufficient resources are available to do so, activities to gather selected new data can be undertaken where these will have a major impact on constraining the hazard model and reducing the overall uncertainties. Such activities are likely to include the following: geological investigations to identify faults and constrain their deformation rates; compilation and refinement of the historical and instrumental earthquake catalogs; and measurement of the shear-wave velocity profile at the site. All of these activities can prove to be time-consuming and should be initiated well in advance of the PSHA activities. In particular, drilling boreholes, field mapping and trenching, and dating of geological samples can entail several months and should be initiated at the earliest possible stage. As indicated in Figure 3, some of these activities could be ongoing while the PTI, in liaison with the TI Leads and the Project Manager, drafts the Project Plan and contracts are placed with all participants in the PSHA. This is feasible since it is usually possible to identify at a very early stage those investigations and data collection activities that will provide vital input to the model development.

Table 1: Suggested timing of project events (based on 30-month total duration).

Project Activities	**Timing (month)**
Early Geological Investigations and Data Collection	-12 (if possible)
Drafting of Project Plan and Contracting Participants	-3 to 0
Launch Meeting	1
Workshop #1	**2 or 3**
Workshop #2	**6, 7 or 8**
Preliminary Hazard Input Document (HID)	18
Hazard Sensitivity Calculations	18-19
Workshop #3	**19 or 20**
Final HID	23
Final Hazard Calculations	23-26
Draft Final Report	23-27
PPRP Review of Draft Final Report	28
Respond to PPRP Comments and Revise Report	29 to 30
Deliver Final Report and PPRP Final Letter	30

Workshops

In addition to the timing of the Workshops within the overall duration of the project, experience from recent projects enables some suggestions to be made regarding the conduct and duration of the projects. One thing that has become particularly clear is that there is value in making the workshops rather formal in their structure, including issuing name badges to participants and observers, assigning seating arrangements, setting clear agendas and enforcing strict time-keeping. There are several benefits to be obtained from such formality, one of these being to convey to the participants—who will be drawn from a small international pool in which most people will know each other and will encounter each other in scientific or project meetings from time to time—the importance of the gathering. Another benefit is that best use will be made of the limited time, and the structured proceedings provide the PPRP, the sponsors and other observers (including regulators) with the best opportunity to observe the process in action.

The seating arrangements allow those who are actively participating in the Workshop (TI Teams, Resource and Proponent Experts) to be sat at the front of the room to facilitate discussion and exchanges. Those sat beyond a certain line in the seating arrangement will have observer status but it has been found to be very helpful to open the floor towards the close of each day's proceedings in order to allow the observers to make comments and to pose questions. An exception is Workshop #3, where members of the PPRP are no longer required to be observers but are encouraged to question the TI Teams regarding the bases for their models. For these sessions, it is helpful to bring the PPRP to the front of the room, which is generally feasible since at the final workshop there are generally no other participants apart from the TI Teams and the Hazard Calculation Team.

In terms of the duration of the Workshops, a clear conclusion from the experience to date is that parallel SSC and GMC sessions should be avoided as far as possible. There are several reasons for this, one of the most important being that the PPRP members generally benefit from collectively observing all of the proceedings, which is also true for other observers (which it is hoped will always include representatives of the relevant regulatory body as well as the project sponsors). Holding parallel sessions also creates an impossible challenge for the PTI. It has been found to be good practice that both TI Leads (and the PTI if this role is played by a third person) should be present at all Workshop sessions in order to ensure that all interface issues are addressed. In view of these considerations, the following arrangements have been found to work well and could be adapted to suit any particular project-specific requirements:

- WS1: 2½-3 days each for SSC and GMC sessions (in sequence), including a common session in the middle (for one day or half-a-day, depending on the scope) to address interface issues and discuss common data such as the earthquake catalog, etc.
- WS2: 3 days each, with no common sessions, in sequence (SSC and then GMC). In some cases, a day of rest may be programmed between the two, primarily for the benefit of the PPRP.
- WS3: Similar to WS1, but with the order reversed so that the GMC sessions are held first; the reason for this is that it is generally found, at this late stage of a project, that requests or requirements from the GMC Team to the SSC Team are more likely than the opposite. The common session is used to re-visit the interface issues identified at WS1, and to present hazard sensitivity results that show the interactions and dependencies of the two models.

Participatory Peer Review Panel (PPRP)

The PPRP is a vitally important part of a SSHAC Level 3 project, especially since the Panel's concurrence that the project has adhered to the SSHAC requirements and that the final model and hazard results are technically defensible is the basis for acceptance. To facilitate the work of the PPRP, it has been found very beneficial to have at least one member of the Panel present as an observer at all WMs, and the strategy of encouraging the PPRP to engage the TI Teams directly at WS3 has also been found to be very effective indeed. Informal debriefings to the TI Leads and the Project Manager, in closed meetings conducted with the sponsor representatives, at the close of each day of the WSs has also proved very useful. Providing the PPRP with copies of all documentations (white papers, data evaluation tables, etc) as and when these become available during the project—for information rather than for review—is also beneficial.

Since the independence of the PPRP is critical in a regulatory context where their concurrence may be taken as the basis for acceptance of the study, it can be beneficial for the PPRP to be engaged directly by the sponsor (rather than through any consulting body contracted to the sponsor). An option that may also be considered, and was implemented in the Level 4 PEGASOS study (Abrahamson et al., 2002), is for the regulator to contract the PPRP. These options are alluded to in Figure 1. To encourage perceptions of the independence of the PPRP, steps can be taken to allow for separate meeting and dining space for the Panel's use.

Project Documentation

The final project report on a SSHAC Level 3 PSHA is an important document, and forms the basis for the technical review by the PPRP. Since the report needs to be comprehensive it will tend to be extensive, and a great deal of unnecessary work can be avoided by establishing formatting guidelines, especially for references, at a very early stage in the project. If all interim documentation conforms to a common format (including such seemingly trivial matters as paper size, font, line spacing, and use of symbols), the work of compiling the final report may be appreciably reduced.

SSHAC Projects within Nuclear Quality Assurance Programs

Analyses and processes that are used for the design or safety assessment of nuclear facilities are typically governed by quality assurance (QA) programs. Since SSHAC Level 3 and 4 studies are commonly used to develop seismic design criteria, the question has been raised regarding whether the SSHAC Level 3 or 4 process can be considered to comply with nuclear-level QA. The position of the USNRC is clear and has been stated in NUREG-2117 (Section 5.12). It is noted that the American Nuclear Standards designed to address ANSI/ASME NQA-1-2008 *Quality Assurance Requirements for Nuclear Facility Applications* specifically refer to and recommend the use of the SSHAC guidelines. As stated in NUREG-2117, "*Therefore, it is the collective, informed judgment of the TI Team (via the process of data evaluation and model integration) and the concurrence of the PPRP (via the participatory* *peer review process) as well as adherence to the national standards described above that ultimately leads to the assurance of quality in the process followed and in the products resulting from the SSHAC hazard assessment framework*." This mitigates the need for any additional QA review process for the products of a SSHAC Level 3 or 4 study.

OTHER SSHAC LEVELS

The focus in this paper has been primarily on SSHAC Level 3 studies, which are the most appropriate for PSHAs conducted for the sites of new or existing nuclear facilities, and from which experience has recently been obtained. However, engagement in this field has also highlighted a number of issues related to the other SSHAC study levels, and how they are perceived and often misunderstood.

Is 4 Always Greater than 3?

A very important point to stress is that NRC makes no distinction between Level 3 and 4 studies in terms of the degree of regulatory assurance that they provide, and the 50.54(f) letter specifically requires Level 3 studies to be conducted. The key difference between the two levels is that the TI Team in a Level 3 study (which produces a single consensus logic-tree) is replaced by a panel of evaluator experts coordinated by a Technical Facilitator Integrator (TFI) in a Level 4 study. The TFI will usually form a composite logic-tree from those developed by the individual experts, which can lead to very large logic-trees, which will not necessarily be superior representations of the center, body and range of the technically-defensible interpretations (CBR of the TDI). The onus for technical challenge of the bases for the models lies primarily with the TFI, whereas in a Level 3 study the TI Team members will naturally enter into challenge and defense since they are required to build a single model capturing their individual views. Level 4 studies invariably require more time, and consequently larger budgets, but they do not necessarily provide a better way of achieving the SSHAC goals or great regulatory assurance.

Level 1 Studies and Requirements for Level 2 Studies

A surprising observation is how few studies claim to be SSHAC Level 1, almost as if this is something to be avoided as being inherently undesirable. Any SSHAC study must demonstrate that a full survey of the relevant literature has been made, that a logic-tree was developed that aimed to capture the CBR of the TDI, and that peer review of the study was conducted (which requires documentation of the review comments and how they were responded to either through revisions or rebuttals). Many of these elements are absent in routine PSHA studies, which would do very well to satisfy the requirements of a SSHAC Level 1 study.

Probably as a result of the conceptions regarding Level 1 studies, there is a tendency to classify many PSHAs that do not adopt Level 3 requirements as being Level 2. The key requirement over and above a Level 1 study needed to implement the Level 2 process is documented communications with members of the technical community regarding specific datasets or models of relevance to the PSHA. The documentation must be detailed and specific, and provide evidence for a serious level of engagement.

Only Integer Levels Exist: There is no SSHAC Level 2+

Experience has taught us that regardless of location, a Level 3 site-specific PSHA requires all of the essential elements specified in NUREG-2117 (Chapter 4). Fulfilling these requirements entails at least two years, core teams (PMT, TI, PPRP, etc) consisting of at least twenty people, and appreciable budgets. There have been many cases of attempts to claim some of the benefits of the Level 3 process without all steps being followed and classifying a PSHA as Level 2+, 2.5 or 2-3, none of which exist and all of which can only mean Level 2 studies. Conducting a single workshop with members of the technical community having specific local knowledge or relevant experience in analogous environments would be a robust way to achieve the requirements for a Level 2 study. The specific purpose of Chapter 4 of the NUREG-2117 was to provide a basis for a project sponsor or regulator to understand the minimum required elements, participants, and processes that must be included for a project to declare itself a SSHAC Level 3 study.

CONCLUDING REMARKS

The SSHAC Level 3 process is a tested and affirmed framework for the conduct of hazard studies for nuclear facilities that can be implemented with confidence and is likely to provide a high degree of regulatory assurance. Although such studies require significant time and budget resources, the investment needs to be viewed in comparison with the time that may be saved in accelerated acceptance of this critical component of most license applications and delays avoided by prolonged reviews. The confidence of utilities and regulators with regards to this approach will be increased by the accumulation of more examples of successful implementation, and continuing the process of incorporating lessons learned into the way the projects are conducted.

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