PROJECT PLAN FOR THE SSHAC LEVEL 2 PILOT PROJECT TO EVALUATE IMPLEMENTATION OF SITE RESPONSE WITHIN SSHAC STUDIES

Prepared for

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EXECUTIVE SUMMARY

This Project Plan identifies the overall framework, key activities, tasks, participants, schedule, and planned documentation for the execution of a Senior Seismic Hazard Analysis Committee (SSHAC) Level 2 study conducted on behalf of the U.S. Nuclear Regulatory Commission (NRC) to investigate efficient and technically defensible incorporation of site response into the SSHAC Probabilistic Seismic Hazard Analysis (PSHA) process. Although this project may utilize available data from specific sites, the purpose of this study is not to evaluate the seismic hazard at any particular site, nor to reevaluate the seismic hazard or outcomes of any prior SSHAC studies. Rather, the outcomes of this study will be used to improve the process used in seismic hazard evaluations involving site response computations and provide technical insights for future regulatory guidance updates. This SSHAC study follows guidance in the NRC document NUREG–2213, “Updated Guidance for SSHAC studies.”

Section 1 of the Project Plan describes the background and regulatory framework. Section 2 provides the overview and purpose of the study, including a description of SSHAC Level 2 processes. Section 3 details the planned process, schedule and deliverables.

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ABBREVIATIONS/ACRONYMS

AF	Amplification Functions
CBR of TDI	center, body, and range of technically defensible interpretations
CEUS	Central and Eastern United States
CFR	*Code of Federal Regulations*
CNWRA	Center for Nuclear Waste Regulatory Analyses
COL	Combined Operating License
DRS	design response spectra
EQL	Equivalent Linear
ESP	early site permit
GMC	ground motion characterization
GMM	ground motion model
GMRS	ground motion response spectra
NL	Non-linear
NPP	nuclear power plant
NRC	U.S. Nuclear Regulatory Commission
NTTF	Near-Term Task Force
PPRP	Participatory Peer Review Panel
PSHA	probabilistic seismic hazard analysis
QA	quality assurance
RG	Regulatory Guide
RVT	Random Vibration Theory
SPRA	seismic probabilistic risk assessment
SSC	seismic source characterization
SSE	safe shutdown earthquake
SSHAC	Senior Seismic Hazard Analysis Committee
SSI	soil-structure interaction
SSM	seismic source model
TI	Technical Integration
WUS	Western United States

PREVIOUS REPORTS

EFFECTIVITY

Revision 0 this document became effective on 11/15/2019. The document revisions consist of the section and table changes listed below.

Section Changed.	Description	Revision No. and Date Effective
1.1, 1.2	Clarification in response to PPRP comments	Rev. 1 6/9/2020
2.2	Clarifications in response to PPRP comments	Rev. 1 6/9/2020
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3.1	Clarification in response to PPRP comments	Rev. 2 8/11/2020
3.2	Clarification in response to PPRP comments	Rev. 2 8/11/2020
Table 3-1	Updated to indicate current progress	Rev. 2 8/11/2020
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1 INTRODUCTION

This Project Plan identifies the overall framework, key activities, tasks, participants, schedule, and quality assurance (QA) requirements for the execution of a U. S. Nuclear Regulatory Commission (NRC) research project. The objective of the project is to improve how site response analysis is integrated into probabilistic seismic hazard analysis (PSHA) to properly account for the epistemic uncertainty and aleatory variability of relevant site response data, models, and methods. The project objective will be achieved by performing a Senior Seismic Hazard Analysis Committee (SSHAC) Level 2 study to investigate how site response inputs should be defined and quantified, and subsequently incorporated into PSHA computations. Although this project may utilize data from existing sites, the purpose of this study is not to evaluate the seismic hazard at a specific site, nor is it to reevaluate the seismic hazard or outcomes of any prior SSHAC studies. Rather, the outcomes of this study will be used to inform future site response analyses and provide information to the Sponsor (NRC) for potential changes or enhancements to regulatory guidance

1.1 Background

In seismic hazard evaluations, site response analyses typically occur after the implementation and/or development of a seismic source model (SSM), ground motion model (GMM), and the subsequent PSHA calculations for the reference-rock conditions specified by the GMM. Site response analysis is site-specific and depends on several factors including the site strata (material types, stiffness, thicknesses) and response of the site strata to dynamic loading. Because site response is site-specific, the ability to accurately model site response depends on the quantity and quality of available site-specific geologic and geotechnical data, and the interpretation and use of that data to develop input models that are used to assess amplification (or de-amplification) of ground motions. The site response input models are assessed for a wide range of input ground motions as part of understanding the change in amplification (or deamplification) as ground motions increase.

In current practice, site response analyses are conducted outside of the SSHAC process used to develop SSM and GMM for the site. For this reason, the process used in the evaluation of data, models, and methods for site response analyses need improved standardized practices to ensure that associated technical judgments and decisions are properly justified and documented and are consistent with the SSHAC goal to capture the center, body, and range of technically defensible interpretations.

For example, the site amplification input parameters may not necessarily represent the center, body, and range of technically defensible interpretations and the epistemic uncertainty may be under- or over-estimated. In addition, the current regulatory guidance [Regulatory Guide (RG) 1.208] recommends multiple approaches that can be used to incorporate site amplification functions into the calculation of the final hazard curves and the subsequent ground motion response spectra (GMRS) estimates at the control point elevation beneath a nuclear power plant (NPP). These acceptable approaches were developed and documented in NUREG/CR–6728 and referred to as Approaches 2, 3, and 4 in that document. New reactor applicants have used either Approach 2 or Approach 3 in their seismic hazard assessments and the operating NPPs' re-assessments of seismic hazard estimates have primarily used Approach 3. There are multiple variants of these approaches. The Technical Integration (TI) Team will be implementing Approaches 3 and 4 in order to develop surface or control point hazard curves and spectra. The project documentation will provide the details of the TI Teams implementation of Approach 3 and 4.

In addition to improving the way site response analyses properly capture uncertainty, the NRC continues to evaluate the most appropriate methods for incorporating site response results into the PSHA calculations and the subsequent use of the PSHA hazard curves to derive GMRS and the foundation input response spectra (FIRS). The FIRS is used for soil-structure interaction (SSI) analyses to determine the seismic demands on nuclear facilities. To this end, the NRC has determined that it is necessary to perform a pilot project (described in this Project Plan) that fully investigates the best approaches for performing and then incorporating the site response results into the calculation of site-specific seismic hazard. The concept behind this project is to perform a pilot study at two sites to (i) perform site response analysis by implementing the SSHAC methodology in order to properly capture the appropriate level of the epistemic uncertainty and aleatory variability in site inputs resulting from site characterization and to evaluate alternative approaches for incorporating the site response results into PSHA computations, and (ii) evaluate alternative approaches for incorporating the site response results into hazard results. In addition to these considerations, the TI Team must consider the downstream use of site response analyses, beyond simply its use in hazard computations. This includes the use of site response analysis results in performing SSI and seismic probabilistic risk assessments (SPRA).

1.2 Regulatory Context and Selection of SSHAC Level 2

For NPPs licensed prior to January 10, 1997, Title 10 of the *Code of Federal Regulations* (10 CFR) 100.10(c)(1) and Appendix A establish the seismic design basis. Regulations in 10 CFR Part 50, Appendix A, General Design Criteria (GDC-)2 and similar principal design criteria require that structures, systems, and components be designed to withstand the effects of natural phenomena (including earthquakes) without loss of capability to perform their intended safety functions. This is a deterministic process that relies on considerable judgement and some level of unspecified margin to ensure safety.

For NPPs licensed after January 10, 1997, 10 CFR Part 50, 10 CFR 100.23, and Appendix S establish the seismic design basis. Appendix S defines the safe shutdown earthquake or SSE as: “Safe-shutdown earthquake (SSE) ground motion is the vibratory ground motion for which certain structures, systems, and components must be designed to remain functional.” In particular, 10 CFR 100.23, “Geologic and Seismic Siting Criteria” requires that the applicant determine the SSE and its uncertainty. Performing a PSHA is identified as an acceptable method to capture uncertainty.

In 2007, to support siting reviews of proposed NPPs, NRC staff developed RG 1.208, “A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion” to replace RG 1.165 (withdrawn in 2010). RG 1.208 provides guidance on satisfying 10 CFR 100.23 requirements and outlines how to perform a PSHA, the output of which is used to determine the SSE GMRS using the performance-based approach.

More recently, the NRC has developed a set of detailed guidelines for the development of formal expert analyses based on the SSHAC process [first described in NUREG/CR–6372 and further elaborated in NUREG–2117 (NRC, 2012)]. The latest NRC SSHAC guidance is contained in NUREG–2213, “Updated Implementation Guidelines for SSHAC Hazard Studies” (NRC, 2018).

Between 2004 and 2017, the NRC staff reviewed a large number of early site permits (ESPs) and Combined Operating License (COL) applications. All of these applications were consistent with 10 CFR 100.23 and Appendix S and nearly all followed the approach described in

RG 1.208. The majority of these applications used Approach 2, described in NUREG/CR–6372 when combining the site response results with the reference rock PSHA hazard curves. However, Approach 2 does not provide control point hazard curves or hazard-consistent uniform hazard response spectrum. Therefore, this project will be implementing Approaches 3 and 4.

In response to the March 2011 Tohoku earthquake and subsequent tsunami, the Commission established a Near-Term Task Force (NTTF) to conduct a systematic review of NRC processes and regulations. NTTF Recommendation 2.1 instructed the NRC staff to issue a request for information to licensees pursuant to 10 CFR 50.54(f). This information request was for licensees and holders of construction permits under 10 CFR Part 50 to re-evaluate seismic hazards at their sites against current NRC requirements and guidance. Based on the information provided by the licensees, the NRC staff determined whether additional regulatory actions were necessary to protect against the re-evaluated hazards. The NRC staff performed a detailed review of the NTTF Recommendation 2.1 submittals from all operating reactor licensees.

As a result of the reviews of the ESP/COLs applications and the NTTF Recommendation 2.1 submittals, staff and industry developed new insights. Consistent with these new insights and a continuing evolution towards a risk-informed, performance-based regulatory structure, the NRC staff recognizes the need for an update of RG 1.208 in the near-term. To support this update, staff recognized that additional research activities are necessary to document the technical bases for the update to RG 1.208.

Risk-informed regulation has been at the forefront of the NRC's licensing strategy for a number of years. The Commission approved the Agency Strategic Plan for 2018–2022, which continues this emphasis, encouraging the staff to focus its regulatory activities on the most safety-significant issues. The objectives of the project described in this Project Plan are consistent not only with this broad agency objective, but also with the Seismic Structural and Geotechnical Engineering Research Plan covering the time period of 2017–2021. Outcomes of this project may also support the development and documentation of technical bases to support the anticipated update to RG 1.208. Activities described herein include methods for performing site response analyses and including the results in PSHA, as well as the application of procedures described in NUREG–2213.

Consistent with guidance in NUREG–2213, Section 3.2.1, a SSHAC Level 2 study was chosen for this project to evaluate incorporation of site response. This level was selected with consideration of the following:

- The study is general in nature and is not providing input to a risk analysis at any given facility.

- The technical complexity of the topic and degree of contention regarding incorporation of site response analyses into the seismic hazard at a site. In particular, multiple methods are currently viewed as acceptable by the NRC as detailed in NUREG/CR–6728.

- Conduct of a Level 2, rather than a Level 1, involves outreach to experts.

The work and methodology identified in this Project Plan will be performed with the goals of improving seismic hazard evaluations involving site response and providing insights for future guidance updates, including RG 1.208. Methodologies with considerable precedence and recognition by the NRC and among the international seismic communities in NUREG–2213

(NRC, 2018) and NUREG–2117 (NRC, 2012) will govern the conduct of the study described in this Project Plan.

1.3 Quality Assurance

The Center for Nuclear Waste Regulatory Analyses (CNWRA®) has a QA program that is reviewed and approved by the NRC, the sponsor of this study. All applicable procedures from the CNWRA QA program will be used in the execution of this study, as appropriate.

1.4 Applicability

This Project Plan is applicable to all project participants, (i.e., those participants whose roles are defined in Section 3 of this Project Plan). Individual Statements of Work issued to consultants and subcontractors engaged on the project will be consistent with this Project Plan but will contain content appropriate to those contracts. This Plan will be finalized prior to conduct of work and any updates to the Plan will be issued as a revision to this plan (documented within the Project Plan) and issued to all project participants.

2 SCOPE OF THE SSHAC LEVEL 2 STUDY

This section describes the scope of the SSHAC Level 2 study and includes an overview of the SSHAC process that will be followed, the purpose of the study, the roles and responsibilities of participants, communication pathways, and planned documentation.

2.1 Overview

As described in NUREG–2213, the essence of the SSHAC process is the structured interaction among experts to produce 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.

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.

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 study 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 studies, regardless of the SSHAC Level at which the study is performed.

The flow chart from NUREG–2213 illustrating a SSHAC Level 2 study is included in Figure 2-1. For this study, although the general SSHAC process will be followed, the topic of the study is site response, so no separate seismic source characterization (SSC) or ground motion characterization (GMC) models will be developed or reviewed. Review of data will be limited to a determination of whether it is representative for the purpose of the study. Instead, methods for incorporating site response in the PSHA will be evaluated, documented, and peer reviewed through the SSHAC process, as discussed in the following section.

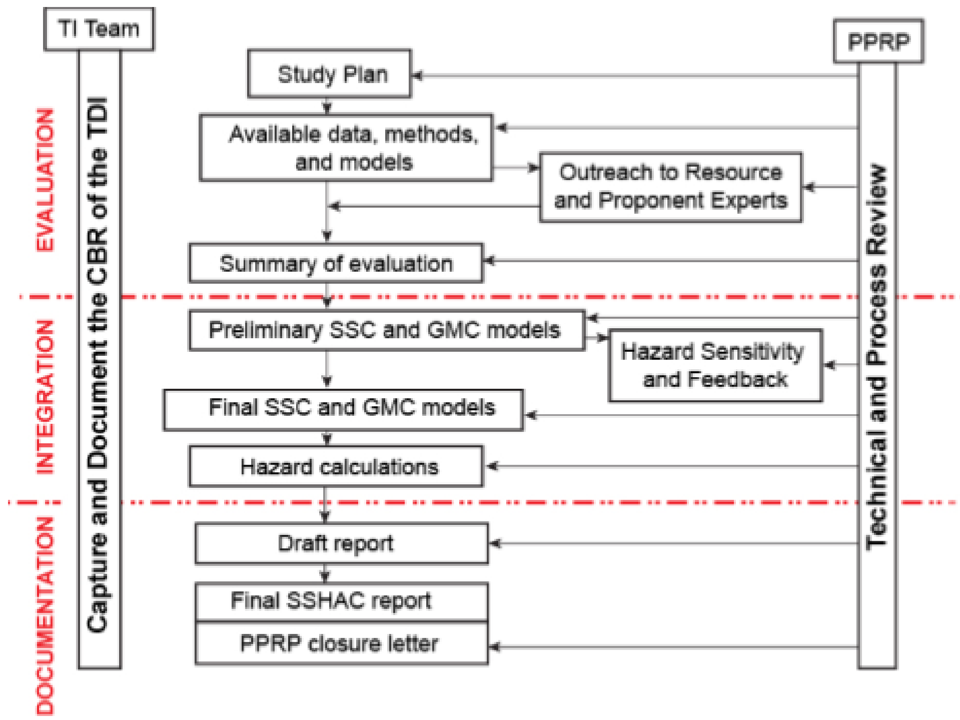

Figure 2-1 Flowchart for a SSHAC Level 2 PSHA study, with time running from top to bottom (from NUREG–2213)

2.2 Purpose

The state of practice for PSHAs conducted for critical facilities is evolving and now often incorporates the concept of partially non-ergodic PSHA, which uses a single-station sigma as the aleatory variability in the development of the reference rock PSHA. This fact emphasizes the need for the present study. The use of single-station sigma removes the site-to-site variability portion of the fully ergodic sigma, which then requires that a proper characterization of epistemic or knowledge-based uncertainties in the site term (e.g., in site response) be included in the final hazard calculations.

All site response analyses will be subject to some degree of epistemic uncertainty in the characterization of site properties. The degree of epistemic uncertainty will vary based on both site-specific data and the physical properties being estimated. For sites that are being investigated with modern methodologies and following the current NRC guidance for commercial power reactors, the epistemic uncertainty for many key physical properties may be fairly low. However, for some more challenging sites, usually outside of new reactor sites, or those investigated decades ago, the epistemic uncertainty in some physical properties may be substantial. It is for this reason that this project will endeavor to apply the SSHAC process to the conduct of site response analysis to develop a consistent, scalable framework for the estimation and subsequent propagation of epistemic uncertainty.

Examples of site properties that may have significant epistemic uncertainty associated with their values include (but are not limited to):

- Estimation of shear-wave velocity profiles, especially at depths below that reached with conventional near-surface techniques or for sites that do not have consistent geophysical measurements;

- Estimation of dynamic properties of near-surface materials for non-linear or equivalent linear analysis (modulus degradation and damping values);

- Estimation of the kappa values within the upper few hundreds of meters near the surface relative to estimates of the total site kappa. The different components of kappa, and the different approaches to estimate their values will be discussed in the project documentation.

In addition to considerations related to epistemic uncertainty, the estimate of the site term must also account for the aleatory variability in site properties (e.g., spatial variability within the site location). The proper differentiation of epistemic uncertainty and aleatory variability is challenging. This project will address methodologies to properly account for this separation.

The overall project goal is to perform a pilot study at two example sites to (i) perform site response analysis by implementing the SSHAC methodology in order to capture the appropriate level of the epistemic uncertainty and aleatory variability in site characterization and (ii) evaluate alternative approaches for incorporating the site response results into development of the PSHA hazard curves and GMRS. In addition to these considerations, the TI Team must consider the downstream use of site response analyses, beyond simply its use in hazard computations. This includes the use of site response analysis results in performing SSI and SPRA.

While the objective of this project is not the calculation of hazard for any particular location, two example sites will be selected. Hazard analysis, including site response evaluations, will be conducted for these two sites following the SSHAC Level 2 process. The objective of the hazard analyses is to compare the impact on hazard from the selection of alternative approaches for incorporating site response evaluation into the PSHA. As practicable, an outcome of this study will be to develop guidelines for using empirical site terms in PSHAs.

In the context of the purpose and scope of this project, a specific constraint of this project is that recommendations will be limited to the incorporation of epistemic uncertainties and aleatory variability resulting from site characterization but will not address model uncertainty associated with model error (i.e., model biases inherent in 1D wave propagation assumption and differences in site response predictions among various software implementations) in 1-D site response.

As noted in Section 1, the broader purpose of this project is to improve seismic hazard evaluations involving site response analysis and achieve the goal of providing insights for future guidance updates, including RG 1.208.

2.3 Roles and Responsibilities

The primary roles and their relationships in the project structure for the SSHAC Level 2 project are illustrated in Figure 2-2. The roles described are adapted from Figure 2-2 from NUREG–2213. As appropriate for this SSHAC Level 2 study, there are not separate SSC and GMC TI Teams and specialty contractors are not needed. Roles and responsibilities specific to this project are included in Table 2-1.

The NRC undertook this study in part because of the advancements in PSHA methodologies in recent years and the recognition of the technical community's move from ergodic to partially non-ergodic approaches in modern seismic hazard estimates. As appropriate, the NRC may incorporate outcomes from this project into guidance updates for seismic hazard studies. In addition to sponsoring the study, a few NRC staff members will take active roles as independent experts in this project. The NRC staff participants in the project include a member of the Participatory Peer Review Panel (PPRP), two members of the TI Team, and the Hazard Analysts and Database Managers. The NRC contractors also serve as a member of the PPRP and the Project Manager. Two TI Team members (including the TI Team lead), a member of the PPRP, and all resource and proponent experts are non-NRC or NRC-contractor staff members who come from various academic institutions or are industry practitioners. This level of diversity will ensure that the viewpoints of the project team are appropriately balanced and that the full center, body, and range of technically defensible interpretations is considered in the study in a way that the outcomes can be useful to the regulator and industry practitioners alike.

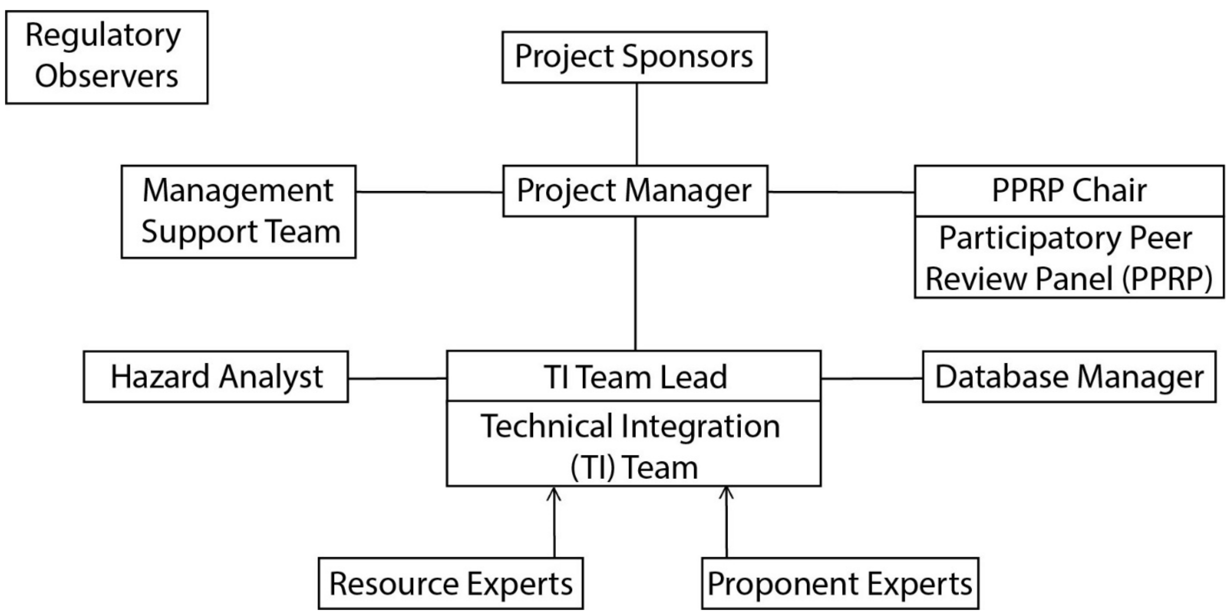

Figure 2-2 Primary roles of participants and their relationships in the project structure for the SSHAC Level 2 project (adapted from Figure 2-2 in NUREG–2213)

Table 2-1 Roles and Responsibilities for the SSHAC Level 2		
Role	**Participant (Organization)**	**Responsibilities**
Project Manager	Miriam Juckett (CNWRA)	Provides overall coordination and responsibility for organizational and administrative aspects of the project. Is the liaison between the Sponsor and the project participants, as needed.
Technical Integration Team Lead and Members	Dr. Adrian Rodriguez-Marek (TI Lead; Independent Consultant) Dr. Jon Ake (NRC) Dr. Cliff Munson (NRC) Dr. Ellen Rathje (Independent Consultant)	Responsible for developing the models and final recommendations for performing site response analysis following the SSHAC process and incorporating the site response results into PSHA hazard computations. As the *Evaluator* experts, TI Team members will objectively examine available data, diverse models, challenge their technical bases and underlying assumptions, and, where possible, test the models against observations. They will also identify the hazard-significant issues and the applicable data to address those issues, compile the available data into a project database (where practicable), and evaluate data relative to their quality and relevance for constructing models. They will also identify the full range of data, models, and methods that exist in the technical community. The TI Teams will rely on available data and literature to make their evaluations. In light of their evaluations of the data, models, and methods in the professional literature, TI Team members as *integrators* will then build models that capture their assessments of knowledge and uncertainties. If existing models and methods are not judged to be adequate or viable, the integrators may develop their own models and methods, or they may refine or enhance existing models and methods. The TI Team also has the responsibility of developing inputs for use by the Hazard Analyst.
Hazard Analysts and Database Managers	Dr. Scott Stovall (NRC) Dr. Thomas Weaver (NRC) Dr. Kristin Ulmer (CNWRA, Hazard Analysis support)	Responsible for establishing and managing necessary data sets and maintaining them in a Team-accessible location. Responsible for executing calculations and sensitivity studies and documenting the final results according to the inputs developed by the TI Team.
Sponsor	Represented by NRC Contracting Officer's Representative, Dr. Scott Stovall (NRC)	Funds the study and provides input as requested on the Project Plan; works with Project Manager to ensure that the purpose, process, and outcomes of the study will meet Sponsor goals.

Table 2-1 Roles and Responsibilities for the SSHAC Level 2		
Role	**Participant (Organization)**	**Responsibilities**
Resource and Proponent Experts	Youssef Hashash Gabriel Toro Brady Cox Tom Houston Ken Stokoe Bob Youngs Katerina Ziotopoulou Jon Stewart Walt Silva	Provides input via presentations and teleconference interviews on site response models and incorporation of site response into the hazard.
Participatory Peer Review Panel (PPRP)	Dr. John Stamatakos (CNWRA), PPRP Chair Jeff Kimball (Independent Consultant) Dr. Dogan Seber (NRC)	Responsible for technical and process reviews to ensure the SSHAC approach is implemented per regulatory guidance. For the technical reviews, the PPRP will ensure that the full range of data, models, and methods have been duly considered in the assessment as appropriate for this study, and all technical decisions are adequately justified and documented. They also ensure adequate oversight and assurance that the Evaluation and Integration aspects of the TI Team's assessments have been performed appropriately. Through their participation at meetings, conference calls, and webinars, the PPRP addresses TI Team concerns, guides selection of sensitivity analyses, reviews inputs to calculations as appropriate, reviews results of calculations and sensitivity analyses, and reviews all draft and final documentation. At the end of the study, if acceptable, documents approval in a closure letter.
NRC - U.S. Nuclear Regulatory Commission; CNWRA – Center for Nuclear Waste Regulatory Analyses; SSHAC – Senior Seismic Hazard Analysis Committee		

2.4 Communications

The SSHAC Level 2 participants will communicate using web based systems and via conference calls to complete the key tasks and activities. A Box account on the NRC Box portal has been established to store the SSHAC Level 2 data, files, references, documents, and results. The Box folders will also facilitate transmittals of documents among the team. The TI Team will communicate internally via weekly (or biweekly, as determined by the TI Team Lead) through conference calls and webinars. The TI Team will also communicate with the (Participatory Peer Review Panel) PPRP, as needed, via conference calls along with webinars, as practicable. The project manager will maintain a calendar accessible to the team in the Box site that will contain the schedule for deliverables, milestones, conference calls, targeted dates for completion of tasks and activities, deadlines for documentation, and meetings.

The organizational structure of a SSHAC study indicates key points of communication, although each SSHAC participant has responsibilities for communicating with other participants. To ensure that the SSHAC work flow process is implemented, the following highlight some of the key interface responsibilities:

- PM and TI Lead communicate with each other and with NRC (Sponsor) on a regular basis

- PPRP communicates with the PM to provide timely feedback to the TI Lead and TI Teams

- TI Lead directs work of the Hazard Analysts, Database Manager, and TI Teams

- Database Manager alerts TI Teams to new data in the database

- Hazard Analysts communicate model issues with TI Teams and time constraints to the TI Lead for computing hazard results

- TI Lead dialogs with Resource and Proponent Experts on their roles and responsibilities for attending the Workshop(s) which are part of executing the SSHAC process.

2.5 Documents and Data

The SSHAC Level 2 project will produce documentation that includes this Project Plan and a final project report. The PM will compile documents on behalf of the Sponsor and the Sponsor will make draft and final documents publicly available through means determined by the Sponsor. The documents will be developed by the SSHAC participants and reviewed by the PPRP. The PPRP will also issue a PPRP Closure Letter documenting their review of the SSHAC Level 2 study. The documentation will include a summary document that details the basic models, parameters, and methods for inputs to the calculations, and which will be included in the final report. Other documentation will be in the form of electronic files, data, and documents supporting the tasks and activities of the SSHAC Level 2 project.

No new data is anticipated to be collected as part of this project. Data and information will be compiled from available data resources and existing documents and will capture the range of views of the technical community. The resources include references from the literature, site-specific data and information collected for representative sites, publicly available data and information developed by other agencies, and other PSHAs. The data and information used to support the models will be documented in a Data Summary table in the final report.

3 KEY TASKS AND ACTIVITIES

This section outlines the key tasks and activities for the SSHAC Level 2 project. The first task is selection of sites, which will then be used in the second major task: convening a SSHAC Level 2 process.

3.1 Site Selection

The evaluation of alternative approaches for incorporation of site response effects into hazard computations will be informed by applying alternative approaches to compute seismic hazard at two pilot study sites. Therefore, the SSHAC process will be focused on the evaluation and integration phases of the two sites. The TI Team will first identify two sites for the pilot study tests. The selection of the two sites should be made in consideration of the types and quality of site characterization data that would be available, the availability of ground motion data for evaluating empirical constraints to the site response, and the types of challenges that would be present at potential locations of existing and future nuclear facilities. Such challenges may include, for example, uncertainty in the depth at which a reference horizon is located and the degree of spatial variability in soil properties.

The team should keep in mind in the selection of the pilot study sites the priorities of the sponsor (NRC). In particular, the NRC staff often must evaluate sites located in the Central and Eastern United States (CEUS), where empirical data are typically not available. Hazard analysis in the CEUS also faces the challenge that the host profile properties are not easily defined because of the potential for regional differences in shear-wave velocity profiles (V_S) and kappa values across the CEUS. This is not generally the case for the Western United States (WUS), where the abundance of strong ground motion recordings allows for better constraints of the effect of regionalization of kappa and V_S.

The team should consider selecting one site in the WUS and one in the CEUS. The advantage of selecting sites in these distinct tectonic environments is that the two sites would cover a range of challenges and data-availability. For example, WUS sites are available that have downhole arrays and/or sites with many recordings where the site term is partially constrained by recordings. In contrast, the CEUS site will be selected based on the abundance of geotechnical data and geophysical profiles with the recognition that there are likely no site recordings.

Identification of these sites is key to the success of the project. It should be made in careful consultation with project participants. Once the sites are selected, existing site characterization data, relevant local and regional geological data, and ground motion data will be gathered. Selection of these sites will be made ahead of the Workshop (Section 3.3). Because the discussion of data usage will be framed around the two pilot study sites, Workshop participants will be given access to the data, as applicable.

3.2 Convene SSHAC Level 2 Process

Based on the sites identified in Subtask 3.1, a basic SSHAC Level 2 process will be convened. The SSHAC process will be focused on the evaluation and integration phases of the two sites (without focus on data gathering, which will have been accomplished in Subtask 3.1 as needed). The activities of the SSHAC process will include a project kick-off meeting, a Workshop, and two working meetings (Table 3-1), as well as conference calls to plan the work to be discussed at the Workshop and the working meetings. The workshop will be the principal venue to obtain inputs from the resource and proponent experts. In addition, the TI Team may conduct phone interviews with resource and proponent experts as needed.

The TI Team will apply Approaches 3 and 4 to each of the sites selected in Section 3.1 and compare the results. The details of the methods used will be determined by the TI-Team after the Resource/Proponent workshop. The project should demonstrate what the logic tree may look like when the selected approach is used, as well as what the overall cost can be of not having sufficient data for constraining site response results.

The TI Team should keep in mind that an objective of the project is to propose recommendations for incorporation of site response in hazard calculations that properly account for the epistemic uncertainties and aleatory variability in site characterization. Therefore, a focus of the SSHAC process will be on how epistemic uncertainties in site characterization map onto the epistemic uncertainties in the amplification factors, and what the impact of aleatory variability is on these factors. The final output must not be simply a model for epistemic uncertainties and aleatory variability in shear wave velocities, but a process to obtain the epistemic uncertainties (and potentially also aleatory variability) in the Amplification Factors (i.e., the center, body and range), where the amplification factors are the factors that modify reference-rock motions to site-specific surface motions.

The quantification of model error in analytical estimates of site response analyses, including potential deviations from one-dimensional site response, are not part of the scope of the project. However, the approach developed by the TI Team can assume that estimates of model error exist and should propose how to incorporate these into the process to determine the center, body and range of values of the amplification factors.

The TI Team will identify, describe, and explain the issues that are relevant for capturing epistemic uncertainty in site response. To this end, the TI Team must select resource experts and proponent experts that have relevant knowledge on these issues. The TI Team is also responsible for preparing sets of questions for the resource and proponent experts that will guide the presentations of these experts towards contributing to achieving the project objectives.

Some of the considerations that the TI Team should take into account include:

- Identification of epistemic uncertainties implies necessarily that epistemic and aleatory uncertainties can be separated or separately identified. For site response, this is not a simple differentiation. Generally, spatial variability is assumed to contribute to aleatory variability. This distinction should be evaluated as part of this project.

- The quantification of epistemic uncertainties in site characterization, including considerations of the quality of the site characterization, the type and number of in-situ geophysical and geotechnical tests conducted, the availability and quality of laboratory data, and the volume of material tested by the in-situ and laboratory tests.

- How uncertainties in site characterization propagate into uncertainties in the Amplification Functions (AF).

- How to incorporate uncertainties in AFs into the PSHA so that mean response is hazard-consistent and hazard fractiles are properly quantified.

- Considerations to how much (if any) of the aleatory variability in site response should be included in the integration of site response results with the PSHA for the reference rock. There have been arguments made to remove entirely the uncertainty related to aleatory variability on the site response results because this uncertainty is accounted for already in the aleatory variability of the reference rock hazard. This consideration should be studied with a particular focus of avoiding under- or over-estimation (i.e., double-counting) of uncertainty

- Model choice: The choice of Random Vibration Theory (RVT) versus time domain approach; Equivalent Linear (EQL) versus Non-linear (NL) approach– these choices introduce additional uncertainties. The TI Team should consider how the choice of model may constrain the way some uncertainties in site characterization map onto site response results and how each of their uncertainties are taken into account.

In addition to these considerations, the TI Team must consider the downstream use of site response analyses, beyond simply its use in hazard computations. This includes the use of site response analysis results in performing SSI and SPRA.

Prior to the workshop, the TI Team will familiarize themselves with the data, participate in pre-workshop discussions, and determine whether additional information is needed from resource and proponent experts. After the workshop, the TI Team will develop a preliminary site response analysis model, provide information to the hazard analysts to conduct a hazard sensitivity evaluation (and assess feedback), develop a final site response analysis model, develop a draft results document for review by the PPRP, and respond to PPRP comments to develop a final report. The PPRP members will review initial materials, observe TI Team activities, review and comment on the draft report, and provide a completion letter.

3.3 Schedule of Tasks and Activities

The following tasks in Table 3-1 were discussed at the Project Kick-off Meeting and subsequent meetings and will be further updated as the project progresses. Updates to the project plan activity table will be recorded in the "change history" at the beginning of the document.

Table 3-1 Project Plan Activity Table			
Activity	**Target Completion**	**Team Lead/Participants**	**Actual Completion**
Technical Tasks			
Site Selection – WUS	End Sept. 2019	Scott Stovall	October 2019
Site Selection – CEUS	End Sept. 2019	Thomas Weaver	October 2019
Collect site data for WUS site a. Collect available Vs data and geotechnical data (for the full array) • Geotechnical data should include, if available, laboratory testing b. Collect geological information with a view of building a deep profile • Possibly search for deep Vs profiles in the vicinity (oil/gas exploration wells) c. Collect ground motion data [Strong motion and broadband instruments (for the full array)] • In the form of a flatfile (NGA West2 format)	End Oct. 2019	Scott Stovall	March 2020
Collect site data for CEUS site a. Collect available Vs data and geotechnical data • Geotechnical data should include, if available, laboratory testing • Data should be selected based on proximity, but include all data that allows for the characterization of deeper profile • Decide on a data management and visualization tools for geotechnical data b. Collect geological information with a view of building a deep profile • Possibly search for deep Vs profiles in the vicinity (oil/gas exploration wells)	End Oct. 2019	Thomas Weaver	(Substantively complete; additional data to be collected at SRS if COVID-related travel restrictions are lifted)

Table 3-1 Project Plan Activity Table

Activity	Target Completion	Team Lead/Participants	Actual Completion
Set up hazard calculations for WUS site a. Select oscillator periods b. Consider a subset of faults and an area source around the site • Recurrence rate values for source zones for National Seismic Hazard Maps documentation • Fault sources parameters from National Seismic Hazard Maps documentation • Simplified when needed (no consideration of time-dependent processes, etc.) c. GMM: SWUS ground motion models with a simplified GMC logic tree (e.g., only one branch for aleatory variability) d. Hazard coding and hazard input must be set up e. Run preliminary hazard for reference condition	Jan. 18, 2020	Cliff Munson (help from David Heeszel, Jon Ake)	Completed, with iterations prior to June 2020
Set up hazard calculations for CEUS site a. Select oscillator periods b. Use CEUS SSC model, with the freedom to simplify sources • Use only highest weighted area source zones • Include Charleston RLME c. Use NGA East for GMM with a simplified logic tree (e.g., simplified aleatory variability) • Contingent on NGA East being coded up, possibly revisit this d. Hazard coding and hazard input must be set up	Jan. 18, 2020	Cliff Munson (help from Roland LaForge, Jon Ake)	Completed, with iterations prior to June 2020

Table 3-1 Project Plan Activity Table			
Activity	**Target Completion**	**Team Lead/Participants**	**Actual Completion**
Conduct tasks that are outcomes of Working Meeting 1 a. Build logic tree for site response b. Apply approach/approaches to build median and epistemic uncertainty of AFs c. Apply approach/approaches to implement AFs into hazard d. Run preliminary hazard and GMRS e. Sensitivity analysis on hazard/site response	To be updated in Jan. 2020 WM	TI Team	Task progress ongoing since January 2020. Updates discussed in 6/2/2020 meeting and in July 2020 WM.
Logistical and Meeting Tasks			
Selection of Invitees	End of Oct. 2019	TI Team, Miriam Juckett (budget)	End of Oct. 2019
Email initial invitations to invitees	End of Oct. 2019	Adrian Rodriguez-Marek	End of Oct. 2019
PPRP reviews invitation list	End of Oct. 2019	PPRP	End of Oct. 2019
Project plan sent to PPRP for review	Mid Nov. 2019	PPRP/Miriam Juckett	Nov. 18, 2019
Determine and invite phone participants	Nov. 25, 2019	TI Team	February 2020
Contract setup for invitees	End of Nov. 2019	Miriam Juckett	January 2020
Logistics for travel and information to attendees	End of Nov. 2019	Miriam Juckett	End of Nov. 2019
Finalize questions, tasks, and presentation guidelines for invitees (Team) and email (Adrian)	Dec. 2, 2019	TI Team	January 2020
Complete phone interviews	After workshop		March 2020
Prepare Workshop agenda; Assign presentations to team members on overview topics; transmit to PPRP for review	Dec. 9, 2019	TI Team, Miriam Juckett	December 2019
PPRP review agenda; finalize agenda with input	Dec. 16, 2019	PPRP; TI Team	December 2019
Complete advance workshop logistics (meeting notice with call-in details, confirm attendees, etc.)	Jan. 21, 2020	Miriam Juckett	Jan. 21, 2020
Complete on-site workshop logistics (print materials, room setup, etc.)	Jan. 27, 2020	Miriam Juckett	Jan. 27, 2020

Table 3-1 Project Plan Activity Table			
Activity	**Target Completion**	**Team Lead/Participants**	**Actual Completion**
Conduct workshop a. Identify issues of hazard significance as they relate to site response b. Capture and evaluate alternative approaches for conducting site response analyses for NPP (both theoretical approaches and user implementation) • An issue is nonlinearity, and when to bring up strain limits beyond which EQL does not work: if these limits are applied to mean hazard it is different than if they are applied to fractiles c. Capture and evaluate alternative approaches for interpreting site characterization data, including consideration of uncertainty d. Capture and evaluate alternative approaches for implementation of site amplification into the hazard e. Evaluate downstream implementations of hazard and site response results (SSI and SPRA)	Jan. 8-29, 2020	All	Jan. 28-29, 2020
Workshop follow-up activities a. PPRP provides comments b. TI Team responds to PPRP comments c. Add documentation from WS to project database	a. Feb. 11, 2020 b. Feb. 25, 2020 c. Mar. 3, 2020	a. PPRP b. TI Team c. Juckett/Stovall	a. Jan. 30, 2020 b. Feb. discussions with PPRP (email exchange and verbal) c. Mar. 13, 2020

Table 3-1 Project Plan Activity Table

Activity	Target Completion	Team Lead/Participants	Actual Completion
Conduct Working Meeting 1 a. Digest information from the WS b. Compile information from phone interviews with proponent/resource experts c. Draft a logic tree for site response for each of the two sites d. Plan work to be conducted towards project objectives e. Decide on how to document process and final results	Jan. 30, 2020	TI Team, Scott Stovall, Thomas Weaver, Miriam Juckett	Jan. 30, 2020
Complete logistics for Working Meeting 2	July 7, 2020	Miriam Juckett	July 7, 2020
Conduct Working Meeting 2 a. Review all initial results b. Decide based on sensitivity analysis proposed approach/approaches for final hazard runs c. Decide/plan if additional sensitivity analyses are needed d. Document preliminary hazard results and outcomes of WM2	July 21-23, 2020	TI Team	July 21-23, 2020
Documentation Tasks			
Running tab of recommendations for updates to guidance	Ongoing	TI Team/ Miriam Juckett	Ongoing throughout project
Maintain documentation of all presentations in WS, WMs, phone interviews	Ongoing	Miriam Juckett/ TI Team	Ongoing throughout project
Tentative results review	Week of Nov. 30, 2020; Revised to May 2021	TI Team	May 27, 2021
Prepare Draft Final Report – send to PPRP	Dec. 31, 2020 Revised to July, 2021	TI Team/Adrian Rodriguez-Marek	July 16, 2021; PPRP briefing July 27, 2021
PPRP reviews draft final report and issues comments	January 31, 2021	PPRP	August 5, 2021

Table 3-1 Project Plan Activity Table			
Activity	**Target Completion**	**Team Lead/Participants**	**Actual Completion**
	Revised to August, 2021		
Address PPRP comments and prepare final report (transmit to PPRP)	Feb. 28, 2021 Revised to mid-September, 2021	TI Team/Adrian Rodriguez-Marek	Sept. 17, 2021
PPRP issues closure letter	March 19, 2021 Revised to early October, 2021	PPRP	Oct. 12, 2021
Final documentation for NRC contract	NLT March 29, 2021 Revised to Sept 30, 2021	Miriam Juckett/ Scott Stovall	Sept. 30, 2021

4 REFERENCES

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10 CFR 100.23. Code of Federal Regulations, Title 10, Energy, § 100.23. "Geologic and seismic siting criteria." Washington, DC: U.S. Government Publishing Office.

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NRC. Regulatory Guide 1.165, "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion." Washington, DC: U.S. Nuclear Regulatory Commission. March 1997.

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APPENDIX A

WORKSHOP AND WORKING MEETING AGENDAS

AGENDA

SSHAC WORKSHOP ON SITE RESPONSE – DAY 1

January 28, 2020

8:00 am – 5:30 pm, ET

SwRI Office, Rockville, MD
1801 Rockville Pike, Suite 105

8:00 – 8:30 am	Introduction: Project description, scope, and objectives	Miriam Juckett Jon Ake
8:30 – 9:30 am	Epistemic uncertainty in ground motion characterization and site response analyses	Adrian Rodriguez-Marek
9:30 – 10:00 am	Break	
10:00 – 10:20 am	Western United States (WUS) Data	Scott Stovall
10:20 – 10:40 am	Central and Eastern United States (CEUS) Data	Thomas Weaver
10:40 – 11:00 am	Sources and Ground Motion Models	Cliff Munson
11:00 – 11:30 am	Uncertainty in laboratory characterization of soils – non-linear behavior	Ken Stokoe
11:30 – 12:00 pm	Discussion – Led by T. Weaver	All
12:00 – 1:00 pm	Lunch (Choose from menu, cash payment)	
1:00 – 1:45 pm	Uncertainty in site characterization – surface wave and borehole studies	Ken Stokoe
1:45 – 2:30 pm	Uncertainty in site characterization – surface wave and borehole studies	Brady Cox
2:30 – 3:15 pm	Discussion – Led by E. Rathje	All
3:15 – 3:45 pm	Break	
3:45 – 4:30 pm	Propagation of epistemic uncertainty and aleatory variability in site response analyses to include randomization approaches	Gabriel Toro

4:30 – 5:00 pm	Discussion – Led by A. Rodriguez-Marek	All
5:00 – 5:30 pm	Questions from observers/PPRP comments and feedback	Observers/PPRP
5:30 – 6:00 pm	TI Team Summary	TI Team
6:30 pm	Group dinner at Pinstripes 11920 Grand Park Ave North Bethesda, MD 20852 (Gluten free and vegetarian options available. PLEASE RSVP TO MIRIAM)	All

AGENDA

SSHAC WORKSHOP ON SITE RESPONSE – DAY 2

January 29, 2020

8:00 am – 5:30 pm, ET

SwRI Office, Rockville, MD
1801 Rockville Pike, Suite 105

8:00 – 8:45 am	Issues with site response at large strains	Ellen Rathje
8:45 – 9:30 am	1D site response – sources of epistemic uncertainty	Youssef Hashash
9:30 – 10:00 am	Break	
10:00 – 10:30 am	How to capture 2D special variability in 1D site response analyses	Katerina Ziotopoulou
10:30 – 12:00 pm	Discussion – Led by C. Munson	All
12:00 – 1:00 pm	Lunch (Choose from menu, cash payment)	
1:00 – 2:00 pm	Approaches to include uncertainty of site response into hazard calculations, including H2T approaches	Bob Youngs
2:00 – 3:15 pm	Discussion – Led by A. Rodriguez-Marek	All
3:15 – 3:45 pm	Break	
3:45 – 4:30 pm	Downstream uses	Tom Houston
4:30 – 5:00 pm	Discussion – Led by J. Ake	All
5:00 – 5:30 pm	Observer comments/PPRP comments and feedback	Observers/PPRP
5:30 – 6:00 pm	TI Team Summary	TI Team

6:30 pm	Group Dinner at Mosaic (186 Halpine Rd) GF/Veg options available, please RSVP to Miriam	All

NRC Site Response SSHAC Level 2 Project
Draft Agenda
Working Meeting (Virtual meeting)
July 21-23 2020

Background

This working meeting marks the full transition from the evaluation to the integration phase of the SSHAC Level 2 project. The working meeting will be conducted over Webex over three days. The agenda is a guide to the discussion and the times are only indicative. However, it would be useful if we keep me presentations to a minimum to ensure that we have as much discussion as necessary. The assigned speaker will introduce the topic with a presentation and will lead the discussion. A short comfort break will be taken when appropriate during the meeting.

Meeting Objectives

- To finalize the logic trees for the Garner Valley and Savannah River sites
- To create an outline of the final report with specific task assignments
- To identify any lingering technical questions and create a plan for how to address these

Day 1: Tuesday July 21, 2020

Time	Topic	Lead
11:00 – 11:10	Overall Structure of the logic tree for the Savannah River Site	Thomas
11:10 – 11:20	Overall Structure of the logic tree for the Savannah River Site	Scott
	Alternatives for the computation of the site factors: the *soon-to-be-renamed* two-step and one-step approaches	
11:20 – 11:45	- Nomenclature and Approach	Ellen
11:45 – 12:10	- Results of a comparison study	Scott
12:10 – 13:00	Approach to sample AFs - Sampling approach for epistemic uncertainty - How to account for aleatory variability - Model error and minimum epistemic uncertainty	Adrian
~~13:00 – 14:00~~	~~Incorporation of results into PSHA: Approach 3 vs. Approach 4~~	~~Cliff~~

Day 2: Wednesday July 22, 2020

Time	Topic	Lead
11:00 – 11:15	Conclude presentation of preliminary results for SRS	Cliff
11:15 – 12:00	Incorporation of results into PSHA: Approach 3 vs. Approach 4	Cliff
12:00 – 12:40	Randomization approaches	Thomas
12:40 – 13:20	Empirical site term approach for Garner Valley	Scott
	Incorporation of fully non-linear analyses	
13:20 – 13:30	- Alternative approaches	Adrian
13:30 – 14:00	- Preliminary results	Thomas

Day 3: Thursday July 23 2020

Time	Topic	Lead
11:00 – 12:00	Logic tree: V_S, kappa, and Su	Scott and Thomas
12:00 – 13:00	Logic tree: MRD Curves	Scott and Thomas
13:00 – 14:00	Outline of final report, timeline for project completion	Team discussion led by **Jon**