ADVANCES IN SEISMIC HAZARD ASSESSMENT FOR NUCLEAR FACILITIES IN THE CENTRAL AND EASTERN UNITED STATES

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ABSTRACT

The United States Nuclear Regulatory Commission (NRC) is currently sponsoring three key projects in the area of probabilistic seismic hazard analysis (PSHA) for the central and eastern United States (CEUS). These projects will provide both new guidance describing the methods to be used for PSHA model development and actual updated seismic hazard assessment input models for the CEUS. These three projects, taken together, will result in an advanced regional PSHA model for critical facilities in the CEUS. They will also provide guidance, a well-documented case study, and a significant number of useful research products, for undertaking PSHA in the US and globally, particularly in low-to-moderate seismicity regions.

The first project is the nearly complete NRC Development Project for Practical Procedures for Implementing the Senior Seismic Hazard Analysis Committee (SSHAC) Guidelines and Updating Existing PSHAs. This research program will provide new implementation guidance to complement the original SSHAC guidelines (which are more formally known as NUREG/CR-6372 [1]). The new guidance will be documented in a new NUREG-series report currently in publication [2]. The NUREG provides guidance on the process used to develop Seismic Source Characterization (SSC) and Ground Motion Characterization (GMC) models. The second project, also nearly complete, is the Central and Eastern United States Seismic Source Characterization (CEUS SSC) for Nuclear Facilities Project. The CEUS SSC project will develop an advanced regional SSC model for approximately half of the United States. Lastly, the Next Generation Attenuation Relationships for Central and Eastern North America (NGA-East) Project will produce a suite of ground motion prediction equations that will form the basis for a new GMC model for low-to-moderate seismicity regions. Both the CEUS SSC project and the NGA-East project are being conducted as SSHAC Level 3 studies utilizing the original and new guidance.

INTRODUCTION

Seismic safety in the design and operation of nuclear facilities in the United States has been evolving since the development of the first rules and guidance for seismic design by the Atomic Energy Commission. The appropriate assessment of seismic hazard at a site is a critical component of assuring safe seismic design. Over the last decades, significant advances have been made in the methods used to conduct PSHAs, which have become an important tool for design. In 1998, the NRC issued a policy decision to move towards a risk-informed and performance-based regulatory framework. Risk-informed frameworks use probabilistic methods to assess not only what can go wrong, but also the likelihood of unacceptable performance. As a result, the use of PSHA, as described in NRC Regulatory Guide 1.208 [3], is the current approach used to assess hazard for new nuclear power plants (NPPs) in the US.

The NRC is currently sponsoring three key projects to advance the state of the art of seismic hazard assessments for NPPs in the CEUS. These projects will provide both new guidance on the methods to be used for PSHA model development and actual updated seismic hazard assessment input models for the CEUS. As shown schematically in Figure 1, these three projects together will result in an advanced regional model for undertaking PSHA for critical facilities in the CEUS. They will also provide guidance, a well-documented case study, and a significant number of useful research products for undertaking PSHA in the US and globally, particularly in low-to-moderate seismicity regions.

The first project is the nearly complete NRC Development Project for Practical Procedures for Implementing the Senior Seismic Hazard Analysis Committee (SSHAC) Guidelines and Updating Existing PSHAs. This research program will provide new implementation guidance to complement the original SSHAC guidelines. The new guidance has been documented in a NUREG-series report currently in publication [2]. The NUREG provides detailed guidance on the assessment process used to develop SSC and GMC models.

Input to a PSHA consists of two elements: SSC models, which characterize the seismic sources that may impact a site, and GMC models, which predict ground motion at a site for a particular scenario earthquake. These

two indispensible components are used to calculate probabilistic hazard results (or seismic hazard curves) at a particular site. The second project, also nearly complete, is the Central and Eastern United States Seismic Source Characterization (CEUS SSC) for Nuclear Facilities Project. The CEUS SSC project will develop an advanced regional SSC model for the eastern half of the United States. Lastly, the Next Generation Attenuation Relationship for Central and Eastern North America (NGA-East) Project will produce a suite of ground motion prediction equations that will form the basis for a new GMC model for low-to-moderate seismicity regions. Both the CEUS SSC project and the NGA-East project are being conducted as SSHAC Level 3 studies utilizing the original and new guidance.

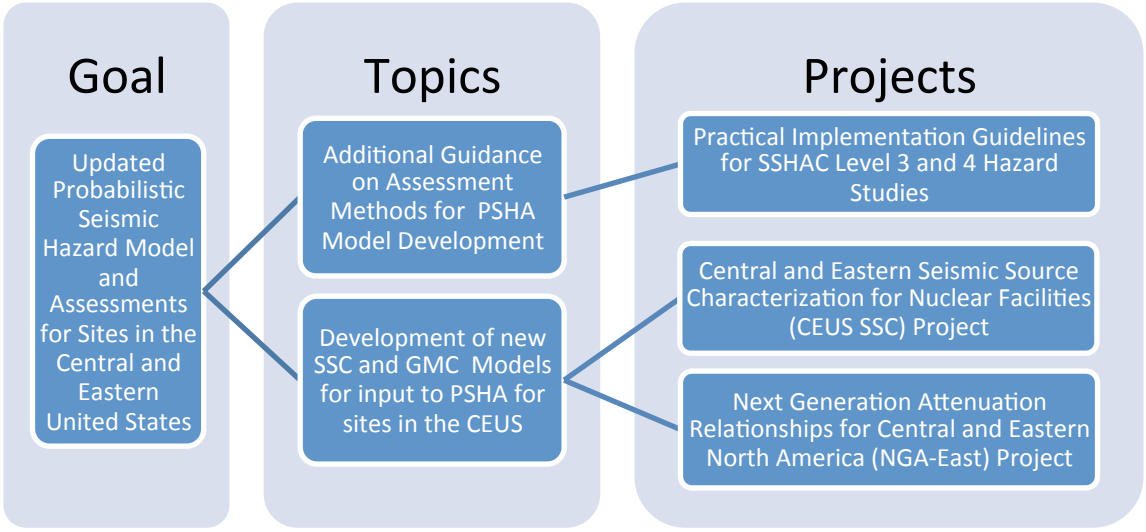

Fig.1: Components of the NRC's program to update seismic hazard assessments for new and existing nuclear plants in the central and eastern United States

DEVELOPMENT OF PRACTICAL IMPLEMENTATION GUIDELINES FOR SSHAC LEVEL 3 AND 4 HAZARD STUDIES

In an effort to standardize PSHA in the 1990s, the NRC sponsored the development of NUREG/CR-6372, "Senior Seismic Hazard Analysis Committee (SSHAC) Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts." The guidance in that document, which has come to be known as the "SSHAC guidelines", provides a useful and robust framework for undertaking PSHA of different levels of complexity. However the SSHAC guidelines do not provide detailed information on how to *implement* PSHAs within the framework, particularly for Level 3 projects.

To further standardize PSHA, and to provide guidance on how and when to update past SSHAC-based studies, in 2008 the NRC initiated a new research program entitled "Developing Practical Procedures for Implementing the Senior Seismic Hazard Analysis Committee (SSHAC) Guidelines and Updating Existing PSHAs". This program developed additional detailed guidance for undertaking the SSHAC assessment process by capturing lessons learned during recent SSHAC Level 3 and 4 assessment projects. The program also provided practical guidelines for updating SSHAC-based PSHAs when new information becomes available. Recently completed, the results are documented in a NUREG-series report (currently in publication). A more detailed discussion of the program and the NUREG, as well as the original SSHAC guidelines, can be found in a companion paper presented at this conference [4].

The first objective of any PSHA model development project is to identify the center, body and range of technically defensible interpretations. The center is defined as the best models for characterizing the seismic sources and the ground-motion predictions in the region. The body is the shape of the distribution around this best estimate that represents the associated uncertainty. The range represents the limits of models or parameter values that are considered possible. This objective is reached in a SSHAC assessment process by properly conducting and completely documenting the activities of evaluation and integration, defined as:

Evaluation: *The consideration of all the data, models, and methods proposed by the larger technical community that are relevant to the hazard analysis.*

Integration: *Representing the center, body, and range of technically defensible interpretations in light of the evaluation process.*

In order to fully evaluate the state of knowledge at the time of a study, any PSHA must begin with the compilation of databases, gathering all available information relevant to the assessment of seismic hazard at the site of interest, and possibly undertaking new data collection. This preliminary phase is followed by a minimum of three required workshops focused on specific topics and with specific goals. The first workshop is focused on data needs and critical issues. The second workshop is focused on compete and probing discussion of alternate models and methods. After the second workshop, the integration phase begins, resulting in a preliminary model. The third workshop is a feedback workshop wherein the preliminary model is presented and probed. Additional key aspects to a SSHAC process are robust participatory peer review and clear and complete documentation. All of these aspects will be incorporated into the CEUS SSC and NGA-East projects.

THE CENTRAL AND EASTERN SEISMIC SOURCE CHARACTERIZATION FOR NUCLEAR FACILITIES (CEUS SSC) PROJECT

The objective of the CEUS SSC project is to develop an up-to-date regional SSC model for the CEUS. Figure 2 shows the study area of the CEUS SSC project. As described in the publically available project plan [5], the SSHAC Level 3 project includes a full assessment and incorporation of uncertainties, a range of diverse technical interpretations from the informed scientific community, an up-to-date earthquake database, complete and appropriate documentation, and peer review. This project is co-operatively sponsored and undertaken by the NRC, the United States Department of Energy (DOE), and the Electric Power Research Institute (EPRI). Technical experts from the DOE, NRC, United States Geological Survey (USGS), and Defense Nuclear Facility Safety Board participated in the study as part of the Technical Integration (TI) Team or as members of the Participatory Peer Review Panel (PPRP) [1].

As discussed in the previous section, the goal of the SSHAC process is to capture the center, body, and range of views of the technically defensible interpretations. To achieve this goal, and meet the requirements of a SSHAC Level 3 study, the project incorporated a number of important elements. These elements include development of a comprehensive database and new tools for documenting the data consideration process; multiple workshops to identify applicable data, debate alternative hypotheses, and discuss feedback; multiple working meetings by the TI Team to develop the SSC models and fully incorporate uncertainties; technical advancements in a number of areas, including development of a uniform earthquake catalog, development of an updated approach for assessing maximum magnitude, data evaluation tables, incorporation of paleoseismic data, and spatial smoothing tools; comprehensive participatory peer review; and proper documentation of all process and technical aspects of the project. By carrying out these activities in accordance with the SSHAC process, regulatory stability is enhanced. Experience has shown that stability is best achieved through proper and thorough characterization of our knowledge and uncertainties, coupled with the involvement of the technical community, regulators, and oversight groups.

The CEUS SSC regional seismic source model will be applicable to sites within the study area shown in Figure 2. Although nuclear plant license applications also require a site-specific refinement of the regional model to meet the requirements of Regulatory Guide 1.208, there is significant benefit in the development of an accepted regional model to be used as a starting point. For many sites, seismic sources at distances up to 300 km or more significantly contribute to hazard at some spectral frequencies. Consequently, seismic hazard models for many sites have significant geologic overlap. If the PSHA are conducted separately, there is a possibility of conflicting assessments for the same regions. A regional source model allows for consistent input into a PSHA and makes PSHA for a particular site more efficient.

[1] A discussion of the roles of the Technical Integration team and the Participatory Peer Review Panel can be found in the companion paper (number 699) in this conference [4], as well as in references [1] and [2].

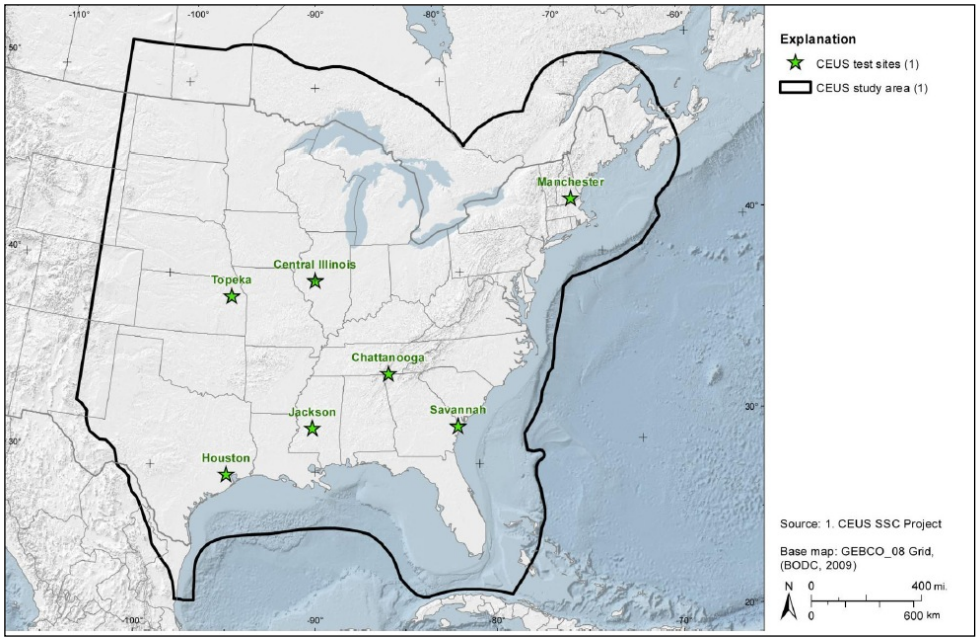

Fig.2: Study area and test sites for the CEUS SSC Project

The CEUS SSC Project demonstrates that a SSHAC Level 3 approach can be used in a regional study to achieve the goals of capturing the knowledge and uncertainties of the broad technical community within a robust and transparent framework. The value of the new CEUS SSC model has been enhanced by the participation of key stakeholders from industry, government, and academia as part of the CEUS SSC Project Team. The CEUS SSC project is expected to be completed at the end of 2011 and will result in a comprehensive report that will be published as a joint EPRI, NRC (NUREG/CR), and DOE report. All research products will be publically available through a CEUS SSC project website that is expected to be published by the end of 2011.

NEXT GENERATION ATTENUATION RELATIONSHIPS FOR CENTRAL AND EASTERN NORTH AMERICA (NGA-EAST) PROJECT

As described in the publically available project plan [6], the objective of the NGA-East project is to develop a new GMC model for the Central and Eastern North American (CENA) region. The GMC model will consist of a set of new ground motion prediction equations (GMPEs), appropriately weighted in a logic tree, for use in probabilistic seismic hazard analyses PSHA. The GMPEs will be formulated in terms of both the median ground motions and the standard deviations. The NGA-East research program follows up the successful multi-investigator project, known as the Next Generation Attenuation (NGA) Relationship project that focused on the western US.

The NGA-East project started in 2008 and is expected to end in 2014. The resulting suite of NGA-East GMPEs will be used in the new GMC model that will replace the EPRI GMC [7,8] model currently used for new NPPs in the CEUS. Although, the project is funded by U.S. organizations, the tectonic region of interest reaches across into Canada; and therefore the ground motion model developed in NGA-East will be applicable to the larger CENA region. A large number of earthquake records used in this project were provided with support from the Geological Survey of Canada (GSC). Additionally, GSC staff is also participating in the project.

A SSHAC Level 3 assessment was selected in order to ensure the necessary regulatory stability and transparency of the resulting NGA-East models. A well-structured approach is required given the complexity, importance and regulatory needs associated with the study. The SSHAC Level 3 process also meets the recommendations provided in NRC Regulatory Guide 1.208. As discussed above, the SSHAC process includes the development of new and complete databases, the full assessment and incorporation of variability and uncertainty, the inclusion of the center, body and range of technically defensible interpretations of the available data, models and methods, the development of exhaustive documentation, and a thorough robust and participatory peer review. All of these aspects have been incorporated into the project and are discussed in the project plan.

The NGA-East project is being sponsored co-operatively by the NRC, DOE, EPRI and the USGS. The project is being led by the Pacific Earthquake Engineering Research center (PEER), located on the Berkeley campus of the University of California. However, the project involves a large number of participating researchers from dozens of organizations in academia, industry and government including the sponsoring organizations. Participants are fulfilling a variety of roles (shown schematically in Figure 3) and are focused in a large number of integrated tasks (shown schematically in Figure 4).

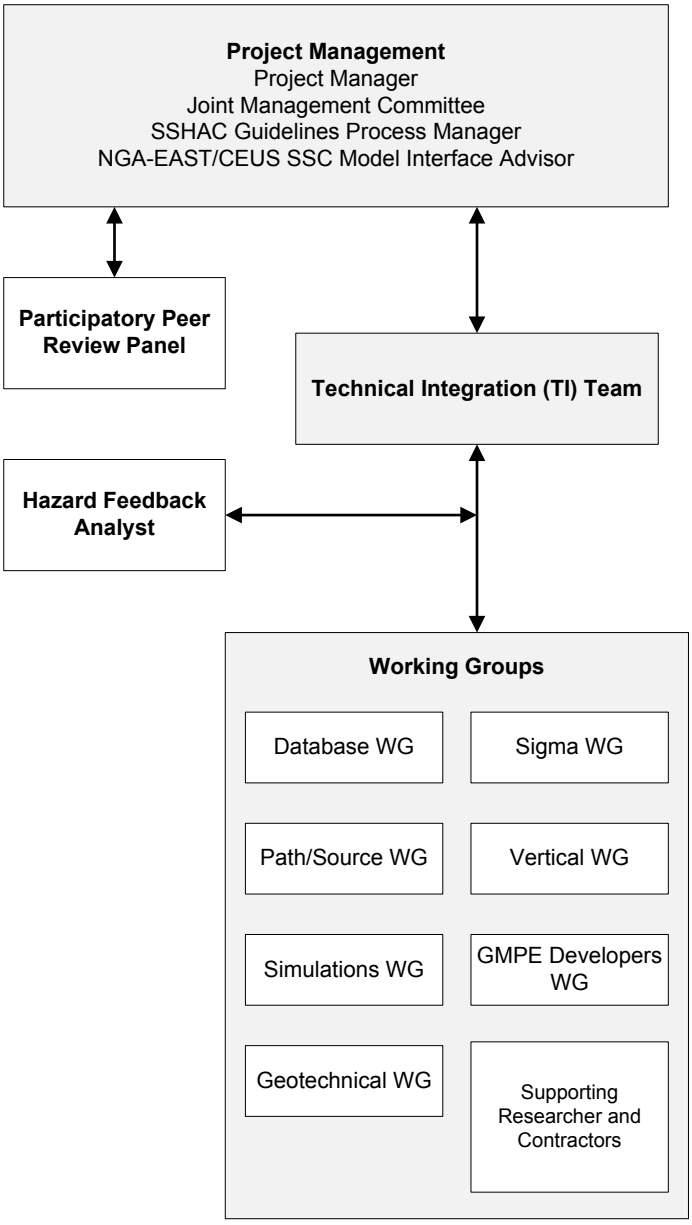

Fig.3: Participants and organization of the NGA-East project

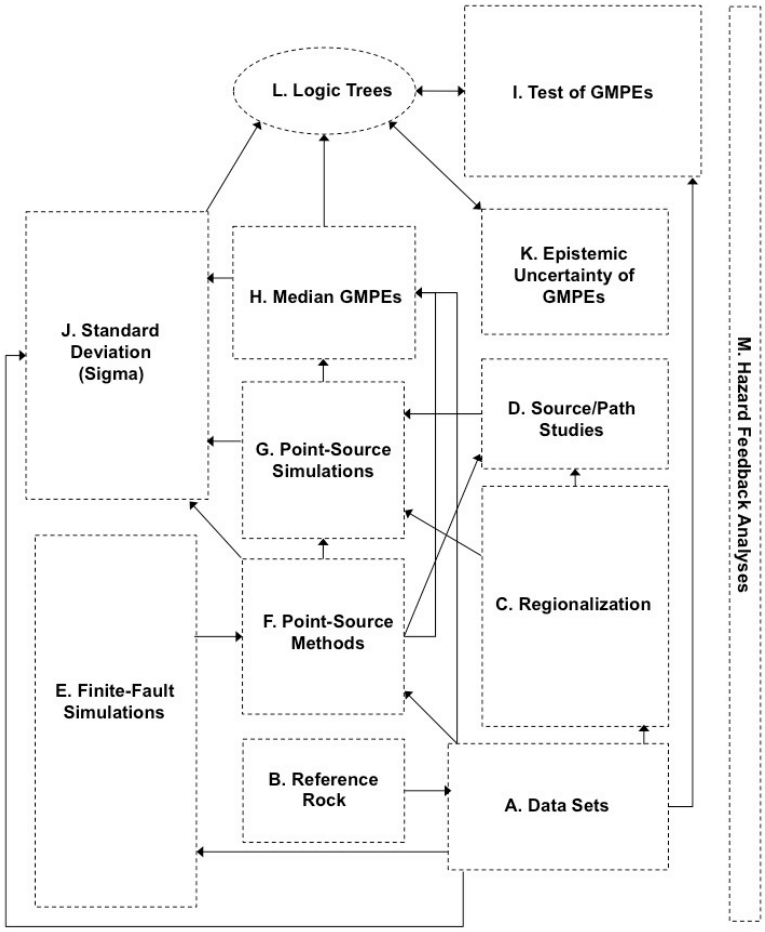

Fig.4: Simplified flowchart showing NGA-East tasks

A unique aspect of the project is that many participants are involved as members of one of seven Working Groups (WGs), each of which is focused on a specific technical area. The WGs, though not a requirement of the SSHAC process, are an essential part of NGA-East due to the complexity of the project and breadth of expertise required. The WGs support the TI team by providing guidance on research needs and/or research products. Some research tasks are performed directly by the WG members while other tasks are performed by other researchers supporting the WG. The main tasks associated with each WG are shown below.

- **Database WG:** develop an exhaustive database of recorded motions in CENA and other Stable Continental Regions, with the associated metadata.
- **Path/Source WG:** develop regionalized models for correlated sets of source (stress-drop) and path parameters (attenuation and quality factor, Q).
- **Simulations WG:** coordinate the validation and forward modeling of ground motion simulation, considering different methods for finite fault and point source simulations.
- **Geotechnical WG:** develop a simplified model to remove site effects at the recording stations, define the reference rock shear wave velocity and kappa values, and the range of conditions to which they apply.
- **Sigma WG:** develop a suite of candidate standard deviation models for the project.
- **Vertical Motions WG:** develop models for vertical-to-horizontal (V/H) ratios to be applied to the horizontal ground motion models.
- **GMPE Developers WG:** develop candidate GMPEs for CENA.

The required workshops are a critical part of a SSHAC assessment process. The workshops are organized into three themes that are discussed below. The term "theme" is used because the NGA-East SSHAC workshops may cover more than a single SSHAC workshop element. The themes will actually be addressed over five or more NGA-East SSHAC workshops. As part of the documentation process for this project, the presentations given at the workshops will be posted to YouTube, and some have already been made available for viewing through the project website [9].

- **Workshop Theme 1 - Significant Issues and Data Needs:** The goals of this workshop are: 1) to identify the technical issues of highest significance to the hazard analysis, and 2) to identify the available data and information that will be needed to address those issues. The discussions of the available data are made by a series of presentations by resource experts who have developed specific data sets. From the standpoint of the SSHAC assessment process, the evaluation of the data for use in the hazard analyses is led by the TI team. In the case of the NGA-East project, a significant amount of technical development work is required and is being led by the WGs. As a result, the WGs will support the TI team by performing a number of critical evaluations of the data and proposing a variety of technical choices.
- **Workshop Theme 2 - Proponent Discussions of Alternative Interpretations:** The goals are: 1) to present, discuss, and debate alternative viewpoints regarding key technical issues; 2) to identify the technical bases for the alternative hypotheses and to discuss the associated uncertainties; and 3) to provide a basis for the subsequent development of preliminary hazard models that consider these alternative viewpoints. An attribute of this workshop is the discussion and debate of the merits of alternative viewpoints regarding key technical issues. Proponents and Resource Experts will present their interpretations and the data supporting them. Alternative viewpoints will be juxtaposed and facilitated discussions will focus on implications to the inputs to the hazard analysis and on uncertainties.
- **Workshop Theme 3 – Presentation and Feedback on Proposed Models:** Typically following the Theme 2 workshop (or workshops), the TI team members prepare their preliminary models, and conduct preliminary calculations and sensitivity analyses. The goal of Workshop 3 is to present and discuss the preliminary models and calculations and provide feedback to the TI team. Feedback can be input by technical specialists or hazard results and sensitivity analyses that shed light on the most important technical issues. This feedback will ensure that no significant issues have been overlooked and will allow the TI team to understand the relative importance of their models, uncertainties, and assessments of weights. At this time, the PPRP will be invited to interrogate the TI team on the models and weights they are proposing. This information will provide a basis for the finalization of the models following the workshop.

The publically available project plan [6] is available at the project website [9]. Also currently available are videos of the presentations given at the first NGA-East SSHAC workshop and at a preliminary workshop on uncertainties in GMPEs called the “Sigma Workshop”. Once, completed, the full project documentation will be made publically available at this website and the NRC reading room. Additionally, a number of technical research products will be published as PEER reports as they are produced. Lastly, the digital database of earthquake records will be available for download as part of the PEER Strong Motion Database [10].

COORDINATION BETWEEN PROJECTS

PSHA computations require compatible SSC and GMC models as input. The NGA-East project is a GMC project in the early phases. However, the complementary CEUS SSC is nearing completion. Because the NGA-East and CEUS SSC models will be used together in PSHA assessments, there is a need for strong interaction between the two projects. Timely dialogue between key participants of both projects is necessary to ensure compatibility of the SSC and GMC models to make sure that the final PSHA estimates reflect the accurate and appropriate use of the CEUS SSC and NGA-East model. Therefore, the GMPEs developed in this project and the implementation guidance developed by the NGA-East TI team, must be compatible with the logic tree-based model that will result from the CEUS SSC Project. To address this interface-based need, the NGA-East project also has a special component called the Model Interface Advisor. Additionally, a number of experts are participating in both projects.

The new NUREG on practical application of the SSHAC guidelines [2] has been compiled contemporaneously with the conduct of the CEUS SSC project, and with the start of the NGA-East project. This was highly beneficial as the NUREG both informed the projects and benefited from experience gained in the projects. Significant synergy

resulted from the three projects occurring simultaneously greatly, which supports the development of very high quality products.

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