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1.0 Introduction

The sitewide probabilistic seismic hazard analysis (PSHA) of the Hanford Site (hereafter Hanford PSHA) in southeastern Washington State was undertaken by Pacific Northwest National Laboratory (PNNL) and its contractors for the U.S. Department of Energy (DOE) Office of River Protection (ORP), DOE Richland Operations Office (RL), and Energy Northwest to provide a detailed characterization of the vibratory ground motion hazard at the Hanford Site from potential future earthquakes. The study was conducted to fulfill the requirements for DOE facilities as well as those for commercial nuclear power plants, through a collaboration and joint sponsorship between DOE and Energy Northwest. The study updates the previous Hanford PSHA, thereby fulfilling DOE's commitment to do so, as required by DOE Order 420.1B (Facility Safety; DOE 2005) and its recent update 420.1C (DOE 2012b). In addition, the study fulfills the requirement from the U.S. Nuclear Regulatory Commission (NRC 2012b) that Energy Northwest conduct a PSHA using Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 procedures for the Columbia Generating Station, as specified by the NRC (2012a). Because the Hanford Site includes several facility sites, the PSHA has been conducted such that seismic hazard is calculated at five sites that are located across the Hanford Site; these are called "hazard calculation sites" in this document.

The Hanford PSHA was conducted using processes that are appropriate for a Study Level 3, as presented in the guidance advanced by the SSHAC in NUREG/CR-6372, *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts* (Budnitz et al. 1997)—known informally as the SSHAC Guidelines—as well as the detailed implementation guidance provided in NUREG-2117, *Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies* (NRC 2012a). SSHAC Levels 1 through 4 are assigned to reflect the hazard significance of technical issues, technical complexity, level of uncertainty in the hazard inputs, level of contention within the technical community, and non-technical factors such as available resources for each specific site being reviewed. At all levels the SSHAC approach is intended to present the best estimate of the seismic hazard (as supported by current data and models) together with an estimate of the full range of uncertainty (resulting from the limitations of the currently available data).

The Hanford PSHA was conducted from April 2012 to August 2014. The project included a kick-off meeting in April 2012 conducted at PNNL facilities in Richland, Washington, and included a tour of the Hanford region. Three workshops were held in Walnut Creek, California, and eight working meetings (four each for seismic source characterization and ground motion characterization) were held in Oakland, California, over the course of the project. As is typical of SSHAC Level 3 projects, the total number of participants entailed a large group of about 50 individuals.

This chapter presents an overview of the PSHA conducted for the Hanford Site to provide project context and background and to identify the scope and objectives of the analysis. The sitewide nature of the PSHA model is described, followed by a brief summary of earlier seismic hazard studies that have considered the location of the Hanford Site. The codes, regulations, and guidelines of relevance to conducting the Hanford PSHA are also listed. Finally, this chapter provides a description of the scope and organization of this report.

1.1 Objectives of the Hanford PSHA

The fundamental object of the Hanford PSHA was to conduct a PSHA using a SSHAC Level 3 process. The outputs of the PSHA can be used for establishing the seismic design of new facilities and for safety reviews of existing facilities. The PSHA was designed specifically to provide results at five hazard calculation sites designated by DOE and Energy Northwest within the Hanford Site. In order to be used for facility-specific purposes, the PSHA results will need to be combined with site response analyses conducted using site-specific geotechnical information. Instructions for the "hand-off" between the PSHA results and site response analyses are included in this report for the five hazard calculation sites within the Hanford Site.

The Hanford PSHA involved the complete characterization efforts required for the seismic hazard analysis, including

- identification and characterization of seismic sources through the development of a complete seismic-source characterization (SSC) model
- characterization of ground motions that would result from potential earthquakes through the construction of a complete ground motion characterization (GMC) model
- full incorporation of uncertainties in the SSC and GMC models using accepted approaches
- development of a family of seismic hazard curves at five sponsor-designated facility sites that express the annual frequency of exceeding different levels of ground motion
- development of various hazard products that will be needed for use in site response analyses for purposes of seismic design development and review.

A key aspect of the objectives of the project was that it comply with all of the requirements for a SSHAC Level 3 PSHA. Accordingly, the project was planned, conducted, and reviewed in strict compliance with established regulatory guidance, as discussed in Section 1.3 below.

1.2 Hanford's PSHA Model and Products

The Hanford PSHA included the seismic source characterization and ground motion characterization required for the seismic hazard analysis of multiple sites on the Hanford Site. The SSC and GMC models developed for the project are applicable to any facility site within the overall Hanford Site. Included in this PSHA report are hazard results for five facility sites specified by the sponsors, as shown in Figure 1.1. The facility sites include four DOE localities: 100-BC Area, 200-West Area, 200-East Area, and the 300 Area. Energy Northwest's Columbia Generating Station is the fifth site at which hazard results are reported in this report.

Key components of the development of the Hanford PSHA are the definition of the reference baserock conditions at which the hazard is calculated, the hazard products provided at this baserock, and specification of the manner in which the hazard results should be used for purposes of obtaining site-specific ground motions. In order to be applicable throughout the Hanford Site, the reference baserock condition was selected to be the top of the Lolo Member of the Wanapum Basalt (see discussion in Section 7.2.5), which exists at depth throughout the Hanford Site.

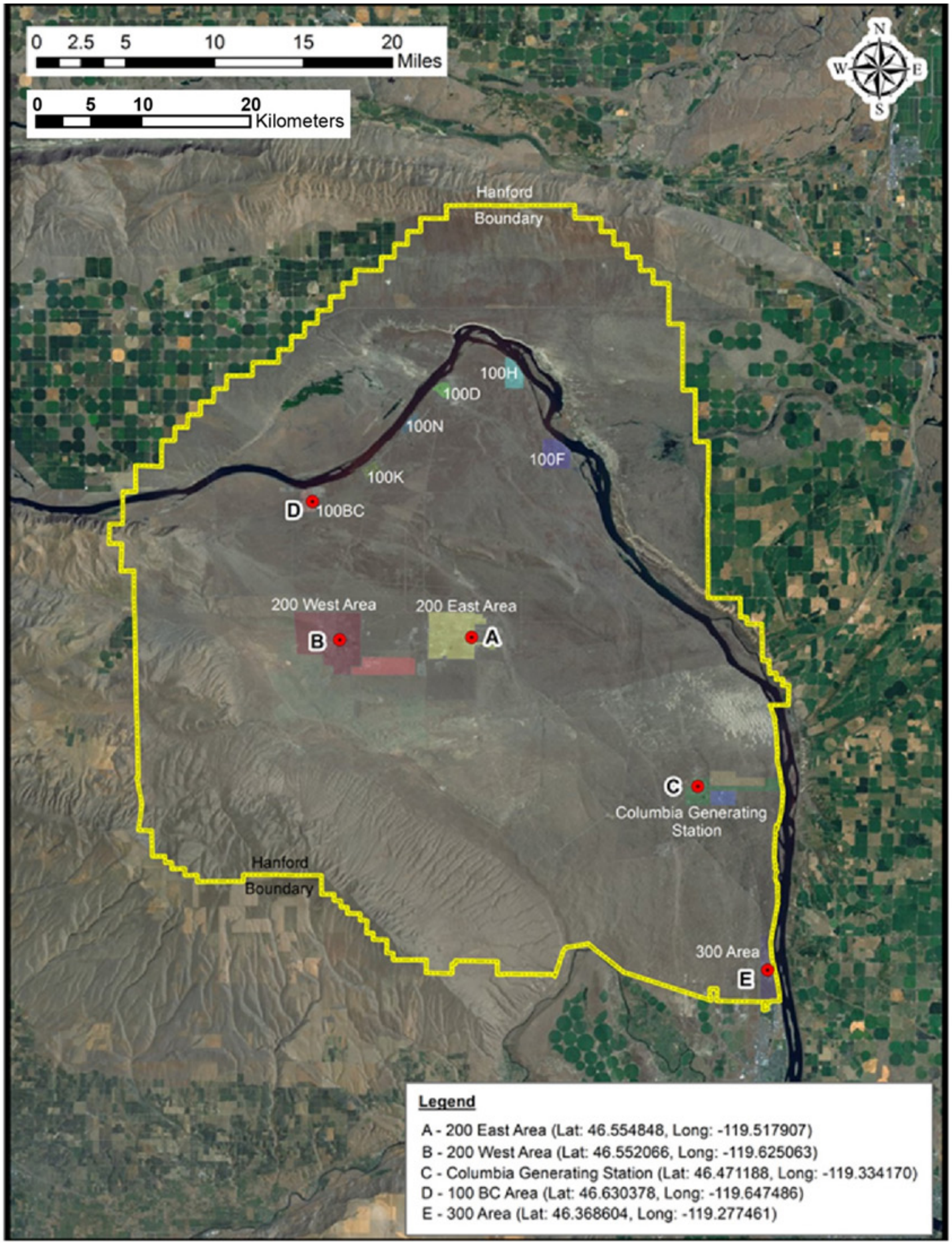

Figure 1.1. Map of the Hanford Site (border shown in yellow) and the five hazard calculation sites (indicated by the red dots). Sites A, B, D, and E are regions containing DOE facilities and Site C is Energy Northwest's Columbia Generating Station.

The hazard products that will be provided at the five facility sites at the baserock are as follows:

- The rock hazard curves at the top of the Lolo flow including mean, 5%, 16%, 50%, 84%, and 95% fractile levels.
- For each of the hazard fractile levels above, uniform hazard spectra (UHS) for annual frequencies of exceedance (AFEs) at 10^{-2}, 10^{-3}, $5x10^{-4}$, $4x10^{-4}$, 10^{-4}, $5x10^{-5}$, 10^{-5}, 10^{-6}, and 10^{-7} levels. The response spectra are provided at sufficient number of frequency points to define the response spectrum fully for the frequency range from 0.01 Hz to 100 Hz.
- For each of the 20 spectra frequencies (from 0.1 Hz to 100 Hz) at which the rock hazard will be computed, magnitude/distance deaggregation of the mean hazard for each of the ground motion levels producing AFEs in the range of 10^{-2} to 10^{-7}.
- At AFEs in the range of 10^{-2} to 10^{-7}, deaggregation earthquake (DE) spectra provided in sufficient detail to represent the corresponding uniform hazard responses (UHRs). The DE spectra are targeted to four spectral frequencies, nominally 0.1, 1, 10, and 40 Hz, to cover the entire frequency range of interest.
- At each spectral frequency, the DE spectra provided in terms of three DE magnitude-distance pairs representing the distribution of earthquakes contributing to the hazard at each AFE, along with the weights representing the relative contribution of each representative DE to the total hazard.
- Recommendations for the applicable vertical-to-horizontal (V/H) spectral ratio as a function of frequency for the soil horizon so that site-specific vertical response spectra can be defined.

In order for the baserock hazard results to be used at various facility sites, recommendations for dynamic soil and rock properties for the interbed sequence above the baserock horizon from the top of the Lolo flow to the top of the Saddle Mountains Basalt are provided. These include:

- Descriptions of basalt and interbed layers including best estimates of shear-wave velocity (V_S), compression-wave velocity (V_P, or Poisson's ratio), layer thicknesses, and material densities. The recommended distribution of low strain damping generated from site kappa evaluations as well as appropriate strain-dependent degradation curves for the various interbed layers of the sequence are provided. The uncertainties are given for V_S, damping (kappa), layer thickness, and the strain-dependent soil properties for the interbed layers.
- Description of appropriate V_S, V_P, damping, and density information for the equivalent half-space models (for the top of the Lolo Member and below).
- Weights for the scenarios that require modeling epistemic uncertainty.
- Description of the recommended shear-wave correlation model between layers of interbed sequence.

In addition to the above, recommendations and instructions are provided regarding the manner in which the hazard products from this study should be used as input to subsequent site response analyses.

1.3 Decision to Replace the Hanford 1996 PSHA

Earthquake-related studies have been conducted at the Hanford Site since the late 1970s when they were conducted for purposes of licensing of the Washington Public Power Supply System nuclear power plant sites. Likewise, studies for DOE were conducted over the past 40 years as part of a variety of activities, including the Basalt Waste Isolation Program. However, the most recent PSHA that followed conventional practice was the PSHA that was published in 1996 (Geomatrix 1996) for the Hanford Site. That study was sponsored by DOE and intended for use at the DOE nuclear facilities. The 1996 PSHA was conducted prior to the issuance of the SSHAC Guidelines (Budnitz et al. 1997), but the study corresponded generally to what would now be considered a SSHAC Level 2 study. From the time of its issuance, the results of the 1996 PSHA have provided the input "free field" ground motions for a variety of ground motion assessments for purposes of design or design review. These include DOE facilities such as the tank farm facilities, the Waste Treatment Plant, and the single-shell tank facilities. In all cases, the 1996 PSHA provided the input ground motions, at appropriate AFEs, which were then modified to incorporate site-specific soil conditions and potential soil-structure interaction effects. Thus, although facility-specific seismic analyses have been conducted for many years at the Hanford Site since completion of the 1996 PSHA, the hazard analysis has not been updated since that time.

The decision to replace the 1996 PSHA was made in light of decision criteria that exist as DOE Orders and Standards that have been developed within the professional community. These criteria are discussed below in Section 1.3.1. Also discussed below are the decision criteria that have more recently been put in place for NRC-regulated facilities (Section 1.3.2). However, the decision by Energy Northwest to participate in the Hanford PSHA was also motivated by NRC directives that were developed in response to the Fukushima Daichi nuclear power plant accident (NRC 2012b). In its letter related to Title 10 of the Code of Federal Regulations 50.54(f) (10 CFR 50.54(f)), the NRC (2012b) directed all western nuclear power plant licensees to conduct a SSHAC Level 3 PSHA to provide a basis for evaluating the existing seismic design bases at these plant sites. Hence, Energy Northwest decided to co-sponsor the Hanford PSHA in order to fulfill that NRC directive.

1.3.1 Decision Criteria Applicable to DOE Facilities

According to DOE Order 420.1B, *Facility Safety* (which was recently been replaced by 420.1C [DOE 2012b]), all DOE facilities are required to assess every 10 years the need to update their natural phenomena hazards (NPHs) analyses, including seismic. The Order includes the following:

DOE Order 420.1C, IV. 3.d. Review and Upgrade Requirements for Existing DOE Facilities.

> *(1) Existing facility or site NPH assessments must be reviewed at least every 10 years for any significant changes in data, criteria, and assessment methods that would warrant updating the assessments. Section 9.2 of DOE-STD-1020-2012 contains criteria and guidance for performing these reviews. The review results, along with any recommended update actions, must be submitted to the head of the field element. If no update is necessary, this result must be documented following the review.*

In addition to specifying the need for a 10-year review, DOE-STD-1020-2012 (DOE 2012a) provides a number of criteria for evaluating whether or not an existing PSHA needs to be updated. The Standard also specifies that the updating evaluation process needs to be thoroughly documented. In addition, the Standard makes reference to American National Standards Institute/American Nuclear Society (ANSI/ANS) Standard 2.29-2008, the original SSHAC report, NUREG-CR 6372 (Budnitz et al. 1997), and the SSHAC Implementation Guidance, NUREG-2117 (NRC 2012a).

DOE-STD-1020-2012

9.2 Periodic Review and Update of NPH Assessments

9.2.1 At a frequency not to exceed ten years, the following aspects of NPH assessments shall be reviewed for changes that would warrant updating the assessments:

- *NPH data and data collection methods;*
- *NPH modeling techniques, either generic or specific to the region of interest ; and*
- *NPH assessment methods.*

9.2.2 Consistent with DOE 420.1C, a preliminary estimate of whether changes to data, models, or methods are "significant" and warrant updating the assessments should be performed and consider the following criteria:

- *Are the changes to data, models, or methods likely to cause a change in the estimates of the major inputs to hazard calculations?*
- *Given potential changes to the hazard inputs, by what magnitude might the calculated hazard results change, and how might the results impact current site design standards?*

9.2.3 The preliminary estimate of how hazard results might change from new inputs will likely be imprecise. An expected significant increase in the hazard results would clearly favor completion of a new assessment. However, even if hazard results are not expected to change significantly, large changes to the input parameters may warrant a new assessment to ensure the NPH assessment continues to have a viable technical basis.

9.2.4 In the case of seismic hazard assessments, a determination of whether an existing assessment remains adequate for future use should consider the criteria in Section 4.1 of ANSI/ANS-2.29-2008 for the suitability of existing studies. Additional guidance on the bases for updating existing seismic assessments can be obtained from NUREG-2117, "Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies."

9.2.5 A decision on updating an NPH assessment should consider the intended application of the assessment results. Such considerations include:

- *The number of facilities affected by the NPH assessment, and the hazards posed by the facilities;*
- *The life-cycle stages of the facilities affected by the NPH assessment;*
- *Whether the assessment results will be used as design input for any future facilities;*
- *NUREG-2117, Chapter 6; and*
- *NUREG-CR 6372, Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and use of Experts, Appendices Vol. 2, Appendix G.*

9.2.6 If the review and evaluation of the changes warrants an update, the updated assessment shall be performed following the criteria in this Standard for new facilities.

9.2.7 If the review and evaluation of the changes does not warrant an update, the review and evaluation results shall be justified and documented.

The applicable part of the ANSI Standard that is cited in DOE-STD-1020-2012 is excerpted below.

ANSI/ANS-2.29-2008

Section 4.1, High Level Requirements A through G, are summarized below:

- *4.1 High Level Requirements*
  - *"…in the second case, the PSHA analyst may have the option to use an existing seismic study as a starting point for a site-specific assessment."*
  - *HLR-A: Scope*
    - *"The assessment of the frequency of earthquake ground motions at a site shall be based on a PSHA that considers the epistemic uncertainty in the analysis inputs and that reflects the composite distribution of the informed technical community. The level of the analysis shall be determined based on the intended application of the PSHA results and on the site-specific complexity (see Sec. 4.3). For PSHA [SSHAC[1]] levels 3 and 4, the analysis shall include a site-specific detailed analysis."*
  - *HLR-B: Data collection*
    - *"…develop a comprehensive up-to-date database."*
  - *HLR-C: Seismic source characterization*
  - *HLR-D: Ground motion characterization*
  - *HLR-E: Local site effects*
  - *HLR-F: Quantification*
    - *"Epistemic and aleatory uncertainties in each element of the PSHA shall be propagated separately and displayed in the final quantification of the ground motion hazard at a site."*
  - *HLR-G: Use of existing studies*
    - *"When use is made of an existing study for PSHA purposes, it shall be confirmed that the basic data and scientific interpretations in the original analysis are still valid in light of current information, the study meets the requirements outlined in HLR-A through HLR-F above, and the study is suitable for the intended application."*

[1] The Standard refers to SSHAC Levels as PSHA Levels. They are synonymous terms.

As part of its seismic hazard review, DOE conducted a Hanford Seismic Summit Meeting on July 15, 2011 (Harrington 2011) with DOE, site contractors, Defense Nuclear Facilities Safety Board staff, and U.S. Geological Survey personnel. At that meeting, the decision criteria given in ANSI/ANS-2.29-2008 were considered and discussed with regard to the 1996 PSHA. It was at this meeting that the DOE decided that the existing 1996 PSHA was not worthy of continued use and that a new PSHA should be initiated. It was also decided that the new PSHA should be conducted using a SSHAC Level 3 process, as discussed in Section 2.1.

1.3.2 Decision Criteria Applicable to NRC-Regulated Facilities

As discussed in Section 2.1, the decision by Energy Northwest to participate in the Hanford PSHA was motivated by the need to address an NRC directive (NRC 2012b) and not by the need to update an existing PSHA. However, because reference is made in DOE-STD-1020-2012 to the decision criteria in NUREG-2117 (NRC 2012a), those criteria are briefly summarized below.

Key parts of the updating process are the identification of new data, models, or methods that have become available, evaluation of the impact of those data, and assessment of potential changes to the PSHA model that might result. The NRC describes this process and offers criteria that can be used to assess whether or not changes to the PSHA model are considered significant:

> *The evaluation process uses this information to test whether it would lead to significant differences in the input models to the hazard analysis and to the hazard results. This is done by reviewing each individual component of the input models and making a judgment about whether and how the new information would lead to different inputs. The assessment includes evaluating the uncertainties and whether these would change with the new data.*
>
> *For a reasoned decision to be made, criteria need to be established for what entails a "significant" change to the hazard analysis. For this assessment, it is recommended that two criteria be used: (1) an assessment should be made of whether or not the new information would lead to a change in the estimates of the CBR of the TDI in the major components of the model (e.g., SSC or GMC) and (2) an analysis should evaluate the magnitude of the change in the calculated hazard results and the significance to the subsequent use of the results. Either of these alone may indicate that an update is required. Clearly, changes in the calculated hazard results are the most diagnostic criteria that would inform a decision on whether or not to update a study. However, much of the credibility and confidence in a hazard study comes from the conclusion that it has appropriately captured the CBR of the TDI. Thus, even if a conclusion can be drawn that the calculated hazard results would not change significantly, large changes in the input models would need to be developed and documented in a SSHAC process to engender high levels of assurance. Simply put, the most important consideration in the decision process is confidence the model used in PSHA continues to have viable technical bases."*
>
> *Assuming that new data, models, or methods lead to a change in the calculated hazard results, an assessment should be made of the significance of those changes to the intended use of the hazard results. Quantitative criteria for evaluating the significance of*

changes in calculated hazard results could be established mindful of their application. For example, if hazard results will be used to establish design bases, some percentage difference in the design bases can be defined as the threshold between a significant and an insignificant change. Or if the hazard results will be used for a risk analysis, the threshold at which a change in hazard input will lead to a significant change in risk (e.g., defined as leading to noncompliance of a risk standard or as a percentage in risk) can be considered a measure of significance. The point of these types of assessments is to ensure that risk-informed significant changes in hazard are present and that these changes will motivate the need for an updating of a hazard study. Replacing an existing hazard study can be costly and time-consuming, hence the need to carefully evaluate the significance of new data, models, and methods. (NRC 2012a, p.116)

1.4 Report Contents and Organization

The next two chapters of this report complete the general introduction to and overview of the Hanford PSHA project by first describing the project organization, structure, and participants (Chapter 2.0), then the key tasks and activities (Chapter 3.0) involved in conducting a PSHA—in general, and specifically for the Hanford Site. The ensuing chapters describe the Hanford PSHA outputs derived from the tasks and activities, including the tectonic setting of the site region (Chapter 4.0), followed by related geological/seismicity studies and analyses (Chapter 5.0) and the earthquake catalog (Chapter 6.0) that make up the Hanford Site SSC database. The Hanford Site GMC databases are described in Chapter 7.0. The respective SSC and GMC models and their technical bases are described in Chapters 8.0 and 9.0. The resulting hazard calculations and sensitivity analyses are presented in Chapter 10.0.

The appendices contain supplemental information as indicated in the narrative. Appendix A includes short biographies of the principal project participants. Appendix B is the Closure Letter issued by the Participatory Peer Review Panel (PPRP). Appendix C contains the earthquake catalog developed for the project. Appendix D provides the Hazard Input Document, which defines the final SSC and GMC models that were provided for hazard calculations. Appendix E contains a detailed description of the Quaternary geologic studies conducted for the Hanford PSHA. Appendix F provides the results of studies conducted to refine estimated earthquake locations using high-resolution techniques. Appendix G, which will appear in the Final Report, provides links to the Data Summary Tables that were developed for the SSC activities. Appendix H contains the spectral analysis of surface waves study and Appendix I includes the study of kappa conducted as part of the GMC activities for the project. Appendix J provides the hazard products described in Section 1.2. Appendix K provides the instructions for the manner in which the results of the Hanford PSHA should be used for site response at particular facility sites and provides an example at the Waste Treatment Plant site. A glossary is provided in Appendix L.

1.5 References

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