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CHAPTER 10 GLOSSARY OF KEY TERMS

Definitions provided in this Glossary were compiled from multiple reference sources, including the SSHAC Guidance in NUREG/CR-6372 (Budnitz et al., 1997); NUREG-2115 (EPRI/DOE/NRC, 2012); NUREG-2117 (U.S. NRC, 2012b); EPRI (2012); and McGuire (2004). The Glossary definitions are consistent with the use of the terms in the EPRI (2004, 2006) GMM Project report and may not correspond exactly to definitions appearing in regulatory documents of the U.S. Nuclear Regulatory Commission (NRC) or Department of Energy (DOE).

Aleatory Uncertainty *or* Aleatory Variability: The uncertainty that is inherent in a random phenomenon and cannot be reduced by acquiring additional data or information. Examples include future earthquake locations and magnitudes.

Anelastic Attenuation: The diminution of ground-motion amplitude due to damping and wave scattering as the waves travel through the earth's crust. It is often quantified by the Quality factor Q and it is parameterized by an exponential decay with distance.

***b*-Value:** A parameter describing the decrease in the relative frequency of occurrence of earthquakes of increasing sizes. It is the slope of a straight line relating absolute or relative frequency (plotted logarithmically in base 10) to earthquake magnitude. It is referred to as β when using natural logarithms.

Coefficient of Variation (COV): A statistical term that measures the relative variation of a quantity. It is calculated as the standard deviation of the quantity divided by the mean of the quantity.

Cluster: An approach (structure) for grouping ground-motion-prediction equations based on similar seismological attributes. This approach (structure) permits evaluation and assessment of within-cluster epistemic uncertainty.

Covariance Matrix: Represents the extension of the concept of variance from random scalars to random vectors. The covariance matrix contains the variance of each component of the vector (in the main diagonal), as well as the covariances between all pairs of components (off-diagonal terms). Also called *variance matrix.*

Distance, Joyner-Boore or R_{JB}: The horizontal distance from a site to the horizontal projection of the earthquake-rupture plane.

Distance, Epicentral: The distance from the epicenter (see below) of an earthquake to a specific location (site).

Distance, Rupture or R_{Rup}: The shortest distance from the earthquake rupture to a specific location (site).

Distance, Hypocentral: The distance from the hypocenter (see below) of an earthquake to a specific location (site).

Earthquake: A sudden movement or trembling of the earth caused by the abrupt release of accumulated strain.

Epistemic Uncertainty: The uncertainty that arises from lack of knowledge about a model or a parameter, which can be reduced by the accumulation of additional information. Epistemic uncertainty is reflected in the different outcomes of viable alternative models, interpretations, and/or assumptions operating on the same data. Examples include geometry of seismotectonic zones and assessed source parameters such as maximum magnitude.

EPRI (2004, 2006) Ground-Motion Model: The EPRI (2004) Ground-Motion Model updated with the EPRI (2006) model for aleatory variability.

Evaluation: The process for considering the complete set of data, models, and methods proposed by the larger technical community that are relevant to the hazard analysis.

Evaluator Expert: An expert who is capable of evaluating the relative credibility of multiple alternative hypotheses to explain a set of observations. An Evaluator Expert considers the available data, listens to Proponent Experts and other Evaluator Experts, questions the technical basis for their conclusions, and challenges the Proponents' positions.

Expert Elicitation: A formal expert assessment technique of conventional decision analysis in which experts are led through a series of assessment steps to address narrowly defined questions about specific uncertain quantities within their areas of expertise.

Expert Assessment: The use of expert judgment to address technical questions and their uncertainties.

Fault: A fracture surface or zone in the earth across which there has been relative displacement.

Fault, Dip-Slip: A fault in which the relative displacement is along the direction of the dip of the fault plane; either downdip (normal fault) or updip (reverse fault).

Fault, Normal: A dip-slip fault in which the block above the fault has moved downward relative to the block below, representing crustal extension.

Fault, Reverse: A dip-slip fault in which the block above the fault has moved upward relative to the block below, and the fault dip is >45°.

Fault, Strike-Slip: A fault in which the relative displacement is along the strike of the fault plane, either right-lateral or left-lateral.

Fault, Thrust: A dip-slip fault in which the block above the fault has moved upward relative to the block below, and the fault dip is <45°, representing crustal compression.

Fault Zone: The zone of deformation comprising a fault; the fault zone may be hundreds of meters wide.

Focal Mechanism: A geometrical representation of earthquake faulting expressed in terms of the strike and dip of the fault plane and the rake angle of the slip vector with respect to the fault plane.

Future Earthquake Characteristics: The expected characteristics of future earthquakes that occur within a particular seismic source. The characteristics identified (e.g., style of faulting, orientation of rupture) are those that are potentially important to ground-motion-prediction equations.

Geometric Spreading: The diminution in ground-motion amplitude as the wave front expands with distance. It is often parameterized by distance raised to a negative power.

Ground-Motion Model (GMM): A model that provides an algorithm to predict ground motions at a particular location, including the associated epistemic and aleatory uncertainties. Elements in a ground-motion model include algorithms for the median ground motion, the aleatory variability about the median, the epistemic uncertainty in the median, and the epistemic uncertainty in the aleatory variability.

Hazard Calculation: The calculation of annual frequencies with which seismic ground-motion amplitudes will be exceeded as a result of possible earthquakes in the region. The calculation is made by considering all possible earthquake magnitudes, locations, and effects with their associated probabilities, as well as the epistemic uncertainty in the underlying models. The results of this calculation may be represented as mean annual frequencies ("mean hazard curves") or fractile annual frequencies ("fractile hazard curves").

Hazard-Informed Approach: An assessment methodology for characterizing seismic sources that places greatest emphasis and focus on those seismic source elements that are most important to the hazard analysis results.

Hazard Input Document (HID): A report that provides the documentation necessary for users to implement the input model (e.g., the seismic-source characterization model or ground-motion characterization model) in PSHA calculations for future applications. The HID includes the logic tree structure (with all branches and weights) for each seismic source, but it does not include the technical basis or justification for the elements of the model.

Hypocenter: The point in the earth at which an earthquake is initiated. Also referred to as the *focus*.

Informed Technical (Scientific) Community: A hypothetical construct of the SSHAC Guidance (Budnitz et al., 1997) that embodies the community distribution of uncertainty sought by the SSHAC process at any study level. The goal of a SSHAC process is to "represent the center, body, and range of the views of the informed technical community." "Informed" means that the technical community is familiar with the project-specific databases and that the individuals have gone through the interactive SSHAC process. Recent SSHAC Implementation Guidance (U.S. NRC, 2012b) has replaced the original wording to avoid confusion; in that guidance, the goal of the SSHAC process is said to be twofold: (1) to consider the data, models, and methods of the larger technical community, and (2) to represent the center, body, and range of technically defensible interpretations.

Integration: The process for representing the center, body, and range of technically defensible interpretations in light of the evaluation process (i.e., informed by the assessment of existing data, models, and methods).

Intensity: A measure of the effects (e.g., damage) of an earthquake at a particular place. Commonly used scales are Rossi-Forel, Mercalli, and modified Mercalli.

Inter-event Variability: The portion of the total aleatory variability in ground motions that represents the variability in average level of ground motions from earthquake to earthquake.

Intra-event Variability: The portion of the total aleatory variability in ground motions that is common to all recordings from an individual earthquake.

Inverse Random Vibration Theory: A technique to calculate the Fourier or power spectrum of the ground motion given the response spectrum and the duration of the motion.

Kappa: A parameter that characterizes anelastic attenuation through the soil and near-surface rock. The definition of kappa used in this study corresponds to zero epicentral distance.

Likelihood Function: A measure of the consistency of a set of model parameter values with a set of observations. It is constructed by calculating the probability density function of the observations given the parameters, and then interpreting it as a function of the parameters, given the observations.

Logic Tree: A series of nodes and branches to sequence the assessments in an analysis by describing alternative models or parameter values or both. At each node is a set of branches that represent the range of alternative credible models or parameter values; the branch weights must sum to unity at each node. The weights on the branches of logic trees reflect scientific judgments in the relative confidence in the alternative models.

Longevity, Hazard Study: The length of time a hazard study is considered adequate for continued use.

Magnitude (general): A measure of earthquake size, classically determined by taking the common logarithm (base 10) of the largest ground motion recorded during the arrival of a seismic wave type and applying a standard correction for distance to the epicenter.

Magnitude, Moment (M, M_w**):** Magnitude derived from the scalar seismic moment, M_o. Approximately equal to local magnitude for moderate earthquakes, and to surface-wave magnitude for large earthquakes. As discussed in Hanks and Kanamori (1979), M_w is derived from Kanamori's (1977) magnitude scale based on strain energy drop and is given by the relationship $\log(M_o \text{ in dyne-cm}) = 1.5M_w + 16.1$. Hanks and Kanamori (1979) defined the moment magnitude scale **M** using the relationship $\mathbf{M} = \frac{2}{3}\log(M_o \text{ in dyne-cm}) - 10.7$. The result is a 0.03-magnitude unit difference between M_w and **M** for the same value of M_o.

Magnitude Scaling: The dependence of ground-motion amplitude on magnitude.

Maximum-Likelihood Method: A statistical technique that estimates the parameters of a model by determining the parameter values that maximize the likelihood function.

Maximum Magnitude (M_{max}**):** The largest earthquake magnitude that a seismic source is assessed to be capable of generating. The maximum magnitude is the upper bound to recurrence curves.

Modeling Uncertainty: The epistemic uncertainty that results from the use of various viable models to explain observed data and predict future phenomena. In principle, it can be reduced or eliminated by further testing, data accumulation, or more detailed modeling. It is one source of epistemic uncertainty.

Observer: A professional from industry or government who is invited by the Project Manager to share technical knowledge and experience on specific topics of discussion. For this study, Observers shared their knowledge and experience regarding ground motion with the TI Team and Project Manager throughout the study. Observers are not considered members of the project team, but they are kept abreast of project activities, decisions, and progress; they attend project meetings at their option.

Participatory Peer Review: As defined in the SSHAC Guidance, an ongoing review for the duration of a project that allows reviewers to observe and comment on the process followed and the technical assessments developed. Reviewers must be recognized experts on the subject matter under review ("peers" in the true sense).

Probabilistic Seismic Hazard Analysis (PSHA): An analytical methodology that estimates the likelihood that various levels of earthquake-caused ground motions will be exceeded at a given location in a given future time period. *See also* **Hazard Calculation.**

Project Manager: As defined in the SSHAC Guidance, a full-time professional who is the point of contact between the project and the project sponsor(s), and who is responsible for ensuring adherence to scope, schedule, budgets, and contractual requirements. The Project Manager organizes workshops and keeps the sponsor(s) apprised of progress.

Project Plan *or* **Work Plan:** A series of tasks designed to implement the project and the SSHAC assessment process. The Project Plan for this study takes full advantage of the updated CEUS ground-motion database and current findings from the ongoing NGA-East Project, as well as from the ongoing USGS Seismic Hazard Mapping Project and other data and developments in seismological understanding of ground motion in the CEUS since late 2003.

Proponent Expert: An expert who advocates a particular hypothesis or technical position.

Quarter-Wavelength Approach: An approach used to quantify the ground-motion amplification factor for an arbitrary site by considering the ratio of time-averaged shear-wave velocity and damping between the source and the site, as well as the effect of kappa at the site.

Random Vibration Theory: A technique to calculate peak values of a time series (in this case, the spectral acceleration), given the Fourier or power spectrum and duration of the ground motion.

Rate of Seismicity: The rate of occurrence of earthquakes above some specified magnitude for a specific region.

Recurrence, Recurrence Rate, Recurrence Curve: The frequency of earthquake occurrence of various magnitudes often expressed by the Gutenberg-Richter relation.

Recurrence Model: A model to express the relative number or frequency of earthquakes having different magnitudes. A common recurrence model is the truncated exponential magnitude distribution.

Reference Rock: Rock defined by specific properties that best represent the properties of a study region for the purpose of developing ground-motion-prediction equations. Accepted current ground-motion-modeling practice defines reference rock for the CEUS region by shear-wave velocity of 2,800 m/s or higher. The EPRI (2004) Ground-Motion Model was based on ground-motion-prediction equations derived using a reference shear-wave velocity of 2,800 m/s or higher, and this definition of reference rock is retained for the update to the EPRI (2004, 2006) GMM.

Residual: The natural logarithm of the ratio of observed peak spectral acceleration (PSA) divided by the predicted PSA. The residuals for each of the EPRI (2004) cluster median models were analyzed to assess the need to update the EPRI (2004, 2006) GMM.

Resource Expert: A technical expert who has either site-specific knowledge or expertise with a particular methodology or procedure useful to the Evaluator Experts in developing the community distribution.

Seismicity: The occurrence, intensity, and distribution of earthquakes in a region; also refers to the frequency and depths of these earthquakes.

Seismic Moment: Scalar measurement of the size of an earthquake. It is the product of the area of rupture, the average slip on the fault, and the shear modulus of the crustal rocks. It is typically expressed in units of dyne-cm.

Seismic Refraction: A method that involves analysis of the travel times of the first energy to arrive at the geophones laid out in a linear array on the surface after acoustic energy is input into the subsurface. Both compressional-wave and shear-wave seismic refraction surveys can be conducted, with compressional-wave refraction by far the most common. Compressional and shear-wave refraction models can be useful to quantify approximate lateral velocity variation beneath the surface-wave arrays, identify the depth and P-wave velocity of the saturated zone (which is preferably constrained during modeling of Rayleigh wave data), determine depth to bedrock, and estimate the maximum velocities in the near surface.

Seismic Source: Traditionally, in a PSHA, a region or volume of the earth's crust that has uniform earthquake potential or uniform earthquake-generating characteristics. In this project, unique seismic sources (faults, regions) are spatially defined to account for distinct differences in earthquake recurrence rate, maximum earthquake magnitude, expected future earthquake characteristics, and probability of generating earthquakes of magnitude 5 or larger.

Seismic Source Characterization (SSC): The parameters that characterize a seismic source for PSHA, including source geometry, maximum magnitude, earthquake recurrence, and future earthquake characteristics. In ground-motion analysis, the term seismic source characteristics refers to the characteristics of the seismic energy release (e.g., seismic moment, stress drop, duration, depth, source mechanism, slip distribution, rupture velocity).

Seismic Source Characterization (SSC) Model: A model that characterizes a seismic source for PSHA, including source geometry, probability of activity, maximum magnitude, and earthquake recurrence.

Seismic Source Zones: Volumes within the earth where future earthquakes are expected to occur. The geometry of seismic sources in the CEUS SSC Project is defined by differences in earthquake recurrence rate, maximum earthquake magnitudes, future earthquake characteristics, and the probability of activity of tectonic features.

Senior Technical Advisor: For this study, a seismologist, ground-motion expert, or seismic hazard expert who contributed technical knowledge and experience on the implementation process, as well as discussing specific topics regarding ground motion with the TI Team and Project Manager throughout the study.

Sensitivity Analysis: The calculation of the effect that a particular input parameter or model has on the output of a seismic hazard analysis. This may be represented as multiple hazard curves for these alternative input assumptions.

Shear-Wave Velocity: An essential parameter used for evaluating the dynamic properties of soils or rock. It represents the propagation speed of shear (i.e., transverse) waves.

V_{S30}: The time-averaged shear-wave velocity to a depth of 30 m. It is calculated as 30 m divided by the one-way vertical travel time of shear waves to a depth of 30 m.

Specialty Contractor: A company or individual that performs specific activities and provides specific products to the Project Manager for evaluation by TI Team (e.g., shear-wave-velocity measurements).

SSHAC (Senior Seismic Hazard Analysis Committee): A committee sponsored by the NRC, DOE, and EPRI to review the state of the art in PSHA and to develop methodologies for using expert judgment and treating uncertainties in seismic hazard analyses. The SSHAC report, which is also called the SSHAC Guidelines, was published as Budnitz et al. (1997).

SSHAC Methodology: The recommended methodology for conducting a PSHA given in Budnitz et al. (1997).

SSHAC Assessment Level: *See* **SSHAC Study Level**.

SSHAC Study: An assessment process to capture uncertainties in relevant technical knowledge and available data.

SSHAC Study Level: One of four study levels identified in the SSHAC Guidelines, ranging from Level 1 projects, which involve very few participants, to Level 4 projects, which involve multiple participants and workshops.

Stability: A characteristic of a hazard input model (e.g., the SSC model) that properly quantifies current knowledge and uncertainties such that the identification of new data, models, and methods is not likely to lead to the need for significant revisions to the model.

Surface-Wave Techniques: Proven nondestructive seismic methods that can be used to determine the variation of shear-wave velocity with depth. These techniques generally involve the measurement of Rayleigh waves. However, surface-wave testing can also be conducted using Love waves. Examples of active surface-wave techniques (SASW, MASW, and MALW) in which acoustic energy is input to the subsurface by an energy source include spectral analysis of surface waves (SASW) and multi-channel analysis of surface waves (MASW). Examples of passive surface-wave techniques include the array microtremor and refraction microtremor (also referred to as passive MASW or linear array microtremor) techniques.

Technical Integration, Technical Integrator (TI): A SSHAC term for the process, as well as an individual or team responsible for the process, of considering the data, models, and methods of the larger technical (scientific) community and assessing and representing the center, body, and range of technically defensible interpretations in a seismic hazard model. In this project, this was done using an enhanced SSHAC Level 2 assessment process.

Uncertainty: A general term. *See* **Epistemic Uncertainty** and **Aleatory Uncertainty**.

Updated EPRI (2004, 2006) Ground-Motion Model (Updated GMM): The ground-motion model developed from this study. The Updated GMM retains the conceptual (structural) framework of the EPRI (2004, 2006) Ground-Motion Model and updates it in order to capture the center, body, and range of current technically defensible interpretations.

Variance: The expected value, taken with respect to its probability distribution, of the squared deviation of an aleatory variable from its expected value.

Weight: A numerical value (≤1.0 or 100%) assigned to alternative credible models or parameter values. Weights reflect scientific judgments that any particular model or parameter value is the correct model or parameter.

Working Meeting: A meeting of the TI Team and Project Manager to consider and discuss a variety of topics. For this study, the PPRP, Senior Technical Advisors, Observers (including NRC Staff), and Resource and Proponent Experts participated in five working meetings, where the principal activities of a SSHAC study occurred: evaluation and integration. The working meetings were held in a conference room (except for Working Meeting #1, which was a conference call), and focused on one or more agenda items that required attention by the TI Team. Handouts, including highlights from the previous meeting, were distributed to all participants during the meeting. Each working meeting for this study was documented.

Work Plan: *See* **Project Plan**

Workshop: For this study, the workshop was a one-day ground-motion meeting to present and discuss the preliminary ground-motion model in a public forum and obtain feedback from Resource and Proponent Experts from the technical community.