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Seismic safety margins research program (Phase I) Interim definition of terms

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SEISMIC SAFETY MARGINS RESEARCH PROGRAM
(PHASE I)

INTERIM DEFINITION OF TERMS

INTRODUCTION

The Seismic Safety Margins Research Program (SSMRP) examines the seismic analysis and design process of nuclear power plants in a systems approach. The seismic analysis and design of a nuclear power plant requires a significant multidisciplinary effort. This effort requires contributions from specialists in geology, seismology; and structural, mechanical, electrical and foundation engineering. For some time there has been a strong motivation to reexamine the traditional process of seismic analysis in a systems context. This motivation arises principally from a widely held belief that conservatism compound in current designs. That is, at each stage, conservatism are introduced to account for uncertainties, and these conservatism compound from one stage to the next. Presently, only minimal compensations for compounding are made in each stage because the conservatism are not quantified. The result may be an over-conservative seismic design. The objectives of the Seismic Safety Margins Research Program (SSMRP) are to estimate the degree of conservatism of the present Standard Review Plan (SRP) seismic safety requirements, and to develop improved requirements and methods for safety assessment.

A methodology being developed in the SSMRP (schematically represented in Fig. 1) will examine the current seismic analysis and design process of nuclear power plants in a system context. Figure 1 depicts the seismic methodology chain (SMC) and its relationship to the SSMRP systems model. The SMC is shown separated from the SSMRP systems analysis by a heavy dashed line to emphasize that, in the SSMRP, the analysis is performed in two parts. The systems analysis (below the dashed line) represents reactor systems using an event-tree/fault tree methodology. It also employs a computational procedure to compute the probability of failure of structures, components, and systems; the probability of radioactive releases; and variations in these probabilities due to uncertainties in the SMC. The specially developed SEISIM code is used for these computations. The code SMACS is being developed to perform the response computations.

Fig. 1. Key elements of a seismic analysis calculational procedure for nuclear power plants. In evaluating possible compounding of conservatisms in such a procedure, the Seismic Safety Margins Research Program (SSMRP) calculates values in the entire system, from seismic input to probability release.

For Phase 2 of the SSMRP, the investigation is being carried out on a specific plant, the Zion Nuclear Power Plant, near Chicago. The choice of a specific plant as a seismic plant was felt to enhance the relevance of the results.

This document attempts to include all terms of importance to those interested in the SSMRP. This document will be updated as necessary. Any comments or suggestions for improvement are welcomed by the authors.

ACCIDENT SEQUENCE. Describes a sequence of failures of individual safety systems leading from an initiating event to release of radioactive material. Accident sequences are associated with event trees. Several accident sequences are possible for a given event tree, each likely leading to a different level of release, each describing a different path through the event tree.

ARMA MODEL. Commonly refers to a class of discrete linear time-domain processes (Auto Regression/Moving-Average). The generation of artificial, nonstationary seismic time histories is possible by use of ARMA models. A study is underway to select the most appropriate ARMA model and best procedure for this purpose. This is an advanced approach and is geared for later use in the program. Other less advanced approaches provide time histories that are currently needed.

BASIC EVENTS. Refers to the events located at the bottom of fault trees. These are the events that initiate paths through the fault trees, and are associated with the failure of basic components of safety systems, such as valves, pumps, and relays. In the SSMRP, each fault tree is associated with a safety system of a nuclear power plant.

BEST ESTIMATE. Usually refers to some method of analysis, modeling, or parameter selection that we believe to be the most accurate in a given set of circumstances or under certain constraints. For example, for Phase I of the Seismic Safety Margins Research Program (SSMRP), we believe the best estimate methodology for soil-structure interaction (SSI) is contained in the computer

program CLASSI, and the best estimate method for building and piping response is a three-dimensional linear time history analysis. Two key factors determine the selection of a specific best estimate method:

- The design of the SSMRP is such that the choice is based on belief or judgment rather than tests in Phase I of the SSMRP.
- The choice is tempered by objectives and constraints, such as time and budget.

CLASSI. A computer program (Continuum Linear Analysis for Soil-Structure Interaction) developed by J. E. Luco, University of San Diego, and H. L. Wong, University of Southern California. This program, which solves certain soil-structure interaction problems, provides the following major features:

- Soil and structure can be modeled in three dimensions.
- Soil layers can be modeled.
- Soil properties are modeled as a linear viscoelastic medium.
- Structure is modeled from its fixed-base eigensystem; that is, the structural model can be much more detailed than with previous methods.
- Input motion is not limited to vertically incident waves; any angle of incidence can be treated.
- Solution is linear.

COMMON CAUSE FAILURE. Failure of components or systems due to a commonly defined error. For example, redundant components or systems are often installed to enhance the safety of nuclear power plants; however, if they are all located in the same area of the plant, they will all experience virtually the same vibration environment during an earthquake. If one system or component fails, we expect the others will also tend to fail also. Redundancy may thus be lost and this is a type of common cause failure. Other examples of common cause failure are operator, test, maintenance, design, manufacturing, construction errors, other common environments, etc.

CUT SET. In the SSMRP, usually a set of component failures which lead to a safety system unable to serve its intended function. The minimum cut set is the minimum set of component failure which renders a safety system inoperable. The term "cut set" is used in conjunction with fault trees and the top event of the fault tree. As the fault trees are folded into event

trees, a much larger fault tree is in essence generated. The term cut set can be applied to this larger fault tree, and it would correspond to an accident sequence of the event tree.

EVALUATION METHOD. Methods, such as analysis, modeling, and parameter selection, that are consistent with licensing methods; for example, those specified in the NRC Standard Review Plan. Such selections are generally believed to err in the direction of conservatism.

EVENT TREE. Used in the SSMRP to define potential sequences of failure of safety systems leading to the release of radioactive material. The probability of each sequence is determined by use of fault trees generated for each safety system. Event trees applies to an entire nuclear power plant, and each tree is associated with an initiating event. Initiating events are defined separately in this document. Thus, the event tree/fault tree method starts with an initiating event, traces through subsequent events based on the probability of failure of various safety systems, and determines the probability of various levels of radioactive material release

EXPERIMENTAL DESIGN. A procedure to reduce the amount of computation from that required by a classical Monte Carlo simulation, but still retaining the feature of broad coverage of pertinent cases, and effective for cases where more than thirty analyses are performed.

FAULT TREE. Used in the SSMRP to describe the failure interactions of components of safety systems. One tree is associated with each safety system. Interaction begins with basic events of the tree; i.e., the failure of certain components, such as a valve, pump, relay. These basic events trigger other possible failures which in turn trigger more possible failures. Finally, the top event, the failure of the safety system itself may be triggered. In the SSMRP, fault trees are used in conjunction with event trees to evaluate the probability of release of radioactive material.

FLUSH. A finite element computer program (name taken from the word fast, plus the names of the authors--Lysmer, Udaka, Seed, and Hwang) to analyze soil-structure interaction (SSI). The program embodies one of several possible approaches to SSI analysis. Idealizations include two-dimensional

approximations, vertically propagating seismic waves, and a stepwise linear approximation to non,inear soil behavior.

FRAGILITY OF COMPONENT. A component is any of several items, such as a pump, valve, pipe or piping system, support. Fragility describes the failure of components, where failure is the inability to perform a specific function. Three aspects are key to the way fragility is handled in the SSMRP:

- Fragility is described in terms of the local response environment at the component (e.g., the peak acceleration that a particular pump might experience during an earthquake), rather than a global parameter like the peak acceleration of an earthquake in the free field. This local response is determined from soil-structure interaction, structural building, and subsystem response calculations.
- Fragility is the inability of a component to perform that function necessary to mitigate an accident condition; for example, fragility of a pump is the inability of that pump to produce a required discharge.
- Fragility is described probabilistically; for example, a fragility curve relates the probability of failure of a particular component to a given local peak acceleration.

FRAGILITY OF STRUCTURE. Similar to fragility of components, except that structures and structural elements, rather than components, are the elements of interest.

HAZARD. A computer code (not an acronym) to generate the hazard curve for the seismic hazard at a given site. The hazard curve describes the probability of occurrence versus earthquake size. HAZARD also generates the frequency spectra for the earthquakes.

INITIATING EVENTS. Failures critical enough to activate the safety systems of a nuclear power plant to help prevent the release of radioactive material. An event tree is associated with each initiating event. Two major categories of initiating events are recognized--pressure boundary rupture and transient initiation. These categories are further subdivided, depending on the capabilities of the particular plant and safety systems activated. An example of a pressure boundary rupture is the rupture of a large pipe. A transient does not involve rupture; an example is a turbine trip triggered by an earthquake.

MARGIN. Real earthquakes with a peak acceleration equal to the safe shutdown earthquake (SSE) result in certain measured responses (e.g., accelerations and strains) in nuclear power plant structures, systems, and components. These responses vary significantly from one earthquake to another, even if each earthquake has the same peak acceleration. We denote the mean of these responses as R. Seismic safety analyses for design earthquakes with a peak acceleration equal to the SSE result in certain predicted responses in nuclear power plant structures, systems, and components. Although methods of analysis acceptable to the NRC are deterministic, the results of their application are not; therefore, design responses also vary from one design earthquake to another. We denote the mean of these responses as D. The quotient D/R is termed the calculation margin, which is generally believed to be greater than one.

The design responses D result in certain mechanical responses, such as stresses and strains in components. These mechanical responses generally are less than some code allowable A, which leads to a design margin A/D.

Finally, even if the code allowable mechanical response is attained, an additional margin is accounted for prior to component failure. If we designate as F the mechanical response at which failure would occur, this final code margin is F/A.

The total margin is the product of these three contributors, that is, calculation margin times design margin

times code margin, or $\frac{D}{R} \times \frac{A}{D} \times \frac{F}{A} = \frac{F}{R}$.

These definitions are somewhat simplistic; for example, the definitions do not attempt to relate to the probability of failure. This is due in part to the inherent limitations of the margin concept.

ON-LINE COMPUTATIONS. Lead directly toward producing the primary results of the SSMRP. For Phase II, the primary results are probability of release (risk), ranking of the contributors to risk, and ranking of the uncertainties of the contributors to risk. Other studies carried out are side studies which contribute insight, provide information for decisionmaking, and can produce significant technical results. For further insight on the role of on-line computations, see response computations.

OUTPUT MODELING. Modeling of the important output features as a simple function of the input parameters, rather than in terms of the full computational model. On-line response computations develop responses for the various components and structures for which fragilities are described. These computations are performed for each value of peak acceleration and spectral shape parameter of interest. For a fixed peak acceleration and spectral shape parameter, considerable variation in response can result, reflecting the statistical nature of earthquake response. Output modeling describes the statistical nature of these responses so as to reduce the amount of on-line computations necessary.

PEAK ACCELERATION. In some response computations, the history of acceleration as it varies with time (acceleration time history) is calculated. The peak acceleration is the largest absolute value of this history.

RANDOM AND MODELING, OR SYSTEMATIC, UNCERTAINTIES. A probabilistic analysis is a modeling tool in which more than one parameter is stochastic rather than deterministic; thus, the concepts of random uncertainty and modeling, or systematic, uncertainty are common. For example, in the SSMRP, the operation of the Zion Nuclear Plant in an earthquake environment is modeled by probabilistic analysis. Many of the parameters derived from this modeling are not deterministic but stochastic--that is, subject to random variation; therefore, the outcome of such an analysis is stated in probabilistic terminology.

It is important that the distinction between random and modeling, or systematic, uncertainties be made clear, since probabilistic analysis addresses both of these uncertainties. Many experimental situations exist in which the real, physical entity can be tested or subjected to, say, random inputs, with some response measured. Since the actual physical entity is tested, the only uncertainties of importance are random uncertainties, except perhaps systematic errors which may exist in the measuring instrument; but these are usually insignificant, and hence not included in an analysis. Conversely, in a modeling uncertainty, many analyses are based entirely on mathematical models, such as differential equations which model the response of some physical entity to certain inputs. Such inputs are usually considered to be known and deterministic; thus, if any "uncertainty" is in this type of analysis, the only source of it is in the mathematical model representing the system--hence, response--under investigation.

Random uncertainties vary in a nondeterministic way under apparent identical conditions, in measured or observed responses (variables), due to factors beyond the control of the analyst. The sources of random variation are numerous in observed responses, e.g., (1) natural variations in the physical properties, operation, and behavior of the physical entity observed; (2) variations in the measurement process to observe a response, including the instruments, procedures, and human factors involved in observing a response; (3) variations in environmental conditions surrounding a measurement; and (4) variations introduced by sampling and other selection procedures in the measurement process. More than one of these causes of variation can be expected to occur when a response is observed; therefore, the measured response should appropriately be modeled as a random variable.

The following examples illustrate random uncertainties:

- Fragilities or failures. Variations between like units in their susceptibility or fragility (response level at which a unit fails; e.g., no longer performs its intended function), owing to several probable causes. These causes include variations in manufacture, variations in the basic elements and materials within the unit, and variations in the conditions and environment surrounding the use of the unit. A specific unit, once placed within an operating environment, can be considered to have a fixed, but known, failure level (e.g., response level below which it does not fail and above which it does fail); thus, its fragility is not random; however, conditions surrounding the operation of such a unit vary continuously; and since inferences about the failure of such a unit are usually made to the population of "identical" units, the failure level of a unit is treated as a random variable.
- Estimated structural parameters. Since inferences about the structural properties, e.g., coefficient of damping, of a building are usually made to the specific building under investigation, properties are appropriately considered to have deterministic or specific, yet unknown, values. The value of the coefficient of damping is usually unknown; therefore, it should be estimated by testing or observing the response of similar structures under similar expected inputs; but, the responses under "identical" conditions cannot be expected to be identical due to variations in, say, materials, radiation of energy, friction, or banging. The measured or observed response of a structure can be treated as a random variable; thus, an estimate of the value of the coefficient of damping for a specific building is a random variable.

- Earthquake time histories. The amplitude spectra (time histories) of two earthquakes are not identical, even if parameters identifying an earthquake, such as maximum amplitude, shape parameter, phase, distance, and orientation from epicenter, are identical. The geological properties surrounding the region of measurement and the unknown sources and cause of the initial disturbance are only two sources of uncontrollable variation. The time history of an earthquake can therefore be treated as a random process.

Modeling, or systematic, uncertainties are variations in the output of a modeling process, such as analytical, simulation, scale-model, due to imperfections in the modeling, design, or analysis. First, the modeling process is specified, including the values of any parameters--e.g., structural properties-coefficient of damping, earthquake parameter-frequency, maximum amplitude; following which, the imperfect values, model, or design introduces a constant uncertainty or bias--variation from the actual or "true" response--in the output of the process. This constant uncertainty exists for the duration of the specified model. The causes or sources of these systematic uncertainties are numerous, such as (1) a mathematical equation, perhaps a differential equation, to model a complex physical process; (2) estimates or subjective opinions to generate values of unknown model parameters; (3) the inability of the analysis methods and models, e.g., fault-event trees or elastic analysis, to completely analyze a system.

It is difficult to assess or specify the uncertainty introduced by a specific model (type of mathematical equation or analysis) or analysis method; therefore, these uncertainties are usually not described, although they are recognized. Conversely, uncertainties introduced by randomly variable estimates based on tests and experimental or sample data inputs (i.e., as values of the model parameters, into the modeling process) are conveniently described by models of the probability distributions of the estimates--or by the characteristics, e.g., mean and variance of the distribution. Similarly, when estimating a model parameter in subjective opinions, uncertainties are not uncommonly described by specifying a range of values or a probability distribution for that parameter.

The following examples illustrate modeling, or systematic, uncertainties:

- Fragility curves. The response level at which a component or subsystem will fail is modeled as a random variable; thus, an input into the

probabilistic analysis is a specification of the probability distribution, usually given in terms of a fragility curve (cumulative distribution function), of the failure level. Only limited information is available about the failure of most components; therefore, only a limited amount of test data or professional opinions are required to develop a fragility curve. In either case, the selected fragility curve is not likely to be the "correct" curve for the component(s) analyzed; thus, the output (e.g., probability of component failure or probability of radioactive release) of the probabilistic analysis will be biased; that is, it will deviate from the "correct" output by a constant. The uncertainty introduced by an estimate (based on test or subjective opinion) can be recognized by specifying a finite family of fragility curves or specifying a probability distribution (e.g., a beta distribution) over a family of fragility curves.

- Structural parameters. Any deviation between the value in the analysis and the "true" value for the Zion Nuclear Power Plant is a modeling or systematic uncertainty, since the structural parameters considered for this particular plant are part of the modeling process. The "true" value of the structural parameters are unknown; so these unknown values are necessarily estimated from test data or subjective opinions. The estimate is unlikely to be exactly equal to the "true" value of the structural parameter; therefore, any output from the modeling process will deviate from the "true" response by a constant amount; thus, estimating a structural parameter in the modeling process introduces a modeling uncertainty. A modeling uncertainty so introduced is usually recognized in the probabilistic analysis by specifying a probability distribution for the structural parameter estimate--either the probability distribution of the estimate, if it is based on test data, or a probability distribution which reflects a subjective professional opinion.
- Earthquake parameters. Several models and modeling parameters enter into the modeling of earthquake time histories; e.g., models of the site effect, ground motion models, geometry--zonation and tectonic regions, upper magnitude cutoff, rate of occurrence, and parameters of the relationship between the number of earthquakes and magnitude. Once the models and values of the model parameter are specified, the resulting family of earthquake time histories and the final output from the probabilistic analysis will vary from the "true" value by a constant amount. These modeling parameters introduce potential systematic

uncertainties into the analysis; where appropriate, these uncertainties are recognized in the probabilistic analysis by specifying a probability distribution for the model parameters.

In one sense, the real difference between a random and a modeling uncertainty is determined by the amount of control the analyst has over a cause or source of variation. If conditions--e.g., materials, operation, operating environment, measuring process--could be controlled precisely, random uncertainty would not exist. Unfortunately--fortunately, from a statisticians point of view, such precise control is not possible. Only the source of variation, which is beyond the control of the analyst, must be treated as random variation or uncertainty. Of course, the philosophy here is that any condition that might introduce a constant bias is recognized and accounted for in the analysis; thus, all uncontrolled conditions result in nondeterministic or random variations in a response.

The design, analysis, models, and model parameters in a probabilistic analysis are under the control of the analyst; therefore, once the modeling process is specified, the output is equal to or deviates from the "true" output by a fixed, but unknown, amount. The effect of different models and parameters on the output can be assessed by sensitivity analysis. Also introducing probability distributions for the parameters describes a measure of uncertainty in the modeling process --particularly in the values of the model parameters. The affect of the modeling uncertainties is reflected by the resulting probability distribution of the output. In the SSMRP, this would be reflected in a probability distribution on the probability of release or other output variables.

Occasionally, systematic uncertainties are appropriately treated as another source of random uncertainty, for convenience, or because accounting for variations in model parameters separately from random uncertainty is unnecessary or undesirable. In an analysis, any systematic uncertainty viewed this way is treated as all other sources of random variation. The overall effect is an increase in the magnitude of random variation; hence, in the case of a probabilistic analysis, where the final output is a probability of failure or release, an increase is likely in the final output probability.

In summary, even if we had adequate test results for many parameters on the Zion facility, we would still have to consider that our estimates of these parameters have some random variation when applied in our analyses. But we do not have such test results, so we necessarily introduce some bias, which is

characterized as a modeling, or systematic uncertainty in our analyses; therefore, the problem is to determine the extent to which each source(s) of systematic uncertainty contributes to uncertainty in the probability of release or other output variables. Such a ranking suggests where the unavailability of test results contributes most to uncertainty in the probability of release; or, conversely, which tests, if performed, could have the greatest effect in reducing the uncertainty. On the SSMRP, sensitivity studies are for just such a purpose.

RESPONSE COMPUTATIONS. The areas of soil-structure interaction, structural building response, and subsystem response are similar: Newtonian equations of motion are defined and solved for earthquake excitation. The solutions are the responses. Response is a very general term which can include displacement, velocity, acceleration, relative displacement, stress, strain force or moment time histories, peak values of these quantities, Fourier analysis, or power or response spectra of these histories.

Response computations are performed in two modes--on-line and off-line or side studies. On-line response computations develop inputs for the SEISIM computer program in a form appropriate to fragility curves. Typically, the on-line computations are statistically oriented and propagate various uncertainties through the entire seismic methodology analysis chain (Monte Carlo calculation). These uncertainties usually include:

- Several different time histories
- Uncertainty in SSI model-shear modulus and damping
- Uncertainty in structural building model-frequency and damping
- Uncertainty in subsystem model-frequency and damping

Off-line response computations, or side studies, investigate specific effects rather than develop blocks of statistical data. For example, in a side study we may investigate the effects of different modeling techniques on structural model properties. Or we may use side studies to reduce the number of variables in the on-line calculation (if structural response is not significantly affected by parametric variations in damping, we might eliminate damping as a variable in the on-line calculations).

On-line computations include models for all of the effects--SSI, building response, and subsystem response; off-line computations focus on one of these three areas. The volume of on-line computations is much greater than for off-line.

RESPONSE INPUT VECTOR. The vector of response values which are an input to the SEISIM computer program. Several vectors are required, each obtained from on-line response computations which have as their input a single set of three components of earthquake motion in the free field. The different elements of this vector correspond to different components which appear on the event-fault trees. The type of response values in each element corresponds to the inputs required by the fragility curves.

RISK. The annual probability of release of radioactive materials in each of the seven release categories in the Rasmussen report (WASH-1400). This definition is peculiar to SSMRP, and is not standard.

SEISIM. A computer program (Seismic Evaluation of Important Safety Improvement Measures) that derives its inputs from

- Seismic hazard curves
- Event-fault trees
- Response input vectors
- Fragility curves
- Release category relationships

and calculates

- Probability of failure of components and systems
- Probability of accident sequences
- Probability of release in each of the categories due to earthquakes.

SEISMIC DESIGN METHODOLOGY CHAIN. Denotes the sequence of analyses used in designing a nuclear power plant. The chain addresses in the SSMRP consists of

- Seismic input characteristics
- Soil-structure interaction
- Major structural response
- Subsystem response
- Fragilities

In conventional seismic design, each of the five areas is handled separately with their own factors of safety. As the design chain is traversed, the factors of safety compound enormously, but safety is not necessarily ensured. In the SSMRP, these five areas are handled together in a systems analysis approach, and risk is the figure of merit, not factors of safety.

SENSITIVITY STUDIES, TYPES I, II, AND III. Studies which perform the following functions, by type:

Type I Evaluates the effects on results due to changes in analytical models

Type II Estimates the risk and uncertainties of risk

Type III Ranks the contributors to the uncertainties on risk

Type I studies are to gain confidence in the analytical models as well as to assess the relative importance of various parameters. Type I studies will be started in Phase I. The determination of risk is a sensitivity study (Type II), since the determination of uncertainties is a necessary part of risk. Types II and III studies will be carried out in Phase III.

SHAKE. A computer program (not an acronym) to calculate the bedrock seismic motion given the free field motion. Idealizations include one-dimension soil column, vertically propagating seismic waves, and stepwise linear approximations to nonlinear soil behavior.

SIDE STUDIES. Provides insight, technical information for decisionmaking, and at times very significant results. These are studies which do not lead directly to the primary results of the program. Many of the sensitivity studies are side studies. Examples are the modeling study for structures and effects of variations in natural frequency and damping on structural response. For further insight into the role of side studies, see response computations.

SIMQ. A computer program (not an acronym) to generate synthetic seismic time histories.

SMACS. A computer program (Seismic Methodology Analysis Chain with Statistics) which encompasses the models of soil-structure interaction, structural response, and subsystem response; and calculates local structural or subsystem response for specified seismic time history. Response quantities calculated can be stresses, displacements, accelerations, etc. SMACS is one of the major computer programs produced by the SSMP.

SPECTRAL SHAPE PARAMETER. In the past, seismic hazard curves have been formulated to relate the annual probability of an earthquake occurring with a

peak acceleration in excess of a given value versus that value. Such curves are a probabilistic statement of the seismic environment we expect at a given site or a probability density function with peak acceleration as the random variable. Now, in addition to peak acceleration, many parameters are required to define the complex three-dimensional motion of an earthquake at any given point at any given site. Conceiving a probability density function with more than one random variable is, however, relatively routine. Early in the program, seismic hazard was characterized in terms of more than one random variable, if possible and meaningful. Such a process would allow us ultimately to estimate the risk more accurately. We chose to make this advance only one step at a time, so we selected two random variables to characterize the seismic hazard. If we look at real earthquakes scaled with the same peak acceleration, one distinguishing feature is their spectral shape. This shape is also important in its effect on structural response. We decided, therefore, to attempt to characterize the seismic hazard in terms of peak acceleration and a parameter relating to the spectral shape--"a spectral shape parameter."

Such a parameter can enter into the process by giving a better perspective to the differing effects of "near" to "distant" earthquakes; that is, whether an earthquake is near or distant from a site can affect the risk because of the differing frequency content. Characterizing the seismic hazard density function in terms of the spectral shape distinguishes the relative frequencies of the various spectral shapes rather than settling for the effect of some average shape.

TOP EVENT. In the SSMRP, usually the event on the very top of a fault tree. A fault tree is constructed for each safety system. Under seismic excitation, components can become inoperative, leading possibly to the system's inability to serve its safety functions. Such a failure is the top event for the fault tree. As the fault trees are folded into event trees, a much larger fault tree in essence is generated. The term top event can also be applied to this larger fault tree, and it would correspond to the failure of a combination of safety systems leading to a release of radioactive material.