4.0 Seismic Event Modeling and Seismic Risk Quantification

4.1 Objectives and Scope

This document is intended to provide practical guidance to NRC risk analysts who routinely use the Systems Analysis Programs for Hands-on Integrated Reliability (SAPHIRE) software and the Standardized Plant Analysis Risk (SPAR) probabilistic risk assessment (PRA) models to determine event and plant condition importances, as well as other ad-hoc risk analyses. It is a complementary document to the Handbook cited in Reference 4-1.

NRC risk analysts perform risk assessment of many plant conditions and events reported by such means as inspection reports, licensee event reports (LERs), generic risk issues that lend themselves to PRA quantification and evaluation. The need for quantification of the event / condition importance in terms of the two common risk measures of core damage frequency (CDF) and large early release frequency (LERF) arise in many of these cases.

This Handbook provides NRC risk analysts with practical guidance for modeling seismic event scenarios and quantifying their CDF using SPAR models and SAPHIRE software.

The Handbook assumes that:

1. The user has hands-on experience with the SAPHIRE code;

2. The user has performed and documented event/condition importance analysis or plant risk assessment cases for a period of at least three months (this is a suggested period, not a firm limit) to ensure adequate proficiency in quantitative risk assessment techniques. The user is the primary author of documentation packages for such analyses that are reviewed and accepted by an NRC program.

The current scope is limited to seismic events during power operation and calculation of CDF only.

Mainstream PRA terms and abbreviations that are used in this document are not defined; the intended reader is assumed to be familiar with them.

The seismic PRA (SPRA) model described in this Handbook can be used for plants with Seismic Margin Assessment (SMA). See Section 4.2.8.

4.2 Seismic Event Scenario Definition

4.2.1 Minimum Input Requirements

The minimum requirements for input into the SPAR model are as follows:

1. Seismic Hazard Vector (frequencies of seismic events)

- The seismic hazard vectors for all 61 U.S. nuclear power plants are obtained from licensees' submittals as part of the effort to address Near- Term Task Force (NTTF) Recommendation 2.1 in 2014 and 2015. These seismic hazard vectors are given in Appendix 4A. Uncertainty information for each of the seismic hazard vector can also be obtained from the licensees' submittals.

2. Seismic fragilities of major structures, systems, and components (SSCs).

   - Seismic fragilities can be found in plants with SPRAs, and some of this information may be available for plants with seismic margins analyses. If not, reference SSC fragilities given in Appendix 4B may be used. Section 4.2.4 provided additional discussion with respect to the usage of these reference SSC fragility.

3. An event tree model representing the seismic sequences.

   - Such an event tree model is provided as a default in a later section.

4.2.2 Example Seismic Hazard Vector

The example seismic hazard vector in Table 4-1 is taken from NUREG-1488, "Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Power Plant Sites East of the Rocky Mountains," (Reference 4-2) and is presented graphically in Figure 4-1:

Table 4-1 Example Seismic Hazard Vector

(Cumulative frequency of exceedance of a *g* value)

***g* value**	**mean *f* per year**
0.05	3.040E-04
0.08	1.777E-04
0.15	6.422E-05
0.25	2.748E-05
0.30	1.979E-05
0.40	1.141E-05
0.50	7.212E-06
0.65	4.043E-06
0.80	2.474E-06
1.00	1.409E-06

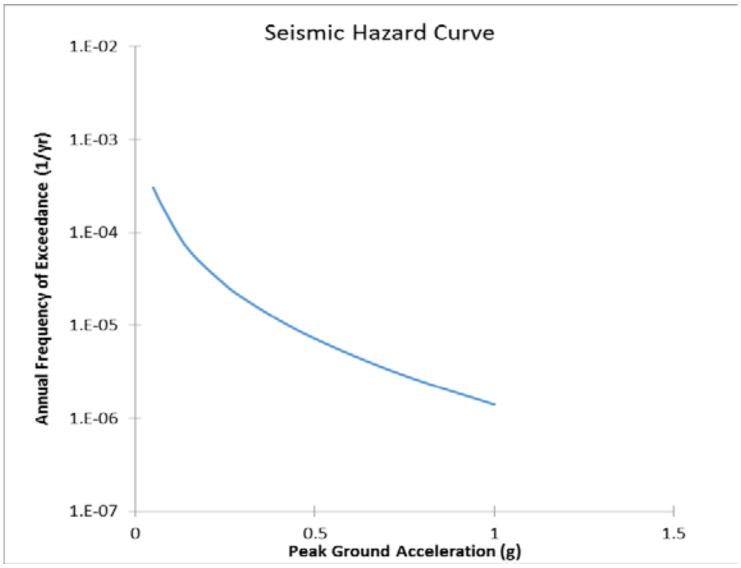

Figure 4-1 Example Seismic Hazard Vector

This vector provides the seismic initiating event frequencies (seismic hazard distribution) as a function of seismic g level. The frequency of a seismic event of magnitude 0.05g or higher is given as 3.04E-04/year.

The plant is designed to withstand a design basis earthquake (DBE) (also known as safe shutdown earthquake (SSE)) of 0.12g peak ground acceleration (PGA). The operating-basis earthquake (OBE) is 0.06g.

4.2.3 Seismic Event Categories

The seismic acceleration range can be partitioned into N categories (bins) to define N discrete seismic event scenarios with increasing intensity. This Handbook recommends using three to five seismic bins as defined below, unless plant-specific considerations require more bins.

For the example case above, three seismic event categories (bins) are defined as follows:

		IE Frequency
IE-EQK-BIN-1	SEISMIC INITIATOR (0.05g - 0.3g)	2.84E-04/year
IE-EQK-BIN-2	SEISMIC INITIATOR (0.3g - 0.5g)	1.26E-05/year
IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5g)	7.21E-06/year

For each bin, a mean acceleration is assigned in terms of the geometric average of the bin end points. For the three bins in question, the bin accelerations are:

Seismic Bin	**Bin Acceleration**
BIN-1 (0.05g-0.3g)	0.122g
BIN-2 (0.3g-0.5g)	0.387g
BIN-3 (>0.5g)	0.707g

The frequency of each bin, which is calculated as the difference of the frequencies of two bin range limits, is calculated as shown in Table 4-2.

Table 4-2 Calculation of Bin Accelerations and Frequencies

Ground Acceleration (g)	Exceedance Frequency	Seismic Bin	Bin Acceleration (g)	Bin Frequency (per year)
0.05	3.04E-04	1 (0.05g-0.3g)	0.122	2.84E-04
0.08	1.78E-04			
0.15	6.42E-05			
0.25	2.75E-05			
0.30	1.98E-05	2 (0.3g-0.5g)	0.387	1.26E-05
0.40	1.14E-05			
0.50	7.21E-06	3 (>0.5g)	0.707	7.21E-06
0.65	4.04E-06			
0.80	2.47E-06			
1.00	1.41E-06			
			Sum =	**3.04E-04**

The three seismic bins chosen here follow the Limerick external events feasibility study (Reference 4-3). The first bin is driven by seismically induced loss-of-offsite power (LOOP) events. The second bin captures other modeled events (small loss-of-coolant accident (SLOCA), large loss-of-coolant accident (LLOCA), LOOP, and structural failures). The third bin is driven by the seismic failure of major structures, leading to direct core damage.

A larger number of bins can be readily introduced into the SPAR models without significantly affecting their quantification times. The current SPAR-AHZ models use five seismic bins. A larger number of bins may be appropriate for the sites to the West of the Rocky Mountains. The need may be based on two factors:

1. Seismicity of the site (seismically more active sites may require more bins);

2. Fragility grouping of major SSCs (one or more key SSCs with a fragility in a seismic range may warrant a bin in that range to make the model more realistic).

After the next step (4.2.4) is completed and if plant-specific low fragility SSCs are identified, redefinition of the seismic event categories (i.e., number of bins, or the bin ranges) may be required to provide better resolution at the lower g level or at the frequency range that is of interest.

4.2.4 SSC Seismic Fragilities

The fragilities of the major SSCs must be obtained to calculate mean seismic failure probabilities. Preferably, the analyst should use the plant-specific fragility value if one exists for the plant. In the absence of plant-specific SSC fragilities, reference fragilities values from power plants of similar vintage may be used as surrogates.

Table 4-3a shows an example of the fragilities considered and how they are treated for SPAR-AHZ purposes. Appendix 4B also provides a convenient table for reference fragilities of commonly-considered SSCs. A more extensive collection of SSC seismic fragilities is available in an NRC document (non-public), which contains proprietary information, in ADAMS as ML071220070.

The fragility information needed for a SSC is either,

Median capacity a_m and β_c OR

Median capacity a_m, β_r and β_u

where $\beta_c = (\beta_r^2 + \beta_u^2)^{1/2}$. The mean seismic failure probability $P_{fail}(a)$ at a bin acceleration level can be calculated by using the following equation:

$$P_{fail}(a) = \Phi\ [\ \ln(a/a_m) / (\beta_r^2 + \beta_u^2)^{1/2}]$$

where Φ is the standard normal cumulative distribution function and

a = median acceleration level of the seismic event;
a_m = median of the component fragility (or median capacity);
β_r = logarithmic standard deviation representing random uncertainty;
β_u = logarithmic standard deviation representing systematic or modeling uncertainty.

High Confidence of Low Probability of Failure (HCLPF) Capacity is a term that is commonly-used in a SPRA or SMA. HCLPF capacity is a measure of seismic ruggedness and it is defined as the earthquake motion level at which there is a high (95 percent) confidence of a low (at most 5 percent) probability of failure of a single SSC or of an ensemble of them. The HCLPF value is calculated by the equation:

$$\text{HCLPF} = a_m \exp(-1.645(\beta_r + \beta_u))$$

The fragilities of key SSCs can be ordered from lowest to highest in a table. The lower fragilities will determine the number of bins and their ranges while the lowest of the critical SSC fragilities would help determine the highest bin. A critical SSC is one if failed would lead to core damage. (Examples include containment, fuel, reactor pressure vessel, steam generators including their supports, etc.)

Generally, ceramic insulators have one of the lowest median capacities among the SSCs modeled in a seismic PRA. Therefore, the failure of ceramic insulator is assumed to trigger the occurrence of LOOP following a seismic event in many plants. Seismic fragility data for ceramic insulators can be taken from Reference 4-4, if plant-specific information is not already available.

As previously discussed, seismic event categories (i.e., number of bins or bin ranges) definitions may be revisited/revised after SSC fragilities are modeled.

Tables 4-3a and 4-3b show some examples of how SSC fragilities are used in two SPAR-AHZ models.

Table 4-3a An Example of Seismic Fragilities and Their Treatment in SPAR-AHZ

SSC Description	Median Capacity (g)	β_c OR β_r	β_u	SSC Failure probability	Comment	HCLPF (g)
Offsite Power	0.35	0.55		2.77E-02	LOOP-EQ-1	
	0.35	0.55		5.72E-01	LOOP-EQ-1	
	0.35	0.55		8.99E-01	LOOP-EQ-3	
RHR Heat Exchanger	0.63	0.46		1.79E-04	RHR-HX-EQ1	
	0.63	0.46		1.45E-01	RHR-HX-EQ2	
	0.63	0.46		5.99E-01	RHR-HX-EQ3	
Surrogate Element	0.64	0.3		1.65E-08		
	0.64	0.3		4.68E-02		0.68
	0.64	0.3		6.30E-01		
Reactor Pressure Vessel	2	0.3	0.35	6.53E-10	CD	
Reactor Pressure Vessel Supports	2	0.3	0.35	1.83E-04	CD	0.75
	2	0.3	0.35	1.20E-02	CD	
Steam Generators	2.5	0.3	0.4	7.73E-10	CD	
Steam Generator Supports	2.5	0.3	0.4	9.53E-05	CD	0.75
	2.5	0.3	0.4	5.77E-03	CD	
Pressurizer	2.5	0.3	0.4	7.73E-10	LLOCA	
Pressurizer Supports	2.5	0.3	0.4	9.53E-05	LLOCA	0.75
	2.5	0.3	0.4	5.77E-03	LLOCA	
Reactor Coolant Pumps	2.5	0.3	0.4	7.73E-10	LLOCA	
Reactor Coolant Pump Supports	2.5	0.3	0.4	9.53E-05	LLOCA	0.75
	2.5	0.3	0.4	5.77E-03	LLOCA	
Control Rod Drive Mechanism	2.5	0.3	0.4	7.73E-10	ATWS	
Reactor Core Upper Internals	2.5	0.3	0.4	9.53E-05	ATWS	0.93
	2.5	0.3	0.4	5.77E-03	ATWS	
Reactor Coolant System Piping	3.8	0.35	0.5	8.82E-09	CD	
	3.8	0.35	0.5	9.10E-05	CD	
	3.8	0.35	0.5	2.93E-03	CD	0.37
Containment Building	1.1	0.3	3.50E-	9.20E-07	CD	
Auxiliary Building	1.1	0.3	3.50E-	1.17E-02	CD	
Turbine Building	1.1	0.3	3.50E-	1.69E-01	CD	

SSC Description	Median Capacity (g)	β_c OR β_r	β_u	SSC Failure probability	Comment	HCLPF (g)
Reactor Coolant Pump Seals	not modeled				SLOCA	
Secondary Side Piping and Supports	not modeled				SLB	
Switchyard Ceramic Insulators	modeled above				LOOP	
Screenhouse	surrogate element is used in SWS FT				SW	
Instrument Air	May be assumed failed in SPRA due to low fragility.					
CST	Assumed failed due to low fragility in SPRA. SWS is credited as alternate.					
RPS	Failure to scram is modeled in the RPS fault tree; surrogate element is used.					

Acceleration (g)	SLOCA	MLOCA	LLOCA	ATWS	LOOP	CD-EQ
0.122	1.50E-05	1.00E-07	1.23E-08	7.73E-10	2.77E-02	2.77E-06
0.387	4.50E-02	4.00E-03	5.91E-04	9.53E-05	5.72E-01	3.55E-02
0.707	2.50E-01	4.00E-02	1.55E-02	5.77E-03	8.99E-01	5.27E-01

SLOCA and MLOCA	IE frequencies are taken from NUREG/CR-4840, Figure 3-6, as in SPRA.
LLOCA	Sum of SG, RCP, PRESSURIZER, and 0.1 times MLOCA.
ATWS	from RPS
LOOP	From Offsite Power
CD-EQ	Sum of RVF,SG,RCS piping, and 3 buildings (Containment, Aux., Turbine)

Plant-specific SPRA assignments are used when available

Table 4-3b SSC Fragilities and Their Treatment in Plant C SPAR-AHZ

	SSC Description	Median Capacity (g)	β_r	β_u	SSC Failure probability	Comment	HCLPF
1	Reactor Pressure Vessel	2	0.3	0.35	6.53E-10	CD	0.69
	Reactor Pressure Vessel Supports	2	0.3	0.35	1.83E-04	CD	
		2	0.3	0.35	1.20E-02	CD	
2	Steam Generators	2.5	0.3	0.40	7.73E-10	CD	0.79
	Steam Generator Supports	2.5	0.3	0.40	9.53E-05	CD	
		2.5	0.3	0.40	5.77E-03	CD	
3	Reactor Coolant System Piping	3.8	0.35	0.50	8.82E-09	CD	0.94
		3.8	0.3	0.35	3.61E-07	CD	
		3.8	0.3	0.35	1.32E-04	CD	
4	Buildings (including containment, turbine and auxiliary buildings)	1.1	0.2	0.35	2.45E-08	CD	0.45
		1.1	0.2	0.35	4.78E-03	CD	
		1.1	0.2	0.35	1.36E-01	CD	
5	CD-EQ1	sum of 1,2,3,4			3.48E-08	CD	
	CD-EQ2				5.06E-03	CD	
	CD-EQ3				1.54E-01	CD	
6	Reactor Coolant Pumps	2.5	0.3	0.40	7.73E-10	LLOCA	0.79
	Reactor Coolant Pump Supports	2.5	0.3	0.40	9.53E-05	LLOCA	
		2.5	0.3	0.40	5.77E-03	LLOCA	
7	Pressurizer	2.5	0.3	0.40	7.73E-10	LLOCA	0.79
	Pressurizer Supports	2.5	0.3	0.40	9.53E-05	LLOCA	
		2.5	0.3	0.40	5.77E-03	LLOCA	
8	10% of MLOCA	**			1.00E-08	LLOCA	
		**			4.00E-04	LLOCA	
		**			4.00E-03	LLOCA	
9	LLOCA-EQ1	sum of 6,7,8			1.15E-08	LLOCA	
	LLOCA-EQ2				5.91E-04	LLOCA	
	LLOCA-EQ3				1.55E-02	LLOCA	
10	SLOCA-EQ1	**			1.50E-05	SLOCA	
	SLOCA-EQ2	**			4.50E-02	SLOCA	
	SLOCA-EQ3	**			2.50E-01	SLOCA	
11	Offsite Power	0.3	0.3	0.35	2.55E-02	LOOP-EQ-1	0.10
		0.3	0.3	0.35	7.10E-01	LOOP-EQ-1	

	SSC Description	Median Capacity (g)	β_r	β_u	SSC Failure probability	Comment	HCLPF
		0.3	0.3	0.35	9.69E-01	LOOP-EQ-3	
12	Control Rod Drive Mechanism	1.8	0.3	0.40	3.67E-08	RPS-EQ-1	0.57
	Reactor Core Upper Internals	1.8	0.3	0.40	1.06E-03	RPS-EQ-2	
		1.8	0.3	0.40	3.08E-02	RPS-EQ-3	
13	EDGs	1.45	0.3	0.35	3.95E-08	EDG-EQ-1	0.50
		1.45	0.3	0.35	2.08E-03	EDG-EQ-2	
		1.45	0.3	0.35	5.96E-02	EDG-EQ-3	
14	CST	1.1	0.3	0.35	9.20E-07	AFW-EQ-1	0.38
		1.1	0.3	0.35	1.17E-02	AFW-EQ-2	
		1.1	0.3	0.35	1.69E-01	AFW-EQ-3	
15	CCW	1.45	0.3	0.35	3.95E-08	CCW-EQ-1	0.50
		1.45	0.3	0.35	2.08E-03	CCW-EQ-2	
		1.45	0.3	0.35	5.96E-02	CCW-EQ-3	
16	RWST	1.1	0.3	0.35	9.20E-07	HPI-EQ-1 *	0.38
		1.1	0.3	0.35	1.17E-02	HPI-EQ-2 *	
		1.1	0.3	0.35	1.69E-01	HPI-EQ-3 *	
17	Screenhouse	1.1	0.3	0.35	9.20E-07	SWS-EQ-1	0.38
		1.1	0.3	0.35	1.17E-02	SWS-EQ-2	
		1.1	0.3	0.35	1.69E-01	SWS-EQ-2	
18	Battery Chargers	1.6	0.3	0.35	1.18E-08	DC-EQ-1	0.55
		1.6	0.3	0.35	1.04E-03	DC-EQ-2	
		1.6	0.3	0.35	3.82E-02	DC-EQ-3	

Notes:

* also use in LPI-EQ1
LPI-EQ2
LPI-EQ3

** SLOCA and MLOCA IE frequencies are taken from NUREG/CR-4840, Figure 3-6.

Acceleration (g)	SLOCA	MLOCA
0.122	1.50E-05	1.00E-07
0.387	4.50E-02	4.00E-03
0.707	2.50E-01	4.00E-02

The following list illustrates the candidate SSCs that may need to be modeled in a SPRA (the list is taken from a specific SPAR and is not intended to be an exhaustive list).

Important Structures
Containment building
Concrete internal structure
Auxiliary building
Turbine building
Intake structure
Refueling water and condensate storage tanks
Diesel Generator fuel oil storage tank (buried)
Auxiliary saltwater system piping (buried)
Major Plant System
Nuclear steam supply system
Residual heat removal system
Safety Injection system
Component cooling water system
Chemical and volume control system
Auxiliary saltwater system
Containment spray system
Main steam system
Auxiliary feedwater system
Diesel generator and auxiliaries
Containment building ventilation system
Control room ventilation system
Vital electrical room ventilation system
4160 V (vital) electrical system
480 V (vital) electrical system
125 V DC electrical system
Operator instrumentation and control system
NSSS instrumentation and control system
Off-site power system
Example Component Categories
Electrical penetrations
Balance-of-plant piping and supports
Air and motor operated valves
Cable tray, conduits, and supports
HVAC ducting and supports

4.2.5 Event Tree Models

The three seismic event tree models developed for the three seismic bins are shown in Figures 4-2 through 4-4.

The example SPRA also modeled medium loss-of-coolant accident (MLOCA) event, but its CDF contribution was not dominant. Therefore, the MLOCA event is left out of the current SPAR-AHZ models. If necessary, it can be added as a transfer into the seismic event trees with minimal additional work. Other events may also be considered on a plant-specific basis and may be added to the model as needed.

4.2.6 Fault Tree Models

The following new fault trees are introduced to represent the seismic event tree nodes. Each of these fault trees contain a single probability and allow transfer into a target event tree, or directly go to a CD end state:

CD-EQ1
CD-EQ2
CD-EQ3
LLOCA-EQ1
LLOCA-EQ2
LLOCA-EQ3
LOOP-EQ1
LOOP-EQ2
LOOP-EQ3
SLOCA-EQ1
SLOCA-EQ2
SLOCA-EQ3

The existing front line and support system fault trees need to be modified to include seismic faults. Figure 4-5 shows an example for a front line system in which the RPS fault tree top logic is revised to include seismic failure basic events. The seismic subtree introduced into the RPS fault tree is shown in Figure 4-6.

Figures 4-7, 4-8, and 4-9 show how seismic subtrees are introduced into a support system.

Seismic fault trees can be added to as many system models as needed, determined by the number of low fragility SSCs.

The seismic sub trees are only activated when the seismic event bin in question is quantified and the associated house event (such as “EQ-BIN-1-OCCURS”) is set to TRUE

4.2.7 New Basic Events

Four types of new basic events are introduced in SPAR-AHZ models:

1. Initiating event frequencies;
2. Basic events;
3. Flags – house events;
4. Fault tree (FT) names; some FT names can be used as basic events (FT not further developed; FT name is used as the basic event).

Example of basic events introduced in SPAR-AHZ models are given in Table 4-4.

For some basic events represented by the FT value, the process flags in the SAPHIRE “Edit Basic Event” dialog are set to type W to make sure that the success path includes the success probability of the FT. This is done for basic events like CD-EQ3 where the seismic failure probability is very high.

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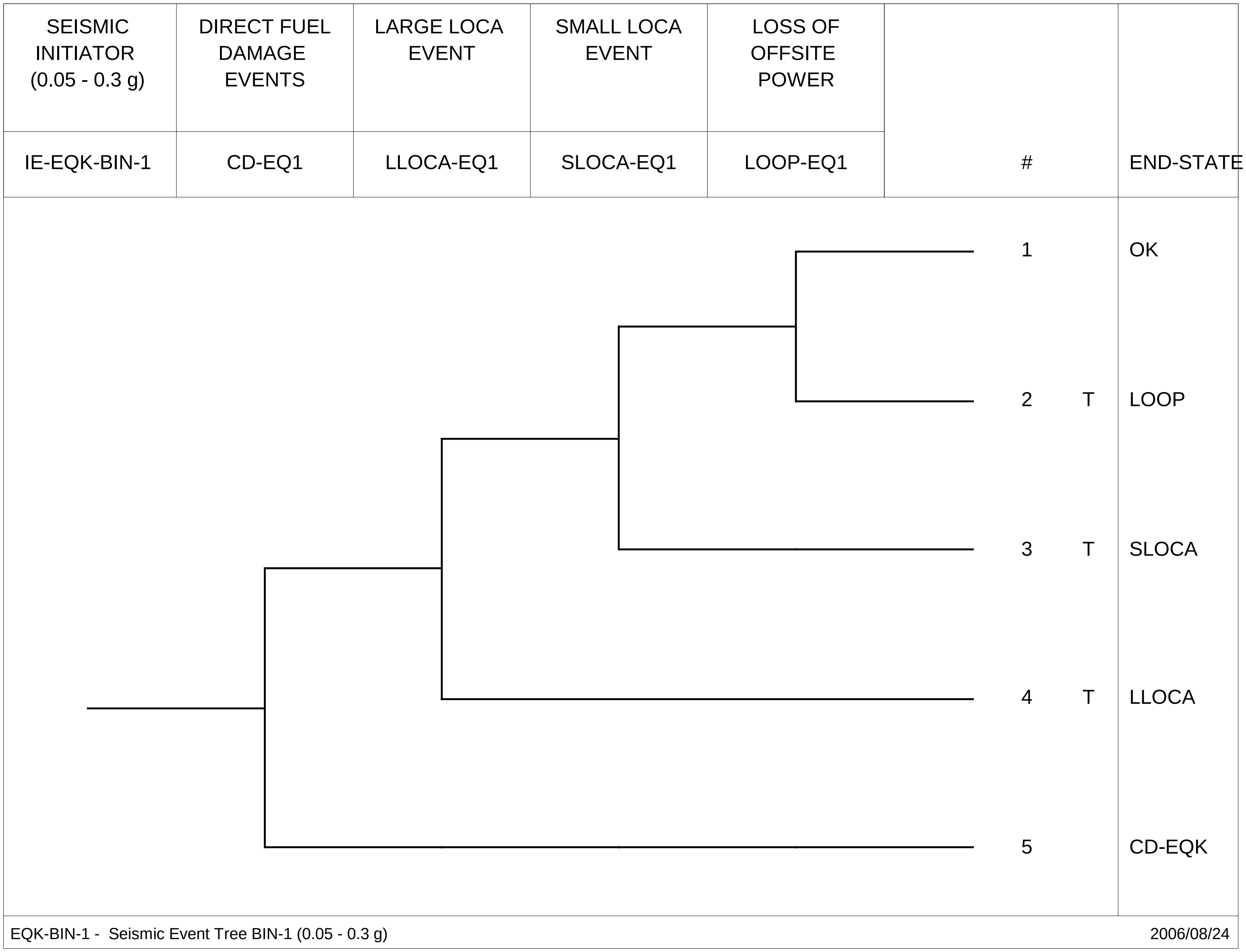

Figure 4-2 Seismic Event BIN-1 Event Tree

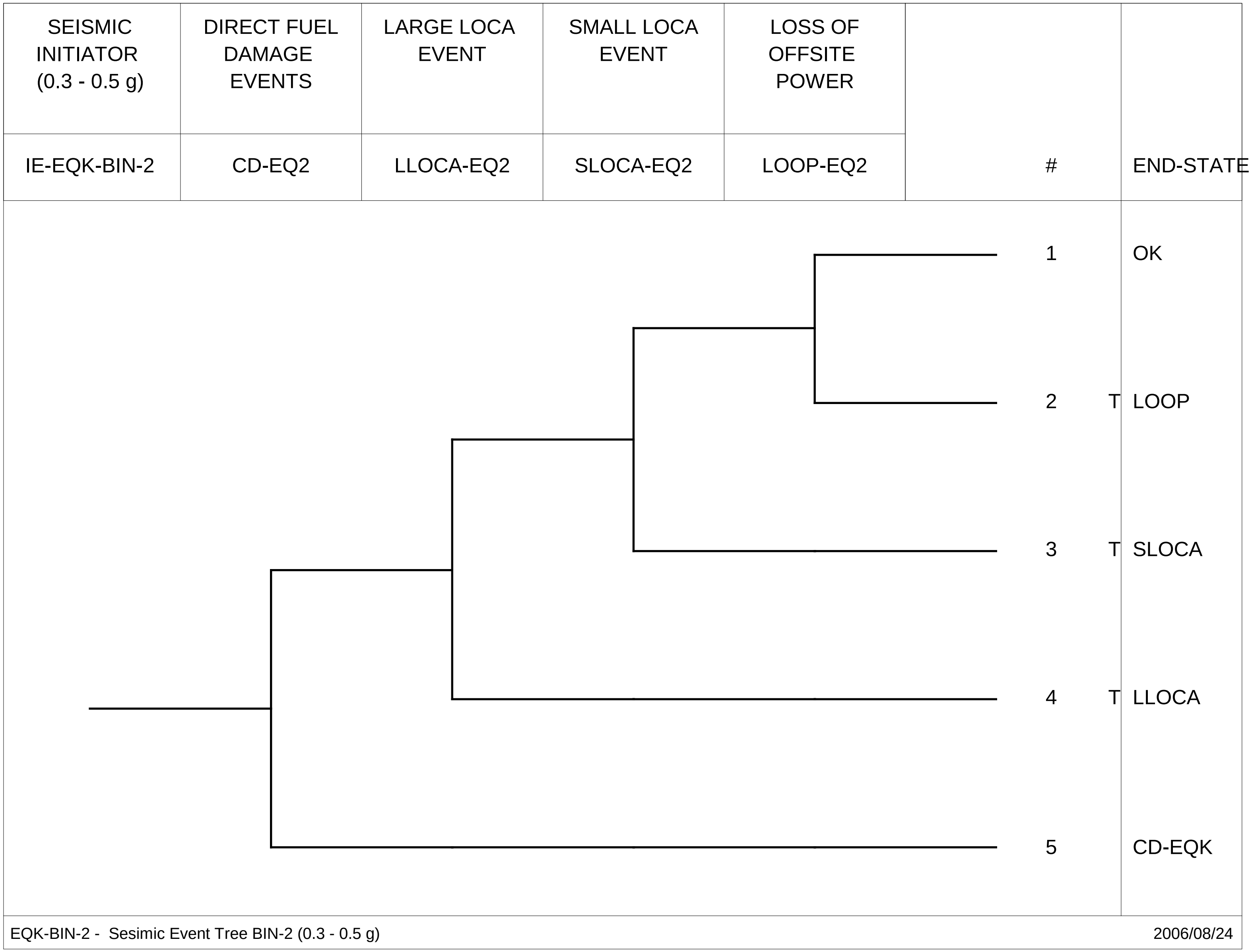

Figure 4-3 Seismic Event BIN-2 Event Tree

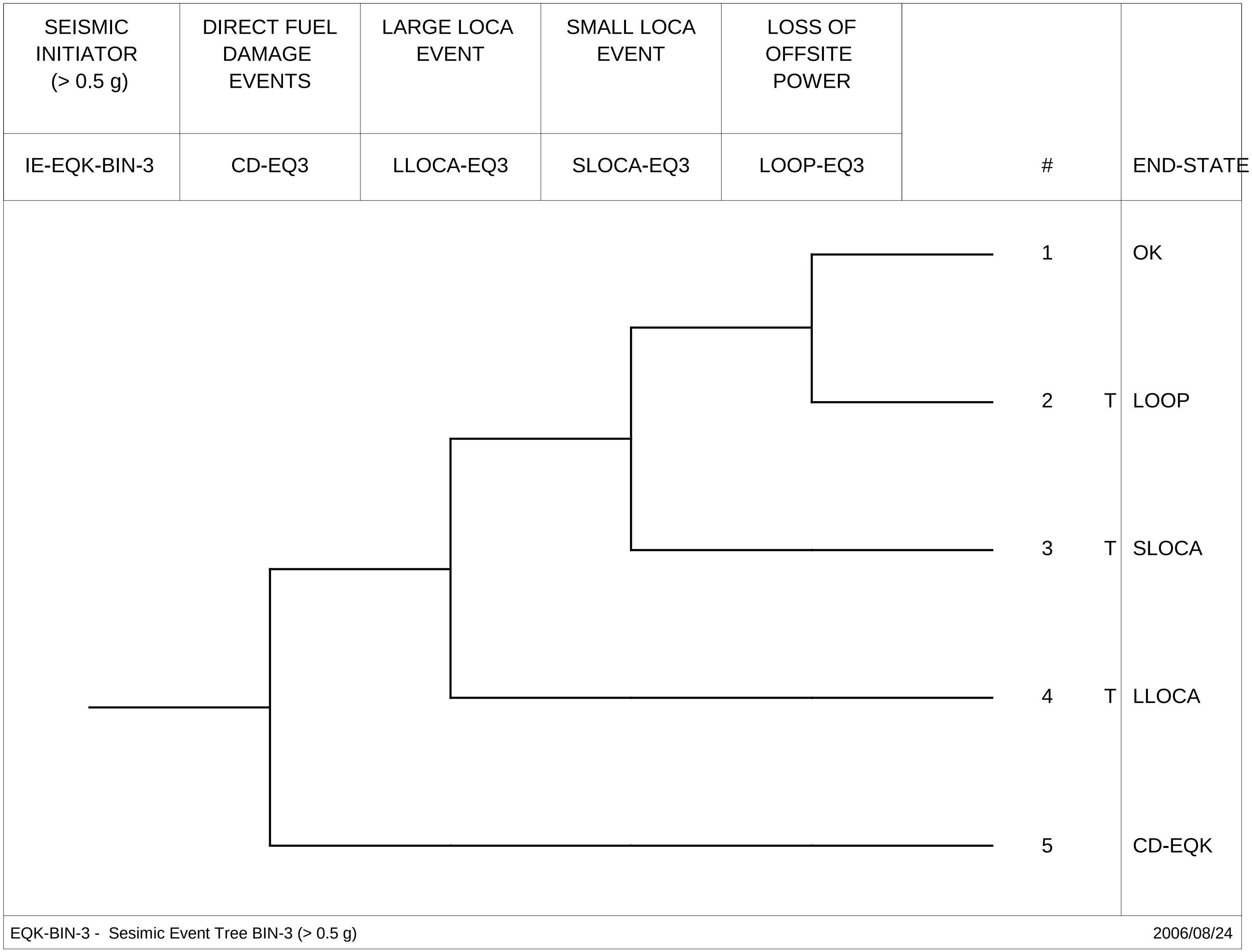

Figure 4-4 Seismic Event BIN-3 Event Tree

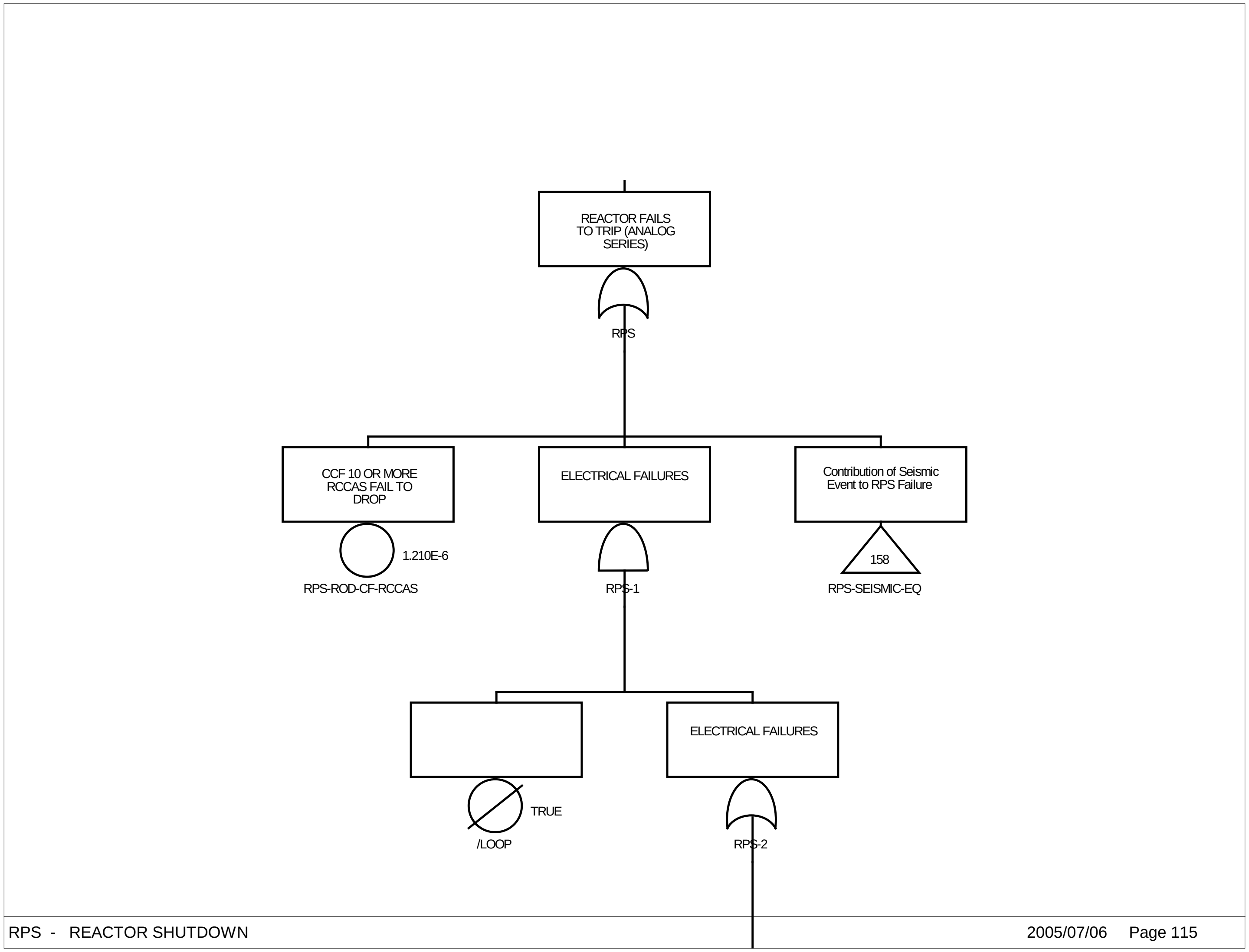

Figure 4-5 RPS Fault Tree (partial top showing introduction of seismic faults)

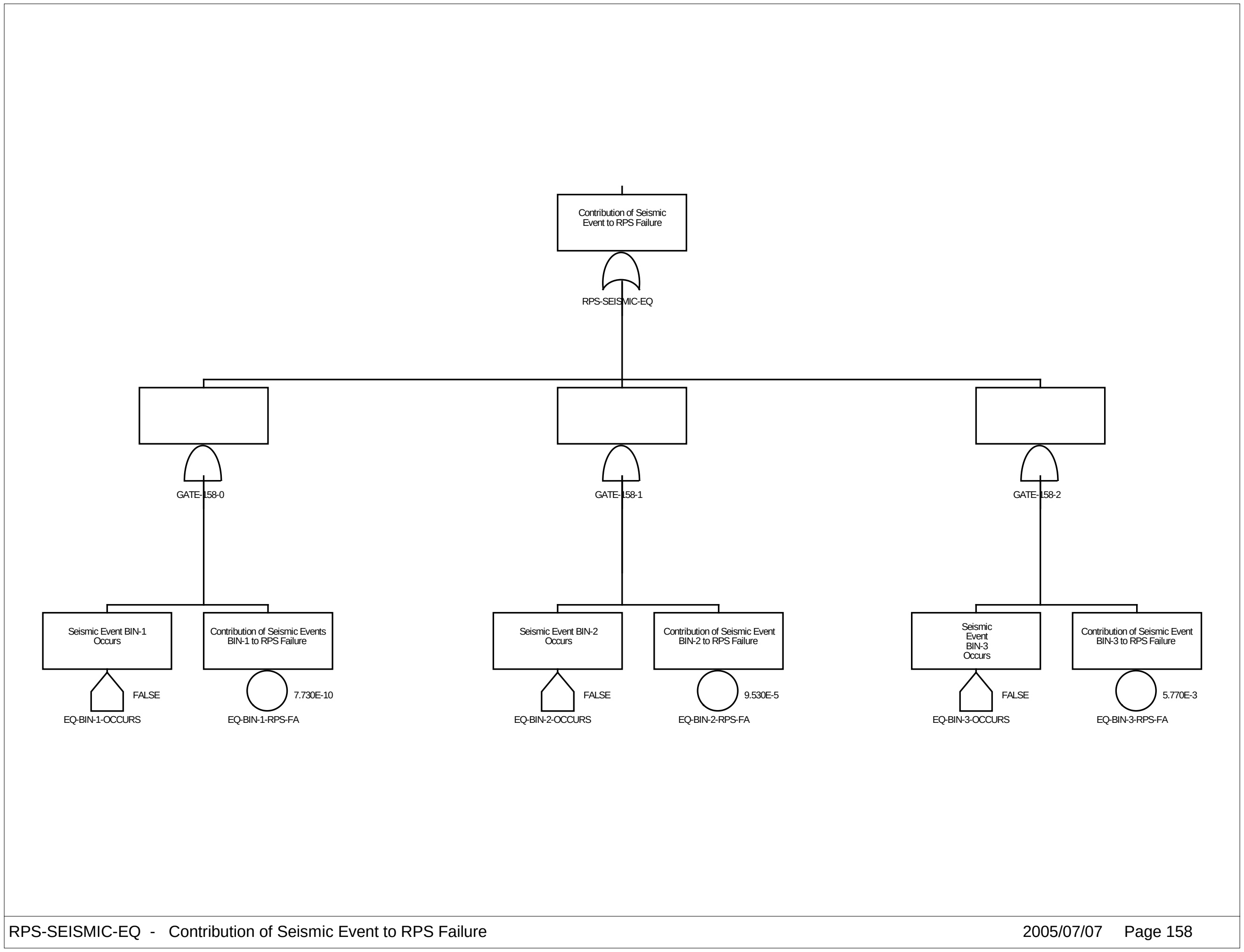

Figure 4-6 RPS-SEISMIC-EQ Fault Tree

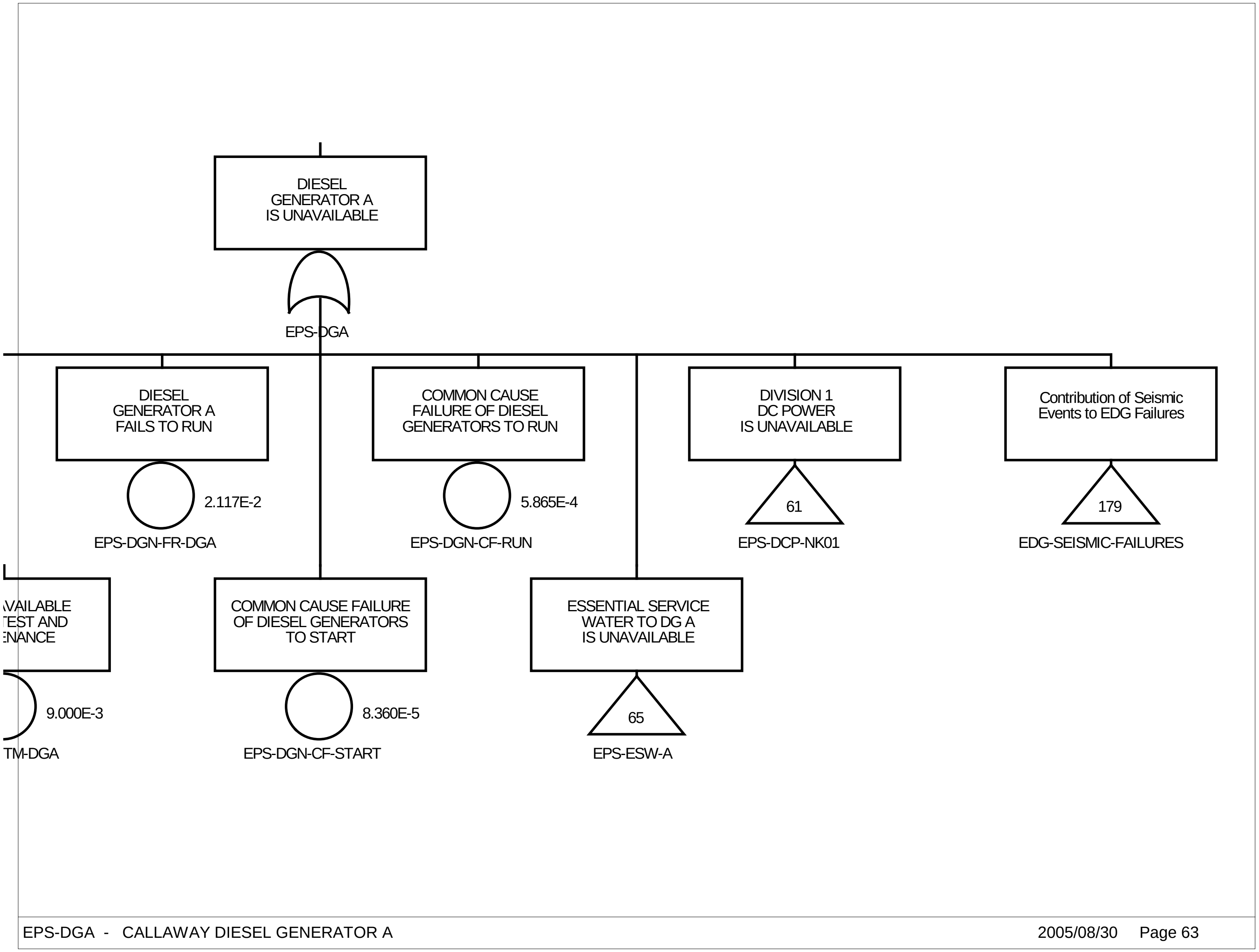

Figure 4-7 Adding Seismic Failures to a Support System - Figure 1 of 3

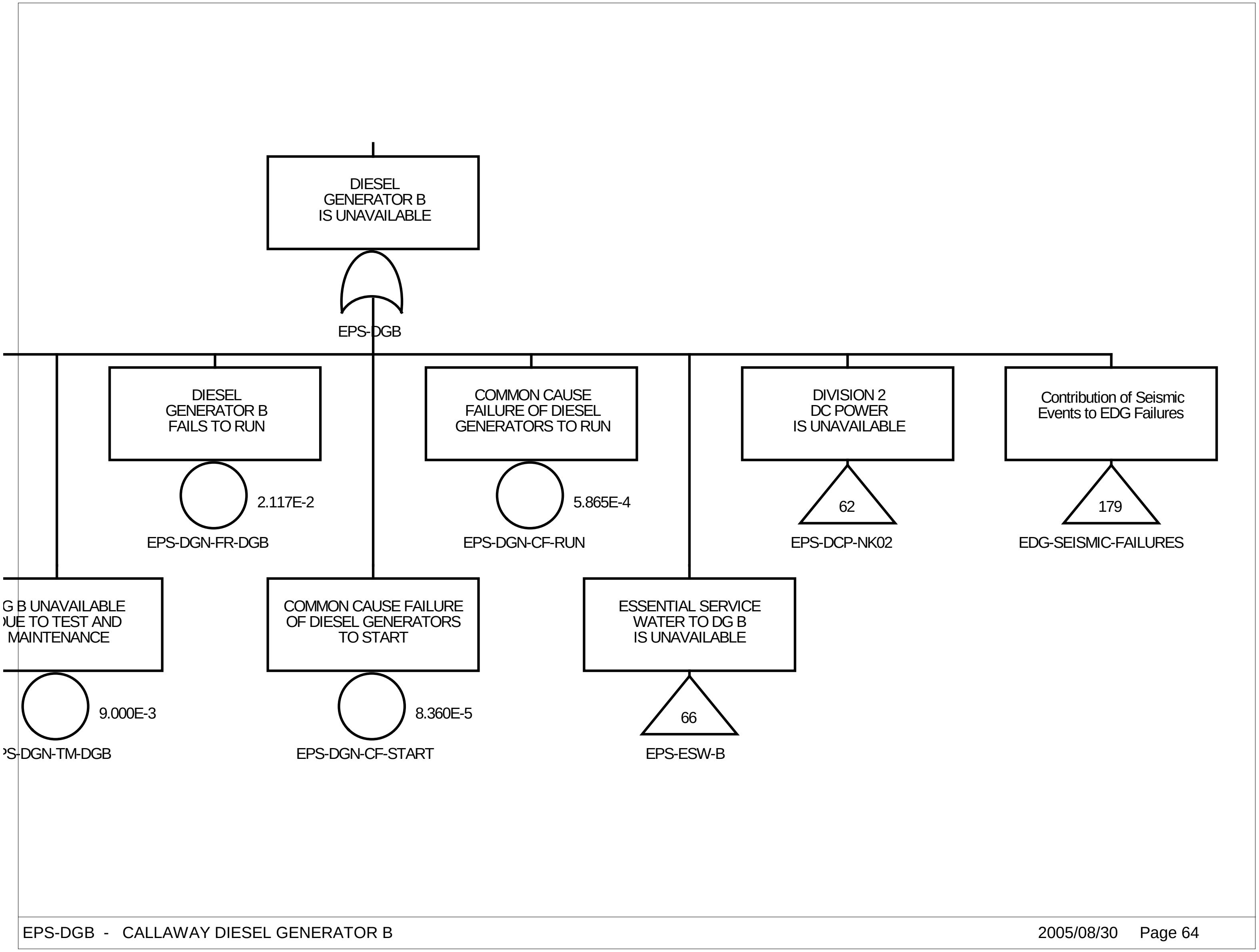

Figure 4-8 Adding Seismic Failures to a Support System - Figure 2 of 3

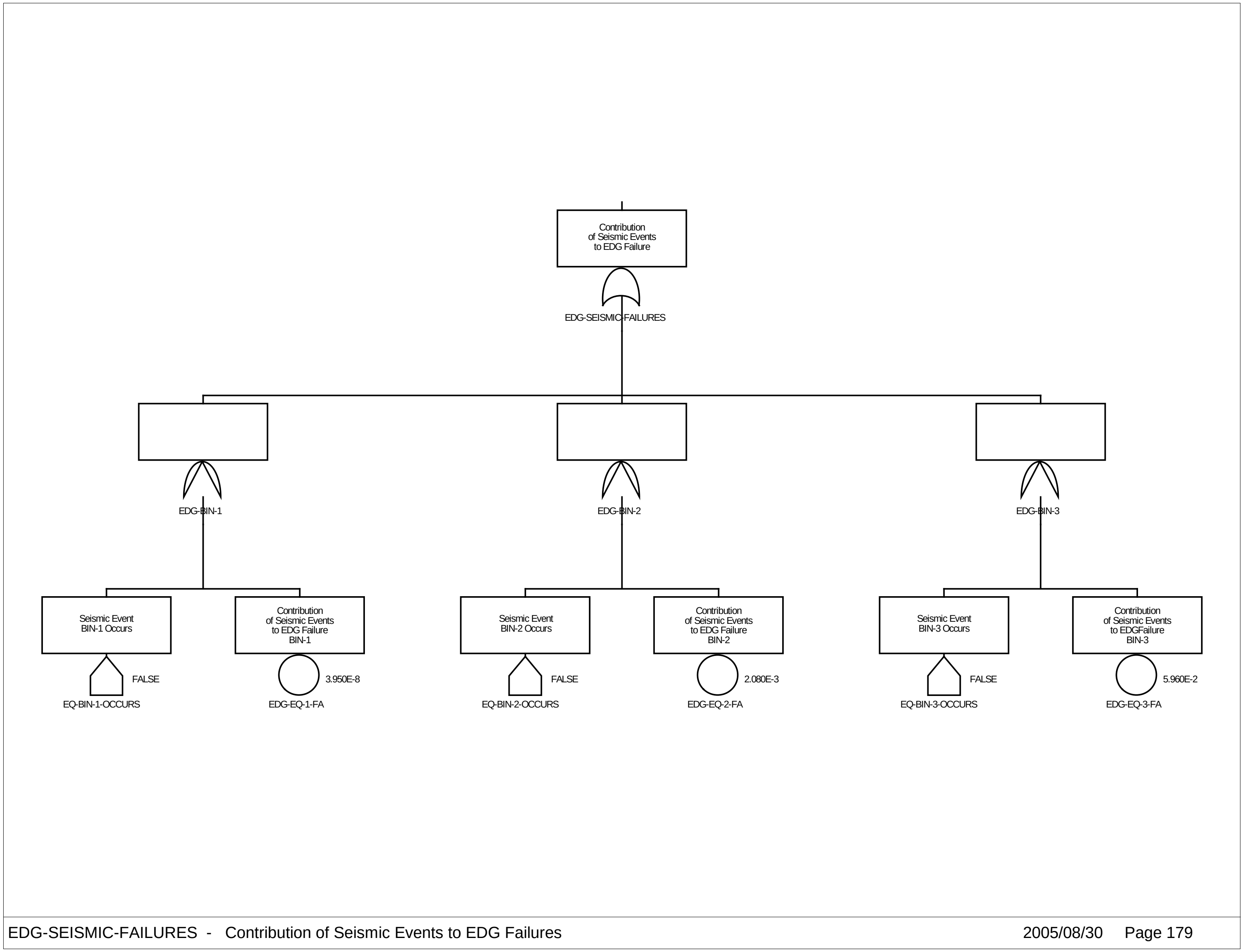

Figure 4-9 Adding Seismic Failures to a Support System - Figure 3 of 3

4.2.8 Application to Seismic Margin Assessment (SMA) Plants

The model described from Section 4.2.5 to Section 4.2.7 can be adapted to develop limited SPRA for plants that have an SMA. For an SMA plant, the following process applies:

i). Obtain the seismic hazard vector from Appendix 4A. Calculate BIN frequencies and assign bin acceleration levels.

ii). Examine the SMA documentation to locate any SSC fragilities and/or HCLPFs. It should be noted that most SMA from IPEEEs have very limited fragilities. Supplement that information with additional SSC fragilities from Appendix 4B.

If a plant-specific HCLPF value is given in the SMA, use that value and the corresponding β_r and β_u from Table 4B-1 to calculate median acceleration. Then use the median acceleration and the betas to calculate SSC failure probabilities for each BIN.

iii). Once the above data is assembled, proceed with modeling as in SPRA.

4.3 Special Modeling Considerations

This section discusses some special issues worth noting for seismic scenario modeling.

4.3.1 Non-safety Systems

The non-safety systems credited in the at-power PRA have high likelihood of failure in BINs 2 and 3. Therefore as a precaution, these non-safety systems should not be credited in BINs 2 and 3. Examples of such systems include main feedwater, normal service water, and instrument and service air.

4.3.2 Seismically-induced LOOP

The frequencies of seismically-induced LOOP events, based on the lowest fragility SSCs (such as ceramic insulators) can be calculated with the information available in Appendices 4A and 4B. Such a calculation is done for all 61 U.S. nuclear power plants and is given in Appendix 1 of Volume 2.

It is recommended that LOOP conditions are postulated without offsite power recovery for SLOCA and LLOCA paths (e.g., emergency buses are supported only by the onsite safety-related power sources).

If credit is taken for other AC power sources (other than normal offsite power and onsite emergency power) for Station Black Out analysis, such credit for any of those power sources may need to be reconsidered for seismically-induced LOOP because those power sources may not be seismically qualified.

Table 4-4 New Basic Events

Name	Description	Calc. Prob.	
CD-EQ1	DIRECT FUEL DAMAGE EVENTS	2.77E-06	FT name; also used as BE
CD-EQ2	DIRECT FUEL DAMAGE EVENTS	3.55E-02	FT name; also used as BE
CD-EQ3	DIRECT FUEL DAMAGE EVENTS	5.27E-01	FT name; also used as BE
EQ-BIN-1-OCCURS	Seismic Event BIN-1 Occurs	0.00E+00	Flag (house event)
EQ-BIN-1-RHR-FA	Contribution of Seismic Event BIN-1 to RHR Failure	1.79E-04	BE
EQ-BIN-1-RPS-FA	Contribution of Seismic Events BIN-1 to RPS Failure	7.73E-10	BE
EQ-BIN-1-SWS-FA	Contribution of Seismic BIN-1 to SWS Failure	1.65E-08	BE
EQ-BIN-2-OCCURS	Seismic Event BIN-2 Occurs	0.00E+00	Flag (house event)
EQ-BIN-2-RHR-FA	Contribution of Seismic BIN-2 to RHR Failure	1.45E-01	BE
EQ-BIN-2-RPS-FA	Contribution of Seismic Event BIN-2 to RPS Failure	9.53E-05	BE
EQ-BIN-2-SWS-FA	Contribution of Seismic BIN-2 to SWS Failure	4.68E-02	BE
EQ-BIN-3-OCCURS	Seismic Event BIN-3 Occurs	0.00E+00	Flag (house event)
EQ-BIN-3-RHR-FA	Contribution of Seismic Event BIN-3 to RHR Failure	5.99E-01	BE
EQ-BIN-3-RPS-FA	Contribution of Seismic Event BIN-3 to RPS Failure	5.77E-03	BE
EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.30E-01	BE
IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.84E-04	IE
IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.26E-05	IE
IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.21E-06	IE
LLOCA-EQ1	LARGE LOCA EVENT	1.23E-08	FT name; also used as BE
LLOCA-EQ2	LARGE LOCA EVENT	5.91E-04	FT name; also used as BE
LLOCA-EQ3	LARGE LOCA EVENT	1.55E-02	FT name; also used as BE
LOOP-EQ1	LOSS OF OFFSITE POWER	2.77E-02	FT name; also used as BE
LOOP-EQ2	LOSS OF OFFSITE POWER	5.72E-01	FT name; also used as BE
LOOP-EQ3	LOSS OF OFFSITE POWER	8.99E-01	FT name; also used as BE
RHR-SEISMIC-EQ	Contribution of Seismic Event to RHR Failure	1.00E+00	FT name
RPS-SEISMIC-EQ	Contribution of Seismic Event to RPS Failure	1.00E+00	FT name
SLOCA-EQ1	SMALL LOCA EVENT	1.50E-05	FT name; also used as BE
SLOCA-EQ2	SMALL LOCA EVENT	4.50E-02	FT name; also used as BE
SLOCA-EQ3	SMALL LOCA EVENT	2.50E-01	FT name; also used as BE
SWS-SEISMIC-EQ	Contribution of Seismic Events to SWS Failure (Screenhouse)	1.00E+00	FT name

4.3.3 Operator Actions

The failure probabilities of some operator actions may increase under high-g seismic event conditions. To be prudent the analyst should examine the set of operator actions modeled in the PRA and revise their human error probabilities (HEPs)if needed, for seismic scenarios. Especially, operator actions implied in recovery (such as power recovery) must be critically examined and adjusted if necessary.

In the absence of a detailed human error analysis for operator actions credited during a seismic event, a model for adjustment of human error probabilities in a SPRA is given in an NRC document which is used during the construction of SPAR-AHZ models. This document, which contains proprietary information, is available (non-public) in ADAMS as ML13280A056 and it may be used as needed.

Furthermore, sensitivity analyses may be performed to understand the effect of dominant HEPs and the adjustments to the HEPs due to a seismic event.

4.3.4 Relay Chatter

The relay chatter evaluation addresses the questions of

a. whether the overall plant safety system could be adversely affected by relay malfunction in a seismic event, and

b. whether the malfunctioning relays have an adequate seismic capacity.

Relay chatter may introduce system actuation failures or spurious actuations. Operator actions may be needed for starting otherwise auto-start safety systems. This Handbook does not provide guidance to address modeling of relay chatter problems explicitly. However, it should be noted that generic relay seismic fragilities are typically lower than that of other SSCs, as shown in Table 4B-1. See NUREG/CR-4840 (Reference 4-5), page 3-32 for a discussion.

Unless the Individual Plant Examination of External Events (IPEEE) or similar reports identified relay chatter vulnerabilities, this issue needs not be pursued for evaluation purposes.

In 2014, as part of the efforts to address lessons learned from the Fukushima events, industry conducted high-frequency seismic testing of typical plant control components. The following component categories are tested with averaged spectral accelerations over the 20 to 40 Hz range:

- Control and protective relays
- Contactors and motor starters
- Molded case circuit breakers
- Control switches
- Process switches and transmitters
- Low- and medium-voltage circuit breakers
- Potentiometers and proximity switches

The results of this test program are documented in the publicly available report Electric Power Research Institute 3002002997, “High Frequency Program: High Frequency Testing Summary” (Reference 4-6).

4.3.5 Seismically-induced Internal Flooding and Fires

For seismically-induced internal flooding scenarios, non-safety system piping failures in the Turbine building could create internal flooding concerns that can potentially fail other components either directly or through propagation of the flood into other areas in seismic BINs 2 and 3. Even for safety-related systems, seismically-induced internal flooding issues may arise if a plant vulnerability or a plant condition is observed.

For seismically-induced fires, the following four seismic-fire interaction issues are identified in the literature:

1. Seismically-induced fires,

2. Degradation of fire suppression systems and features,

3. Spurious actuation of suppression and/or detection systems, and

4. Degradation of manual firefighting effectiveness.

It is recommended that a Fire PRA include a qualitative assessment of these issues.

After the Fukushima events, consideration of concurrent events (or induced events) became a subject of renewed interest. Recommendation 3 of the NTTF’s report, which is classified as a Tier 3 activity, concluded that the staff should evaluate potential enhancements to the capability to prevent or mitigate seismically-induced fires and floods (SIFFs). A publicly available NRC report on investigating the feasibility for modeling and quantitatively evaluating seismically-induced fires and floods in a PRA is available in ADAMS with Accession No. ML16004A250. As part of the SECY-15-0137, the staff indicated that broad regulatory activities pertaining to seismic, fire, and flooding events, operating experience involving SIFFs, and actions taken in response to the Fukushima accident, the staff’s conclusion is that additional requirements related to SIFF are not needed. In the SRM-SECY-15-0137 dated February 8, 2016, the Commission has approved staff’s recommendation to close NTTF Recommendation 3.

Therefore, the issues of seismically-induced flooding and fires are mentioned but not further pursued in this Handbook at this time.

4.3.6 Seismically-induced SLOCA and MLOCA

Generic frequencies of seismically induced SLOCA and MLOCA can be calculated from Figure 3-6 of NUREG/CR-4840 (Reference 4-5). Figure 4-10 of this Handbook shows the calculations of the SLOCA and MLOCA probabilities for the PGA values for the three seismic bins discussed in Section 4.2.3. An MS EXCEL file containing these values is placed in ADAMS with Accession No. ML071220066 as well as in the RASP Tool Box website. The EXCEL file can also be used to calculate the SLOCA and MLOCA probabilities for more than 3 seismic bins.

4.3.7 Seismic Correlation Coefficients

One of the important elements of SPRA, which is different from the Internal Events PRA, is the treatment of dependencies or correlations in the seismic capacities of SSCs and in their responses to earthquakes. Specifically, the major dependence arises from the earthquake itself since it subjects all the components in the plant to the effects of vibratory motion. The questions of interest include whether the failures of component are somehow correlated or dependent and how the analyst can quantitatively account for that correlation or dependency. This issue is important because whether these capacities and responses are independent or partially (or even totally) dependent, especially for identical or nearly identical SSCs that are co-located or nearly so, can make a difference to the insights derived from many seismic PRAs.

NUREG/CR-4840 (Reference 4-5) provides simple rules for assigning the response correlation so that the tedious response correlation task could be avoided. These rules are given in Table 4.5. These rules include situations for which the recommended correlation is 0.5 or 0.75. For practical reasons, it is common practice to exclusively use correlation of 1 or zero, which simplifies the SPRA modeling.[1] For identical, redundant equipment, a correlation of 1 should be assumed. For all other equipment, a correlation of zero should be assumed.[2] If excessive conservatism in the results is observed due to this shortcut, other correlation coefficients may be introduced for a selected few SSC groups at the cost of model complication.[3] As an example, in the seismic modeling in Figures 4-7 and 4-8, the seismic correlation is assumed to be 1 because the "EDG Seismic Failures" gate for both EDG A and EDG B transfer to the same fault tree in Figure 4-9.

Table 4.5 Rules for Assigning Response Correlation

Rule #	Description
1	Components on the same floor slab and sensitive to the same spectral frequency range (*i.e.*, ZPA, 5-10 Hz. or 10-15 Hz) will be assigned response correlation = 1.0.
2	Components on the same floor slab sensitive to different ranges of spectral acceleration will be assigned response correlation = 0.5.
3	Components on different floor slabs (but in the same building) and sensitive to the same spectral frequency range (ZPA, 5-10 Hz or 10-15 Hz) will be assigned response correlation = 0.75.
4	Components on the ground surface (outside tanks, etc.) shall be treated as if they were on the grade floor of an adjacent building
5	"Ganged" valve configurations (either parallel or series) will have response correlation = 1.0.
6	All other configurations will have response correlation equal to zero.

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[1] NUREG/CR-4840 proposed to assign perfect (100%) correlation or dependency to the seismic response and capacity of identical SSCs if they are co-located or nearly so, and zero correlation or dependency otherwise. It was recognized early-on (a) that the 100%-correlation assignment is surely conservative for most situations in which it is applied, albeit perhaps not by much for many situations; and (b) that "zero correlation otherwise" is likely to be non-conservative in some situations. However, it was also generally thought that the differences are typically not likely to be important nor to compromise the major safety insights."

[2] Also see Appendix D *Correlation between Seismic Failures* in publicly-available report EPRI 3002000709 "Seismic Probabilistic Risk Assessment Implementation Guide".

[3] As of 2016, NRC/RES has a draft NUREG/CR report titled "Correlation of Seismic Performance in Similar SSCs (Structures, Systems, and Components)," ADAMS No. ML16035A002.

4.3.8 Multi-Unit Effects

The effect of a seismic event on sites with multiple NPPs should be considered at least from the following aspects:

1. Credit for cross-ties between two units.

In many PRAs for an NPP, credit is taken for cross ties to a second unit on the same site. Examples of this credit are:

- Electrical ties between units
- Ties of emergency feed-water supply (*i.e*. CST) between units
- Ties of refueling water (in RWST) between units
- Ties of service water (or sea water) systems between units.

Such credit during seismic events should be either eliminated, or at least discounted. The reason of discounting the credit is that the SSCs of the second unit will either be dedicated to the second unit due to the likely trip of the unit, or at least will have additional (and maybe correlated) failures due to the nature of the event.

2. Credit for an off-site emergency AC power Source

In station blackout (SBO) scenarios, credit is often taken for off-site AC power sources and their transmission lines to the site. These SSCs are likely not seismically qualified to the same level as the conventional AC power sources that are already modeled. Credit for off-site AC power sources should not be taken in SBO scenarios if such sources and their transmission lines are deemed to be affected by the seismic event.

3. Magnitude of Fission Product Release

When a multi-unit site experiences a high-intensity seismic event, a multi-unit trip leading to core damage for multiple units is considerably more likely than that due to other random events (such as internal events at-power). This would increase the potential fission product release magnitude and frequency compared to a single-event core damage.

Since LERF is not in the scope of this document, this subject is mentioned but not pursued further.

4.4 CDF Quantification for Seismic Events

This section summarizes the CDF quantification for seismic events only.

Seismic sequences are automatically generated from the three seismic event trees. The CDF frequencies are quantified and CDF cutsets are identified using the SAPHIRE software. Tables 4-6 through 4-8 provide an illustration of the results and output for a plant-specific SPAR-AHZ seismic PRA model.

4.5 LERF Quantification for Seismic Events

LERF modeling and quantification is not currently addressed.

4.6 References

4-1. U.S. Nuclear Regulatory Commission, “Risk Assessment of Operational Events Handbook: Volume 1 - Internal Events,” Revision 2, January 2013, ADAMS Accession Number ML13030A049.

4-2. U.S. Nuclear Regulatory Commission, “Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Power Plant Sites East of the Rocky Mountains,” NUREG-1488, April 1994, ADAMS Accession Number ML052640591.

4-3. Idaho National Laboratory, “A Feasibility and Demonstration Study – Incorporating External Events into SPAR Models,” February 2005, ADAMS Accession Number ML15174A003.

4-4. U.S. Nuclear Regulatory Commission, “A Methodology for Analyzing Precursors to Earthquake-Initiated and Fire-Initiated Accident Sequences," NUREG/CR-6544, April 1998, ADAMS Accession Number ML071650470.

4-5. U.S. Nuclear Regulatory Commission, “Procedures for the External Event Core Damage Frequency Analyses for NUREG-1150,” NUREG/CR-4840, November 1990, ADAMS Accession Number ML063460465.

4-6. Electric Power Research Institute *3002002997, High Frequency Program: High Frequency Testing Summary*, September 2014

4-7. U.S. Nuclear Regulatory Commission, “An Approach to the Quantification of Seismic Margins in Nuclear Power Plants,” NUREG/CR-4334, August 1985, ADAMS Accession Number ML090500182.

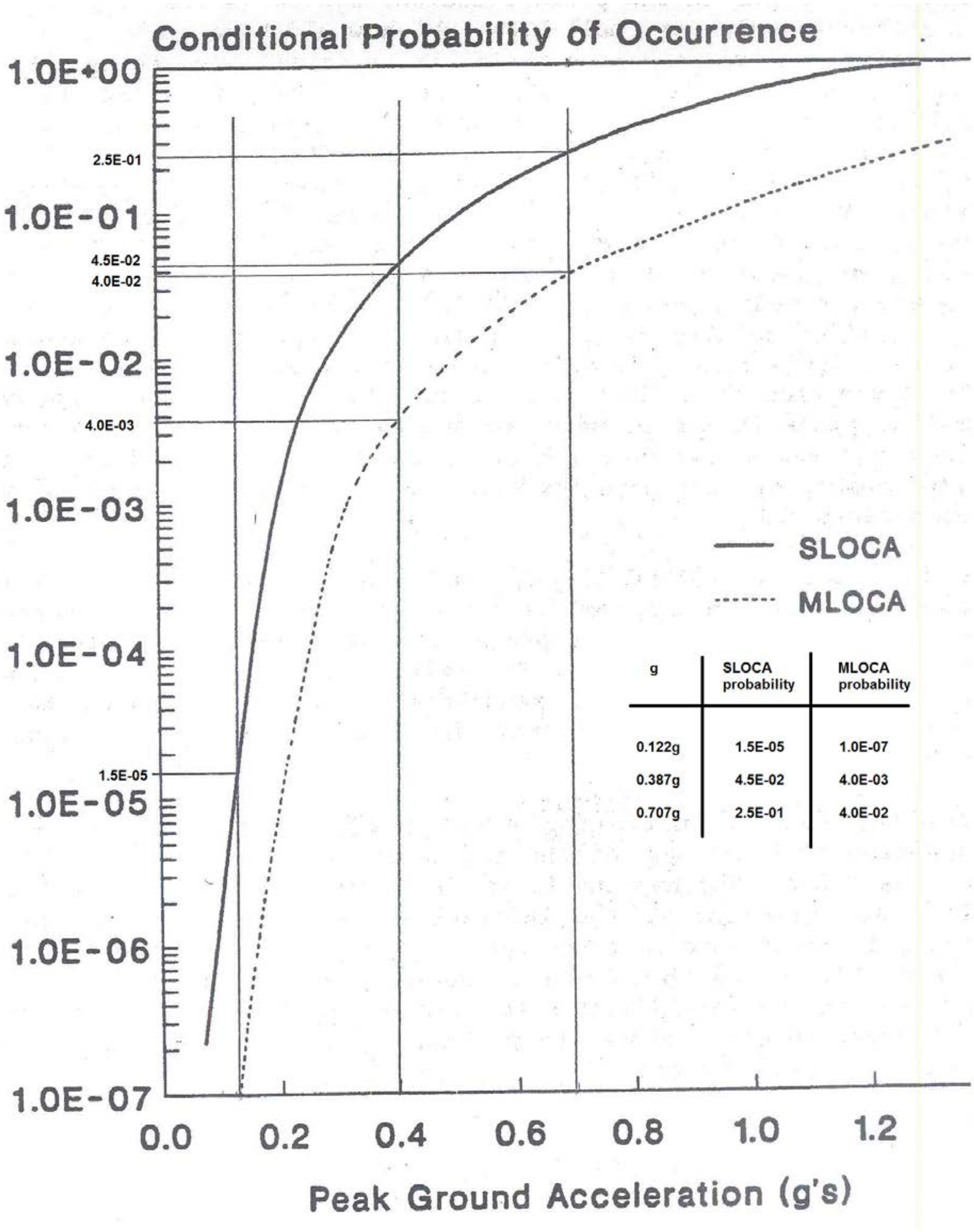

Figure 4-10 Estimation of Seismically-induced SLOCA and MLOCA Probabilities for a 3-seismic-bin scenario

(NUREG/CR-4840, Figure 3-6)

Table 4-6 Seismic Event BIN Frequencies

	IE Freq.	CCDP	CDF
EQK-BIN-1	2.84E-04	2.55E-05	7.26E-09
EQK-BIN-2	1.26E-05	3.86E-02	4.86E-07
EQK-BIN-3	7.21E-06	6.13E-01	4.42E-06
Sum =	**3.04E-04**		**4.91E-06**

Table 4-7 Seismic Event Sequence Frequencies

Event tree	Sequence	CDF	Cutsets	End State	
EQK-BIN-3	5	3.80E-06	1	CD-EQK	Direct CD
EQK-BIN-3	3-11	5.37E-07	3	CD-EQK	SLOCA
EQK-BIN-2	5	4.47E-07	1	CD-EQK	Direct CD
EQK-BIN-3	4-3	3.33E-08	2	CD-EQK	LLOCA
EQK-BIN-2	3-11	2.65E-08	2	CD-EQK	SLOCA
EQK-BIN-3	2-17	2.48E-08	32	CD-EQK	LOOP
EQK-BIN-2	2-17	7.17E-09	29	CD-EQK	LOOP
EQK-BIN-3	3-13	5.37E-09	1	CD-EQK	SLOCA
EQK-BIN-3	3-24	4.92E-09	4	CD-EQK	SLOCA
EQK-BIN-3	3-03	3.37E-09	56	CD-EQK	SLOCA
EQK-BIN-1	2-18-03	3.04E-09	32	CD-EQK	LOOP
EQK-BIN-2	2-18-03	2.77E-09	32	CD-EQK	LOOP
EQK-BIN-3	2-19-13	2.01E-09	6	CD-EQK	LOOP
EQK-BIN-3	2-19-04	1.68E-09	6	CD-EQK	LOOP
EQK-BIN-1	2-17	1.67E-09	18	CD-EQK	LOOP
EQK-BIN-1	2-18-06	1.51E-09	26	CD-EQK	LOOP
EQK-BIN-2	2-18-06	1.38E-09	26	CD-EQK	LOOP
EQK-BIN-3	2-18-03	8.83E-10	24	CD-EQK	LOOP
EQK-BIN-1	5	7.87E-10	1	CD-EQK	Direct CD
EQK-BIN-2	3-03	6.15E-10	34	CD-EQK	SLOCA
EQK-BIN-3	3-12	5.37E-10	1	CD-EQK	SLOCA
EQK-BIN-3	2-19-20	4.51E-10	5	CD-EQK	LOOP
EQK-BIN-3	2-18-06	4.38E-10	20	CD-EQK	LOOP
EQK-BIN-2	4-3	3.48E-10	1	CD-EQK	LLOCA
EQK-BIN-3	4-2	3.28E-10	7	CD-EQK	LLOCA
EQK-BIN-3	2-19-09	2.65E-10	1	CD-EQK	LOOP
EQK-BIN-2	3-13	2.65E-10	1	CD-EQK	SLOCA
EQK-BIN-3	2-19-19	2.24E-10	23	CD-EQK	LOOP
EQK-BIN-3	2-19-18	2.20E-10	3	CD-EQK	LOOP
EQK-BIN-1	2-18-45	1.80E-10	32	CD-EQK	LOOP
EQK-BIN-2	2-18-45	1.64E-10	31	CD-EQK	LOOP
EQK-BIN-3	3-23	1.58E-10	14	CD-EQK	SLOCA
EQK-BIN-2	3-24	5.40E-11	1	CD-EQK	SLOCA
EQK-BIN-3	2-12	5.03E-11	8	CD-EQK	LOOP

Event tree	**Sequence**	**CDF**	**Cutsets**	**End State**	
EQK-BIN-3	2-02-05	4.70E-11	10	CD-EQK	LOOP
EQK-BIN-2	4-2	4.46E-11	1	CD-EQK	LLOCA
EQK-BIN-3	3-07	4.44E-11	1	CD-EQK	SLOCA
EQK-BIN-3	2-18-45	4.01E-11	12	CD-EQK	LOOP
EQK-BIN-1	2-18-09	3.28E-11	7	CD-EQK	LOOP
EQK-BIN-2	2-18-09	3.00E-11	7	CD-EQK	LOOP
EQK-BIN-2	3-07	2.94E-11	1	CD-EQK	SLOCA
EQK-BIN-2	3-12	2.65E-11	1	CD-EQK	SLOCA
EQK-BIN-2	2-19-20	2.33E-11	5	CD-EQK	LOOP
EQK-BIN-1	2-18-12	2.32E-11	7	CD-EQK	LOOP
EQK-BIN-2	2-18-12	2.12E-11	7	CD-EQK	LOOP
EQK-BIN-1	2-18-42	2.08E-11	8	CD-EQK	LOOP
EQK-BIN-2	2-18-42	1.90E-11	8	CD-EQK	LOOP
EQK-BIN-2	2-19-09	1.37E-11	1	CD-EQK	LOOP
EQK-BIN-2	3-23	9.83E-12	6	CD-EQK	SLOCA
EQK-BIN-2	2-12	9.76E-12	4	CD-EQK	LOOP
EQK-BIN-3	2-18-09	8.14E-12	4	CD-EQK	LOOP
EQK-BIN-2	2-02-05	7.90E-12	4	CD-EQK	LOOP
EQK-BIN-2	2-19-04	6.42E-12	2	CD-EQK	LOOP
EQK-BIN-2	2-19-13	6.42E-12	4	CD-EQK	LOOP
EQK-BIN-3	2-18-12	4.21E-12	2	CD-EQK	LOOP
EQK-BIN-2	2-19-18	2.74E-12	1	CD-EQK	LOOP
EQK-BIN-3	2-18-42	2.52E-12	2	CD-EQK	LOOP
EQK-BIN-3	3-05	1.71E-12	1	CD-EQK	SLOCA
EQK-BIN-2	3-05	1.13E-12	1	CD-EQK	SLOCA
	TOTALS	**4.91E-06**	**591**		

Table 4-8 Seismic Event CDF Cutsets

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
1	82.97	3.80E-6	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			CD-EQ3	DIRECT FUEL DAMAGE EVENTS	5.270E-01
2	11.73	5.37E-7	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			SLOCA-EQ3	SMALL LOCA EVENT	2.500E-01
3	9.75	4.47E-7	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			CD-EQ2	DIRECT FUEL DAMAGE EVENTS	3.550E-02
4	0.73	3.33E-8	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LLOCA-EQ3	LARGE LOCA EVENT	1.550E-02
5	0.58	2.65E-8	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			EQ-BIN-2-SWS-FA	Contribution of Seismic BIN-2 to SWS Failure	4.680E-02
			SLOCA-EQ2	SMALL LOCA EVENT	4.500E-02
6	0.20	8.69E-9	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			AFW-TDP-FS-1C	AFW TDP 1C FAILS TO START	6.000E-03
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
7	0.16	7.25E-9	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			AFW-TDP-TM-1C	AFW TDP 1C UNAVAILABLE DUE TO TEST AND MAINTENANCE	5.000E-03

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
8	0.14	6.00E-9	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			AFW-TDP-FR-1C	AFW TDP 1C FAILS TO RUN	4.141E-03
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
9	0.12	5.37E-9	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			RCS-XHE-XM-CDOWN1	OPERATOR FAILS TO INITIATE RAPID COOLDOWN	1.000E-02
			SLOCA-EQ3	SMALL LOCA EVENT	2.500E-01
10	0.11	4.92E-9	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-RPS-FA	Contribution of Seismic Event BIN-3 to RPS Failure	5.770E-03
			SLOCA-EQ3	SMALL LOCA EVENT	2.500E-01
11	0.07	3.07E-9	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-RHR-FA	Contribution of Seismic Event BIN-3 to RHR Failure	5.990E-01
			LPR-XHE-XM	OPERATOR FAILS TO INITIATE LPR SYSTEM	6.000E-03
			SLOCA-EQ3	SMALL LOCA EVENT	2.500E-01

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
12	0.05	2.02E-9	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			AFW-TDP-FS-1C	AFW TDP 1C FAILS TO START	6.000E-03
			EQ-BIN-2-SWS-FA	Contribution of Seismic BIN-2 to SWS Failure	4.680E-02
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
13	0.04	1.68E-9	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			AFW-TDP-TM-1C	AFW TDP 1C UNAVAILABLE DUE TO TEST AND MAINTENANCE	5.000E-03
			EQ-BIN-2-SWS-FA	Contribution of Seismic BIN-2 to SWS Failure	4.680E-02
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
14	0.04	1.45E-9	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			AFW-MOV-CC-102	AFW TDP 1C MAIN STEAM VALVE 102 FAILS TO OPEN	1.000E-03
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
15	0.04	1.40E-9	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			AFW-TDP-FR-1C	AFW TDP 1C FAILS TO RUN	4.141E-03
			EQ-BIN-2-SWS-FA	Contribution of Seismic BIN-2 to SWS Failure	4.680E-02
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
16	0.03	9.23E-10	IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.842E-04
			EPS-DGN-CF-RUN	COMMON CAUSE FAILURE OF DIESEL GENERATORS TO RUN	5.865E-04
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01
			LOOP-EQ1	LOSS OF OFFSITE POWER	2.770E-02

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01
17	0.02	8.44E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			EPS-DGN-CF-RUN	COMMON CAUSE FAILURE OF DIESEL GENERATORS TO RUN	5.865E-04
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01
18	0.02	8.36E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-RPS-FA	Contribution of Seismic Event BIN-3 to RPS Failure	5.770E-03
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			PPR-SRV-OO-SRV3BLIQ	SAFETY RELIEF VALVE 3B FAILS TO RECLOSE AFTER PASSING WATER	1.000E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
19	0.02	8.36E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-RPS-FA	Contribution of Seismic Event BIN-3 to RPS Failure	5.770E-03
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			PPR-SRV-OO-SRV3ALIQ	SAFETY RELIEF VALVE 3A FAILS TO RECLOSE AFTER PASSING WATER	1.000E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
20	0.02	7.87E-10	IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.842E-04
			CD-EQ1	DIRECT FUEL DAMAGE EVENTS	2.770E-06
21	0.02	7.87E-10	IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.842E-04
			AFW-CKV-CC-301	CONDENSATE STORAGE TANK DISCHARGE CHECK VALVE FAILS	1.000E-04
			LOOP-EQ1	LOSS OF OFFSITE POWER	2.770E-02
22	0.02	7.87E-10	IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.842E-04
			AFW-XHE-XA-SUCT	OPERATOR FAILS TO ALIGN SWS/XTIE RMST TO AFW SYSTEM	1.000E-04
			LOOP-EQ1	LOSS OF OFFSITE POWER	2.770E-02
23	0.02	7.20E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			AFW-CKV-CC-301	CONDENSATE STORAGE TANK DISCHARGE CHECK VALVE FAILS	1.000E-04
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
24	0.02	7.20E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			AFW-XHE-XA-SUCT	OPERATOR FAILS TO ALIGN SWS/XTIE RMST TO AFW SYSTEM	1.000E-04
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
25	0.02	7.06E-10	IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.842E-04
			EPS-DGN-FR-1A	DIESEL GENERATOR 1A FAILS TO RUN	2.117E-02
			EPS-DGN-FR-1B	DIESEL GENERATOR 1B FAILS TO RUN	2.117E-02
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01
			LOOP-EQ1	LOSS OF OFFSITE POWER	2.770E-02
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
26	0.02	6.45E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			EPS-DGN-FR-1A	DIESEL GENERATOR 1A FAILS TO RUN	2.117E-02
			EPS-DGN-FR-1B	DIESEL GENERATOR 1B FAILS TO RUN	2.117E-02
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01
27	0.02	5.80E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			AFW-PMP-FR-TD1C	AFW TURBINE-DRIVEN 1C PUMP UNIT ONLY FAILS TO RUN	4.000E-04
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
28	0.02	5.37E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			RCS-XHE-XM-RCSDEP	OPERATOR FAILS TO DEPRESSURIZE THE RCS	1.000E-03
			SLOCA-EQ3	SMALL LOCA EVENT	2.500E-01
29	0.02	4.93E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			ED-BIN-2-RHR-FA	Contribution of Seismic Event BIN-2 to RHR Failure	1.450E-01
			LPR-XHE-XM	OPERATOR FAILS TO INITIATE LPR SYSTEM	6.000E-03
			SLOCA-EQ2	SMALL LOCA EVENT	4.500E-02
30	0.02	4.62E-10	IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.842E-04

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
			EPS-DGN-CF-RUN	COMMON CAUSE FAILURE OF DIESEL GENERATORS TO RUN	5.865E-04
			EPS-XHE-XL-NR04H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 4 HOURS	5.000E-01
			LOOP-EQ1	LOSS OF OFFSITE POWER	2.770E-02
			RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	2.000E-01
31	0.01	4.22E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			EPS-DGN-CF-RUN	COMMON CAUSE FAILURE OF DIESEL GENERATORS TO RUN	5.865E-04
			EPS-XHE-XL-NR04H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 4 HOURS	5.000E-01
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
			RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	2.000E-01
32	0.01	4.18E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-RPS-FA	Contribution of Seismic Event BIN-3 to RPS Failure	5.770E-03
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			PPR-SRV-OO-SRV3ALIQ	SAFETY RELIEF VALVE 3A FAILS TO RECLOSE AFTER PASSING WATER	1.000E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
			SWS-TRAINA-ALIGNED	SW TRAIN A ALIGNED TO TURBINE BLDG	5.000E-01
33	0.01	4.18E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
			EQ-BIN-3-RPS-FA	Contribution of Seismic Event BIN-3 to RPS Failure	5.770E-03
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			PPR-SRV-OO-SRV3ALIQ	SAFETY RELIEF VALVE 3A FAILS TO RECLOSE AFTER PASSING WATER	1.000E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
			SWS-TRAINB-ALIGNED	SW TRAIN B ALIGNED TO TURBINE BLDG	5.000E-01
34	0.01	4.18E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-RPS-FA	Contribution of Seismic Event BIN-3 to RPS Failure	5.770E-03
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			PPR-SRV-OO-SRV3BLIQ	SAFETY RELIEF VALVE 3B FAILS TO RECLOSE AFTER PASSING WATER	1.000E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
			SWS-TRAINA-ALIGNED	SW TRAIN A ALIGNED TO TURBINE BLDG	5.000E-01
35	0.01	4.18E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EQ-BIN-3-RPS-FA	Contribution of Seismic Event BIN-3 to RPS Failure	5.770E-03
			EQ-BIN-3-SWS-FA	Contribution of Seismic BIN-3 to SWS Failure	6.300E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			PPR-SRV-OO-SRV3BLIQ	SAFETY RELIEF VALVE 3B FAILS TO RECLOSE AFTER PASSING WATER	1.000E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
			SWS-TRAINB-ALIGNED	SW TRAIN B ALIGNED TO TURBINE BLDG	5.000E-01
36	0.01	3.53E-10	IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.842E-04
			EPS-DGN-FR-1A	DIESEL GENERATOR 1A FAILS TO RUN	2.117E-02
			EPS-DGN-FR-1B	DIESEL GENERATOR 1B FAILS TO RUN	2.117E-02
			EPS-XHE-XL-NR04H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 4 HOURS	5.000E-01
			LOOP-EQ1	LOSS OF OFFSITE POWER	2.770E-02
			RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	2.000E-01
37	0.01	3.48E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			EQ-BIN-2-SWS-FA	Contribution of Seismic BIN-2 to SWS Failure	4.680E-02
			LLOCA-EQ2	LARGE LOCA EVENT	5.910E-04
38	0.01	3.37E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			AFW-MOV-CC-102	AFW TDP 1C MAIN STEAM VALVE 102 FAILS TO OPEN	1.000E-03
			EQ-BIN-2-SWS-FA	Contribution of Seismic BIN-2 to SWS Failure	4.680E-02
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
39	0.01	3.23E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			EPS-DGN-FR-1A	DIESEL GENERATOR 1A FAILS TO RUN	2.117E-02
			EPS-DGN-FR-1B	DIESEL GENERATOR 1B FAILS TO RUN	2.117E-02
			EPS-XHE-XL-NR04H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 4 HOURS	5.000E-01
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
			RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	2.000E-01
40	0.01	3.17E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			LLOCA-EQ3	LARGE LOCA EVENT	1.550E-02
			LPR-XHE-XM	OPERATOR FAILS TO INITIATE LPR SYSTEM	6.000E-03
41	0.01	3.00E-10	IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.842E-04
			EPS-DGN-FR-1A	DIESEL GENERATOR 1A FAILS TO RUN	2.117E-02
			EPS-DGN-TM-1B	DIESEL GENERATOR 1B UNAVAILABLE DUE TO TEST AND MAINTENANCE	9.000E-03
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01
			LOOP-EQ1	LOSS OF OFFSITE POWER	2.770E-02
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01
42	0.01	3.00E-10	IE-EQK-BIN-1	SEISMIC INITIATOR (0.05 - 0.3 g)	2.842E-04
			EPS-DGN-FR-1B	DIESEL GENERATOR 1B FAILS TO RUN	2.117E-02
			EPS-DGN-TM-1A	DIESEL GENERATOR 1A UNAVAILABLE DUE TO TEST AND MAINTENANCE	9.000E-03
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01
			LOOP-EQ1	LOSS OF OFFSITE POWER	2.770E-02
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01
43	0.01	2.74E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			EPS-DGN-FR-1B	DIESEL GENERATOR 1B FAILS TO RUN	2.117E-02
			EPS-DGN-TM-1A	DIESEL GENERATOR 1A UNAVAILABLE DUE TO TEST AND MAINTENANCE	9.000E-03
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01
44	0.01	2.74E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			EPS-DGN-FR-1A	DIESEL GENERATOR 1A FAILS TO RUN	2.117E-02
			EPS-DGN-TM-1B	DIESEL GENERATOR 1B UNAVAILABLE DUE TO TEST AND MAINTENANCE	9.000E-03
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01
			LOOP-EQ2	LOSS OF OFFSITE POWER	5.720E-01
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01
45	0.01	2.70E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EPS-DGN-CF-RUN	COMMON CAUSE FAILURE OF DIESEL GENERATORS TO RUN	5.865E-04
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
46	0.01	2.65E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			CVC-XHE-XM-BOR	OPERATOR FAILS TO INITIATE EMERGENCY BORATION	2.000E-02
			EQ-BIN-3-RPS-FA	Contribution of Seismic Event BIN-3 to RPS Failure	5.770E-03
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
47	0.01	2.65E-10	IE-EQK-BIN-2	SEISMIC INITIATOR (0.3 - 0.5 g)	1.258E-05
			EQ-BIN-2-SWS-FA	Contribution of Seismic BIN-2 to SWS Failure	4.680E-02
			RCS-XHE-XM-CDOWN1	OPERATOR FAILS TO INITIATE RAPID COOLDOWN	1.000E-02
			SLOCA-EQ2	SMALL LOCA EVENT	4.500E-02
48	0.01	2.30E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			AFW-XHE-XA-SUCT	OPERATOR FAILS TO ALIGN SWS/XTIE RMST TO AFW SYSTEM	1.000E-04
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
49	0.01	2.30E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			AFW-CKV-CC-301	CONDENSATE STORAGE TANK DISCHARGE CHECK VALVE FAILS	1.000E-04
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01
50	0.01	2.06E-10	IE-EQK-BIN-3	SEISMIC INITIATOR (> 0.5 g)	7.212E-06
			/CD-EQ3	DIRECT FUEL DAMAGE EVENTS	4.730E-01
			EPS-DGN-FR-1A	DIESEL GENERATOR 1A FAILS TO RUN	2.117E-02
			EPS-DGN-FR-1B	DIESEL GENERATOR 1B FAILS TO RUN	2.117E-02
			EPS-XHE-XL-NR08H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 8 HOURS	2.500E-01
			LOOP-EQ3	LOSS OF OFFSITE POWER	8.990E-01

Cut No.	% Cut Set	Frequency	Basic Event	Description	Event Prob.
			/RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	8.000E-01
			/SLOCA-EQ3	SMALL LOCA EVENT	7.500E-01

Appendix 4A. Generic Seismic Hazard Vectors

The generic hazard vectors for 58 sites east of the Rocky Mountains are obtained from licensees' submittals in 2014 as part of the effort to address NRC Near-Term Task Force (NTTF) Recommendation 2.1.

The hazard vectors for the remaining 3 sites (Columbia, Diablo Canyon, and Palo Verde) are obtained from licensees' submittals in 2015 as part of the effort to address NRC NTTF Recommendation 2.1.

The submittals are available at the following NRC SharePoint site:

http://epm.nrc.gov/environmental/jlltg/Seismic/Forms/AllItems.aspx?RootFolder=%2Fenvironmental%2Fjlltg%2FSeismic%2FSeismic%202%2E1%20Reeval%2FSeismic%202%2E1%20Site%20Specific%2F01%20Seismic%20Reevaluation%2FFull%20Seismic%20Hazard%20Submittals

Table 4A-1 provides the seismic hazard vectors for the 61 U.S. nuclear power plants. Uncertainty information for each of the seismic hazard vector can also be obtained from the licensees' submittals.

G-values are in term of peak ground acceleration (PGA).

Table 4A-1 Seismic Hazard Vectors for the 61 U.S. nuclear power plants

mean frequency of exceedance (per year)									
	1/2	**3/4**	**5/6**	**7/8/9**	**10/11**	**12/13**	**14**	**15/16**	**17/18**
	ANO	**Beaver Valley**	**Braidwood**	**Browns Ferry**	**Brunswick**	**Byron**	**Callaway**	**Calvert Cliffs**	**Catawba**
g value	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**
0.03	2.60E-03	1.83E-03	1.52E-03	2.95E-03	1.56E-03	1.35E-03	8.25E-03	8.08E-04	2.49E-03
0.05	1.22E-03	7.68E-04	6.31E-04	1.46E-03	8.00E-04	6.41E-04	4.54E-03	2.81E-04	1.22E-03
0.075	6.12E-04	3.81E-04	3.07E-04	7.68E-04	4.17E-04	3.49E-04	2.69E-03	1.18E-04	6.51E-04
0.1	3.57E-04	2.19E-04	1.83E-04	4.62E-04	2.45E-04	2.26E-04	1.78E-03	6.39E-05	4.06E-04
0.15	1.55E-04	1.35E-04	8.70E-05	2.09E-04	1.05E-04	1.20E-04	9.17E-04	2.64E-05	2.01E-04
0.3	3.21E-05	1.99E-05	2.26E-05	4.37E-05	1.99E-05	3.68E-05	2.28E-04	5.39E-06	5.54E-05
0.5	9.43E-06	5.08E-06	7.39E-06	1.26E-05	5.13E-06	1.37E-05	6.54E-05	1.51E-06	2.00E-05
0.75	3.38E-06	1.40E-06	2.76E-06	4.63E-06	1.67E-06	5.66E-06	2.17E-05	5.04E-07	8.41E-06
1.00	1.55E-06	4.59E-07	1.29E-06	2.21E-06	7.32E-07	2.85E-06	9.66E-06	2.18E-07	4.36E-06
	19	**20**	**21/22**	**23/24**	**25**	**26**	**27/28**	**29/30**	**31**
	Clinton	**Columbia**	**Comanche Peak**	**Cook**	**Cooper**	**Davis Besse**	**Diablo Canyon**	**Dresden**	**Duane Arnold**
g value	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**
0.03	5.15E-03		2.24E-04	2.10E-03	7.73E-04	9.11E-04		1.60E-03	3.04E-04
0.05	2.20E-03		7.27E-05	9.06E-04	2.94E-04	4.14E-04		7.21E-04	1.12E-04
0.075	9.94E-04		2.87E-05	4.46E-04	1.38E-04	2.11E-04		3.75E-04	5.23E-05
0.1	5.40E-04		1.48E-05	2.67E-04	8.15E-05	1.25E-04		2.32E-04	3.13E-05
0.15	2.16E-04		5.86E-06	1.29E-04	3.83E-05	7.94E-05		1.16E-04	1.54E-05
0.3	4.09E-05		1.28E-06	3.37E-05	9.16E-06	1.43E-05		3.19E-05	4.29E-06
0.5	1.12E-05		4.06E-07	1.08E-05	2.67E-06	4.31E-06		1.08E-05	1.51E-06
0.75	3.71E-06		1.52E-07	3.85E-06	8.85E-07	1.50E-6		4.17E-06	5.98E-07
1.00	1.61E-06		7.15E-08	1.70E-06	3.79E-07	6.42E-07		2.00E-06	2.92E-07

	32/33	**34**	**35**	**36**	**37**	**38**	**39/40**	**41**	**42/43**
	Farley	**Fermi**	**Fitzpatrick**	**Fort Calhoun**	**Ginna**	**Grand Gulf**	**Hatch**	**Hope Creek**	**Indian Point**
g value	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**
0.03	1.93E-04	9.04E-04	7.84E-04	1.61E-03	5.19E-04	7.53E-04	1.45E-03	9.93E-04	1.20E-03
0.05	7.25E-05	3.91E-04	2.91E-04	6.95E-04	2.07E-04	2.31E-04	6.87E-04	4.46E-04	7.04E-04
0.075	3.57E-05	2.00E-04	1.28E-04	3.35E-04	9.91E-05	8.28E-05	2.87E-04	2.30E-04	4.52E-04
0.1	2.24E-05	1.24E-04	7.04E-05	1.97E-04	5.87E-05	4.02E-05	1.47E-04	1.40E-04	3.25E-04
0.15	1.19E-05	6.18E-05	2.99E-05	9.23E-05	2.78E-05	1.55E-05	5.69E-05	6.67E-05	1.97E-04
0.3	3.84E-06	1.70E-05	6.65E-06	2.24E-05	7.24E-06	3.29E-06	7.25E-06	1.51E-05	7.45E-05
0.5	1.52E-06	5.73E-06	2.07E-06	6.61E-06	2.45E-06	9.35E-07	1.11E-06	4.04E-06	3.17E-05
0.75	6.60E-07	2.18E-06	7.77E-07	2.14E-06	9.52E-07	3.07E-07	2.69E-07	1.23E-06	1.45E-05
1.00	3.44E-07	1.03E-06	3.70E-07	8.72E-07	4.61E-07	1.30E-07	8.79E-08	4.89E-07	7.79E-06
	44/45	**46/47**	**48/49**	**50/51**	**52**	**53/54**	**55/56**	**57/58/59**	**60**
	LaSalle	**Limerick**	**McGuire**	**Millstone**	**Monticello**	**Nine Mile Point**	**North Anna**	**Oconee**	**Oyster Creek**
g value	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**
0.03	4.52E-03	9.50E-04	2.07E-03	8.60E-04	5.28E-04	8.04E-04	**	2.71E-03	2.34E-03
0.05	1.98E-03	4.47E-04	9.66E-04	5.615E-04	2.44E-04	3.00E-04	1.07E-03	1.31E-03	1.01E-03
0.075	9.50E-04	2.37E-04	5.06E-04	2.08E-04	1.30E-04	1.32E-04	9.55E-04	7.14E-04	4.43E-04
0.1	5.57E-04	1.48E-04	3.14E-04	1.24E-04	8.28E-05	7.31E-05	6.51E-04	4.60E-04	2.32E-04
0.15	2.61E-04	7.34E-05	1.56E-04	8.1E-05	4.27E-05	3.11E-05	3.71E-04	2.43E-04	8.88E-05
0.3	6.66E-05	1.95E-05	4.50E-05	1.84E-05	1.23E-05	6.92E-06	1.37E-04	7.59E-05	1.50E-05
0.5	2.01E-05	6.44E-06	1.70E-05	5.97E-06	4.33E-06	2.16E-06	5.70E-05	2.95E-05	3.54E-06
0.75	6.42E-06	2.44E-06	7.41E-06	2.43E-06	1.70E-06	8.08E-07	2.54E-05	1.28E-05	1.06E-06
1.00	2.59E-06	1.15E-06	3.92E-06	1.08E-06	8.18E-07	3.85E-07	1.39E-05	6.71E-06	4.39E-07

** Information not provided in the licensee's submittal

	61	62/63/64	65/66	67	68	69/70	71/72	73/74	75
	Palisades	**Palo Verde**	**Peach Bottom**	**Perry**	**Pilgrim**	**Point Beach**	**Prairie Island**	**Quad Cities**	**River Bend**
g value	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**
0.03	2.87E-03	[redacted]	1.15E-03	7.68E-04	2.47E-03	9.36E-04	1.43E-04	7.92E-04	5.20E-04
0.05	1.29E-03	[redacted]	6.70E-04	3.86E-04	1.39E-03	3.69E-04	5.48E-05	3.21E-04	1.80E-04
0.075	6.34E-04	[redacted]	4.27E-04	2.17E-04	8.57E-04	1.67E-04	2.64E-05	1.57E-04	8.15E-05
0.1	3.77E-04	[redacted]	3.04E-04	1.38E-04	5.99E-04	9.41E-05	1.58E-05	9.50E-05	4.80E-05
0.15	1.78E-04	[redacted]	1.83E-04	9.05E-05	3.50E-04	4.14E-05	7.62E-06	4.71E-05	2.26E-05
0.3	4.61E-05	[redacted]	6.82E-05	1.90E-05	1.24E-04	9.28E-06	1.99E-06	1.33E-05	5.30E-06
0.5	1.48E-05	[redacted]	2.93E-05	5.74E-06	5.08E-05	2.66E-06	6.49E-07	4.65E-06	1.50E-06
0.75	5.18E-06	[redacted]	1.38E-05	1.95E-06	2.23E-05	8.43E-07	2.39E-07	1.84E-06	4.86E-07
1.00	2.21E-06	[redacted]	7.63E-06	8.34E-07	1.15E-05	3.36E-07	1.10E-07	8.96E-07	2.05E-07
	76	**77/78**	**79/80**	**81**	**82/83**	**84**	**85/86**	**87/88**	**89/90**
	Robinson	**Saint Lucie**	**Salem**	**Seabrook**	**Sequoyah**	**Shearon Harris**	**South Texas**	**Surry**	**Susquehanna**
g value	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**
0.03	6.20E-03	1.38E-04	8.46E-04	1.90E-03	6.64E-04	9.03E-04	8.67E-05	1.37E-03	5.08E-04
0.05	3.72E-03	5.21E-05	3.67E-04	1.11E-03	2.39E-04	3.31E-04	4.16E-05	4.36E-04	2.17E-04
0.075	2.38E-03	2.40E-05	1.84E-04	7.14E-04	9.04E-05	1.37E-04	2.31E-05	1.57E-04	1.09E-04
0.1	1.66E-03	1.40E-05	1.11E-04	5.13E-04	4.18E-05	6.99E-05	1.52E-05	7.50E-05	6.59E-05
0.15	9.09E-04	6.36E-06	5.13E-05	3.11E-04	1.30E-05	2.60E-05	8.28E-06	2.66E-05	3.20E-05
0.3	2.33E-04	1.43E-06	1.15E-05	1.15E-04	1.68E-06	4.70E-06	2.71E-06	4.44E-06	8.57E-06
0.5	6.44E-05	3.82E-07	3.24E-06	4.78E-05	4.15E-07	1.37E-06	1.07E-06	1.13E-06	2.94E-06
0.75	1.94E-05	1.12E-07	1.07E-06	2.14E-05	1.45E-07	5.01E-07	4.69E-07	3.71E-07	1.15E-06
1.00	7.51E-06	4.32E-08	4.58E-07	1.14E-05	6.86E-08	2.36E-07	2.45E-07	1.64E-07	5.62E-07

	91	**92/93**	**94**	**95/96**	**97**	**98/99**	**100**
	Three Mile Island	**Turkey Point**	**V.C. Summer**	**Vogtle**	**Waterford**	**Watts Bar**	**Wolf Creek**
g value	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**	**mean f per year**
0.03	9.20E-04	5.98E-05	2.71 E-03	6.46E-03	7.04E-04	3.27E-03	2.55E-03
0.05	4.60E-04	2.65E-05	1.44E-03	4.04E-03	2.47E-04	1.56E-03	1.18E-03
0.075	2.60E-04	1.32E-05	8.13E-04	2.68E-03	1.07E-04	8.42E-04	5.95E-04
0.1	1.71E-04	7.82E-06	5.21E-04	1.93E-03	5.95E-05	5.35E-04	3.57E-04
0.15	9.09E-05	3.56E-06	2.63E-04	1.11E-03	2.57E-05	2.74E-04	1.67E-04
0.3	2.69E-05	7.87E-07	7.23E-05	2.87E-04	5.28E-06	7.83E-05	4.31E-05
0.5	9.40E-06	2.11E-07	2.55E-05	6.78E-05	1.36E-06	2.70E-05	1.50E-05
0.75	3.67E-06	6.42E-08	1.05E-05	1.49E-05	4.15E-07	1.03E-05	6.08E-06
1.00	1.77E-06	2.59E-08	5.38E-06	3.72E-06	1.71E-07	4.91E-06	3.04E-06

For the three sites West of Rocky mountains, this information is obtained from licensees' submittals as part of the effort to address Near-Term Task Force (NTTF) Recommendation 2.1 in 2015. (See ML15078A243 for Columbia, ML15070A607 and ML15070A608 for Diablo Canyon, and ML15076A073 for Palo Verde)

20 Columbia		**27/28 Diablo Canyon**		**62/63/64 Palo Verde**	
g value	**mean f per year**	**g value**	**mean f per year**	**g value**	**mean f per year**
0.03	7.03E-03	0.05	2.30E-02	0.03	1.07E-03
0.05	3.94E-03	0.1	8.40E-03	0.05	3.97E-04
0.075	2.41E-03	0.25	2.00E-03	0.075	1.84E-04
0.10	1.67E-03	0.5	4.30E-04	0.1	1.07E-04
0.20	6.46E-04	0.7	1.70E-04	0.15	5.00E-05
0.30	3.53E-04	1	4.90E-05	0.3	1.23E-05
0.50	1.54E-04	1.2	2.60E-05	0.5	3.70E-06
0.75	7.45E-05	1.6	8.20E-06	0.75	1.24E-06
1.0	4.22E-05	2.0	3.20E-06	1.0	5.30E-07
		3.0	5.00E-07	1.5	1.43E-07
		4.0	1.30E-07		

Appendix 4B. Reference SSC Seismic Fragilities

Reference SSC seismic fragilities and the failure probabilities for SSCs in each seismic bin as derived from these fragilities are given in Table 4B-1. In the absence of plant-specific fragility information for a SSC, the values from this table can be used as surrogates.

> ***Clarification:*** The generic values in this table are intended for use by NRC risk analysts when obtaining risk insights for operational events via the SDP, the ASP Program, Notice of Enforcement Discretion (NOED) evaluations, and event assessments under the NRC's Incident Investigation Program (MD 8.3). The NRC does not endorse the use of these generic values in general. Other appropriate NRC endorsed or NRC guidance, and applicable codes and standards should be considered for specific regulatory applications. Please refer to Section 1.2, "Scope of the Handbook," of this handbook regarding the scope of methods and guidance in this handbook.

A seismic fragility library is being constructed from plant-specific SSC fragilities available in recent sources, such as IPEEEs. The currently available seismic fragility information in this library is placed in ADAMS as an EXCEL file with Accession No. ML071220070 as well as in the RASP Tool Box website.

Table 4B-1 Generic SSC Seismic Fragilities

Clarification: The generic values in this table are intended for use by NRC risk analysts when obtaining risk insights for operational events via the SDP, the ASP Program, Notice of Enforcement Discretion (NOED) evaluations, and event assessments under the NRC's Incident Investigation Program (MD 8.3). The NRC does not endorse the use of these generic values in general. Other appropriate NRC endorsed or NRC guidance, and applicable codes and standards should be considered for specific regulatory applications. Please refer to Section 1.2, "Scope of the Handbook," of this handbook regarding the scope of methods and guidance in this handbook.

							Failure probability Pf at X g		
Component	**Median Capacity, g**	**beta-r**	**beta-u**	**HCLPF Capacity, g**	**Failure Mode**	**Source**	**0.122**	**0.387**	**0.707**
Offsite power	0.3	0.30	0.45	0.10	Failure of ceramics	1	4.81E-02	6.81E-01	9.44E-01
Electrical equipment - Function during seismic event	1.0	0.30	0.35	0.34	Chatter functional failure	1	2.52E-06	1.97E-02	2.26E-01
Large flat-bottom storage tanks	1.1	0.30	0.35	0.37	Buckling or wall failure	1	9.20E-07	1.17E-02	1.69E-01
Battery chargers	1.6	0.30	0.35	0.54	Functional failure	1	1.18E-08	1.04E-03	3.82E-02
Inverters	1.6	0.30	0.35	0.54	Functional failure	1	1.18E-08	1.04E-03	3.82E-02
Cable trays	2.5	0.35	0.50	0.61	Support failure	1	3.75E-07	1.12E-03	1.93E-02
HVAC ducts	2.5	0.35	0.50	0.61	Support failure	1	3.75E-07	1.12E-03	1.93E-02
Heat exchangers and small tanks	1.9	0.30	0.35	0.65	Rupture	1	1.30E-09	2.79E-04	1.60E-02
Recirculation pumps	1.9	0.30	0.35	0.65	Support failure	1	1.30E-09	2.79E-04	1.60E-02
Transformers	1.9	0.30	0.35	0.65	Loss of function /structural failure	1	1.30E-09	2.79E-04	1.60E-02
Motor-driven pumps	2.0	0.30	0.35	0.68	Support failure	1	6.53E-10	1.83E-04	1.20E-02

							Failure probability Pf at X g		
Component	**Median Capacity, g**	**beta-r**	**beta-u**	**HCLPF Capacity, g**	**Failure Mode**	**Source**	**0.122**	**0.387**	**0.707**
Air handling units	2.5	0.30	0.40	0.75	Structural failure	1	7.73E-10	9.53E-05	5.77E-03
Pressurizer	2.5	0.30	0.40	0.75	Structural failure of support	1	7.73E-10	9.53E-05	5.77E-03
Control rod drive and hydraulic drive units	2.5	0.30	0.40	0.76	Functional failure	1	7.73E-10	9.53E-05	5.77E-03
Electrical equipment - Function after seismic event	2.5	0.30	0.40	0.77	Chatter functional failure	1	7.73E-10	9.53E-05	5.77E-03
Buried welded steel piping	2.0	0.25	0.30	0.80	Buckling	1	4.00E-13	1.30E-05	3.87E-03
Accumulators	2.5	0.30	0.35	0.85	Structural failure	1	2.87E-11	2.59E-05	3.07E-03
Turbine-driven pumps	2.5	0.30	0.35	0.85	Support failure	1	2.87E-11	2.59E-05	3.07E-03
Air-operated valves	3.8	0.35	0.50	0.93	Loss of function	1	8.82E-09	9.10E-05	2.93E-03
Motor-operated valves	3.8	0.35	0.50	0.93	loss of function	1	8.82E-09	9.10E-05	2.93E-03
Piping	3.8	0.35	0.50	0.93	Loss of support	1	8.82E-09	9.10E-05	2.93E-03
Safety relief, manual and check valves	3.8	0.35	0.50	0.93	Loss of function	1	8.82E-09	9.10E-05	2.93E-03
Diesel generator and support systems	3.1	0.30	0.35	1.06	Functional failure	1	1.13E-12	3.19E-06	6.72E-04
Switchgear and motor control centers	3.1	0.30	0.35	1.06	Functional failure	1	1.13E-12	3.19E-06	6.72E-04

							Failure probability Pf at X g		
Component	**Median Capacity, g**	**beta-r**	**beta-u**	**HCLPF Capacity, g**	**Failure Mode**	**Source**	**0.122**	**0.387**	**0.707**
Batteries and battery racks	3.8	0.30	0.35	1.30	Structural failure of supports	1	4.37E-14	3.61E-07	1.32E-04
Panelboards and instrumentation panel	3.8	0.30	0.35	1.30	Functional failure	1	4.37E-14	3.61E-07	1.32E-04
Containment, buildings	0.75	0.21	0.21	0.50	Structural failure	IP3	4.83E-10	1.29E-02	1.4.21E-01
Reactor internals and core assembly	1.8	0.30	0.40	0.55	Structural failure	1	3.67E-08	1.06E-03	3.08E-02
Reactor pressure vessel	2.0	0.30	0.35	0.68	Support failure	1	6.53E-10	1.83E-04	1.20E-02
Steam generators	2.5	0.30	0.40	0.75	Structural failure of support	1	7.73E-10	9.53E-05	5.77E-03
Reactor coolant pump	2.5	0.30	0.40	0.75	Structural failure of support	1	7.73E-10	9.53E-05	5.77E-03
Seismically induced small LOCA probability						4840	1.50E-05	4.50E-02	2.50E-01
Seismically induced medium LOCA probability						4840	1.00E-07	4.00E-03	4.00E-02
Sources:	1	NUREG/CR-6544, Table 6-1							
	IP3	Indian Point unit 3 IPEEE							
	4840	Seismically-induced SLOCA and MLOCA probabilities are taken from NURE/CR-4840, Figure 3-6.							

Appendix 4C. Seismic Fragility / PGA / HCLPF

The complete fragility description of any particular SSC includes a representation of both the probabilities of failure vs. PGA and the uncertainty of the analyst in estimating those probabilities. ("Failure", in this context, refers to inability to perform the assigned safety function.)

In the absence of variability and uncertainty, the capacity of an element could be defined by a single number, the precise PGA at which the element would fail. Because of earthquake-to-earthquake variations in the dynamic response and capacity for the same nominal PGA, one must recognize that the capacity can be represented only by a distribution -- specifically, a distribution of failure probability vs. PGA. Further, because of incomplete technical knowledge (both theoretical and observational) about the probabilistic seismic behavior of elements and systems, it is necessary to describe the uncertainty in these fragility distributions.

Figure 4C-1, which is Figure 2-1 of NUREG/CR-4334, “An Approach to the Quantification of Seismic Margins in Nuclear Power Plants,” (Ref. 4-7), presents one way of displaying such a full fragility description. The curves on this figure are very stylized and do not represent any particular functional form. The solid curve in the middle represents a "best-estimate" curve, the "median fragility curve.” Corresponding to an ordinate of 0.50 is the ("best estimate" of the) median capacity, A_m, Point A. The PGA corresponding to Point B is the ("best estimate" of the) PGA at which there is only a 5% probability of failure.

The dashed lines in Figure 4C-1 reflect the uncertainty in the analyst's estimation of the probability distribution -- the uncertainty in the PGA value corresponding to a given probability of failure, or conversely, the uncertainty in the probability of failure corresponding to a given PGA. For example, Point D corresponds to the 95% (lower) confidence estimate of the median capacity. Specifically, the analyst is 95% confident that the median capacity exceeds this PGA level. Similarly, Point C represents the high (95%) confidence estimate of the PGA at which there is only a small (5%) probability of failure.

In those situations in which full fragility descriptions have been developed (mainly in full-scope seismic PRA studies), we have chosen the HCLPF to be represented by Point C. It is important to realize that this choice is only a convention, because the HCLPF point should not connote such numerical precision.

In current PRA practice, it has been conventional to assume a particular model for the fragility description. This is the (double) lognormal, in which the fragility can be fully described by only three parameters: the "best estimate" of median capacity (A_m); a randomness measure, β_R that measures the slope or spread of the median fragility curve; and an uncertainty measure, β_U that is a measure of the separations between the median curve and the 95% and 5% curves in Figure 4C-1. Under these circumstances, and assuming that the lognormal model exactly characterizes the fragility at issue, it can be shown that Point B is below the median point by a factor of exp ($-1.65\ \beta_R$). Also, Point D is below the median by a factor of exp ($-1.65\ \beta_U$), and Point C is below the median by exp [$-1.65(\beta_R + \beta_U)$].

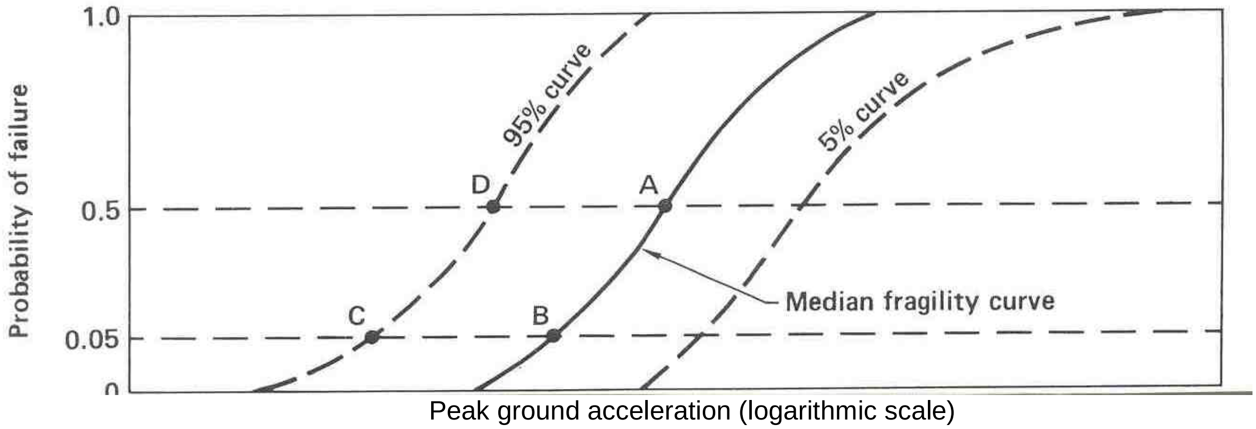

Figure 4C-1 Fragility Curves. Peak ground acceleration corresponding to Point A represents the median capacity. Peak ground acceleration corresponding to Point C represents the HCLPF capacity.

(Source: NUREG/CR-4334 (1985), Figure 2-1)

Composite variability (β_c):

The composite variability includes the aleatory (randomness) uncertainty (β_R) and the epistemic (modeling and data) uncertainty (β_U). The logarithmic standard deviation of composite variability, (β_c), is expressed as $(\beta_R^2 + \beta_U^2)^{1/2}$.

HCLPF capacity:

The high confidence of low probability of failure (HCLPF) capacity is a measure of seismic ruggedness. In seismic PRA, this is defined as the earthquake motion level at which there is a high (95 percent) confidence of a low (at most 5 percent) probability of failure. Using the lognormal fragility model, the HCLPF capacity is expressed as A_m [exp(-1.65($\beta_R + \beta_U$)]. When the logarithmic standard deviation of composite variability β_c is used, the HCLPF capacity could be approximated as the ground motion level at which the composite probability of failure is at most 1 percent. In this case, HCLPF capacity is expressed as A_m[exp-2.33 β_c]. In deterministic SMAs, the HCLPF capacity is calculated using the Conservative Deterministic Failure Methodology method.

Peak ground acceleration (PGA):

Maximum value of acceleration displayed on an accelerogram; the largest ground acceleration produced by an earthquake at a site.

Source: ANSI/ANS-58.21-2007 American National Standard External-Events PRA Methodology

Acceleration is the rate of change in velocity of the ground shaking (how much the velocity changes in a unit time), just as it is the rate of change in the velocity of your car when you step on the accelerator or put on the brakes. Velocity is the measurement of the speed of the ground motion. Displacement is the measurement of the actual changing location of the ground due to shaking. All three of the values can be measured continuously during an earthquake. The peak ground acceleration (PGA) is the largest acceleration recorded by a particular station during an earthquake.

http://earthquake.usgs.gov/learn/glossary/?term=acceleration

Appendix 4D. Correspondence between PGA and Severity of Earthquakes

There are two methods of measurement for describing the effects of earthquakes. The Richter Scale measures magnitude, or the energy released by an earthquake. The Modified Mercalli Scale measures intensity, or an earthquake's impact or effect as felt at a particular location.

In seismology, the scale of seismic intensity is a way of measuring or rating the *effects* of an earthquake at different locations. The Modified Mercalli Scale is commonly used in the United States by seismologists seeking information on the severity of earthquake effects. Intensity ratings are expressed as Roman numerals between I at the low end and XII at the high end.

The Intensity Scale differs from the Richter Scale in that the effects of any one earthquake vary greatly from place to place, so there may be many Intensity values (e.g., IV, VII) measured from one earthquake. Each earthquake, on the other hand, should have just one Magnitude, although the several methods of estimating it will yield slightly different values (e.g., 6.1, 6.3).

Ratings of earthquake effects are based on the relatively subjective scale of descriptions. As one can see from the list in Table 4D-1, rating the Intensity of an earthquake's effects does not require any instrumental measurements. Thus, seismologists can use newspaper accounts, diaries, and other historical records to make intensity ratings of past earthquakes, for which there are no instrumental recordings. Such research helps promote understanding of the earthquake history of a region, and estimate future hazards.

Table 4D-1 also provides some information for the use of the Richter Scale, PGA, and Modified Mercalli scales for seismic events. The relation between Modified Mercalli scale and PGA is taken from a paper which is based on regression analysis of eight significant California earthquakes.

Although there are some empirical relationships, no exact correlations of intensity, magnitude, and acceleration with damage are possible since many factors contribute to seismic behavior and structural performance.

Table 4D-1 Modified Mercalli Scale versus PGA

Modified Mercalli Intensity	Equivalent Richter Magnitude	Witness Observations	Intensity Peak Accel. (% g)
I	1.0 to 2.0	Felt by very few people; barely noticeable.	<0.17
II	2.0 to 3.0	Felt by a few people, especially on upper floors.	0.17-1.4
III	3.0 to 4.0	Noticeable indoors, especially on upper floors, but may not be recognized as an earthquake.	0.17-1.4
IV	4	Felt by many indoors, few outdoors. May feel like heavy truck passing by.	1.4-3.9
V	4.0 to 5.0	Felt by almost everyone, some people awakened. Small objects moved. Trees and poles may shake.	3.9-9.2
VI	5.0 to 6.0	Felt by everyone. Difficult to stand. Some heavy furniture moved, some plaster falls. Chimneys may be slightly damaged.	9.2-18
VII	6	Slight to moderate damage in well built, ordinary structures. Considerable damage to poorly built structures. Some walls may fall.	18-34
VIII	6.0 to 7.0	Little damage in specially built structures. Considerable damage to ordinary buildings, severe damage to poorly built structures.	34-65

		Some walls collapse.	
IX	7	Considerable damage to specially built structures, buildings shifted off foundations. Ground cracked noticeably. Wholesale destruction. Landslides.	65-124
X	7.0 to 8.0	Most masonry and frame structures and their foundations destroyed. Ground badly cracked. Landslides. Wholesale destruction.	>124
XI	8	Total damage. Few, if any, structures standing. Bridges destroyed. Wide cracks in ground. Waves seen on ground.	>124
XII	8.0 or greater	Total damage. Waves seen on ground. Objects thrown up into air.	>124

Table 4D-2 PGA vs. Richter and Modified Mercalli Scales

Peak Ground Acceleration (% g)	PGA (representative)	Equivalent Richter Magnitude	Modified Mercalli Intensity Scale
<0.17			I
0.17-1.4			II –III
1.4-3.9			IV
3.9-9.2			V
9.2-18	0.15g	5.0 to 6.0	VI
18-34	0.30g	6	VII
34-65	0.50g	6.0 to 7.0	VIII
65-124	1.00g	7	IX
>124	1.25g	7.0 or greater	X+

This table gives the peak ground motion ranges that correspond to each unit of Modified Mercalli intensity value according to regression of the observed peak ground motions and intensities for several earthquakes in California. Equivalent Richter scales are also included.

External Events: Frequencies of Seismically-Induced LOOP Events for SPAR Models	Appendix 1 Rev. 1.02

Appendix 1. Frequencies of Seismically-Induced LOOP Events for SPAR Models

1. Objective

This Appendix provides frequencies of seismically-induced loss of offsite power (LOOP) events for U.S. nuclear power plants (NPPs). These LOOP frequencies could be used for external events scenarios in event importance calculations.

2. Input

The inputs to these calculations are:

i). seismic initiating event frequencies (seismic hazard distribution) as a function of seismic g level obtained from licensees' submittals as part of the effort to address NRC Near-Term Task Force (NTTF) Recommendation 2.1 in 2014 and 2015;

ii). structures, systems and components (SSCs) (for example ceramic insulator) fragilities as a function of g level (NUREG-6544, April 1998).

Attachment A provides the details.

3. Summary of Results

The input data is combined as a weighted average over the g levels to obtain mean value estimates, as shown in Attachment A. The following information is provided as shown in Table 1:

1. Seismic initiating event mean frequency of a 0.05g or higher earthquake per year;

2. Given an earthquake occurs, the conditional LOOP probability caused by the earthquake (based on failure of ceramic insulators);

3. Frequency of seismically induced LOOP event (per year).

Tables 2 and 3 compare the seismically induced LOOP frequency with frequencies of other "internal LOOP events." Average durations of the LOOP events are also provided in the same tables.

4. Comments

i). These results show that the seismically-induced LOOP frequencies are at least two orders of magnitude lower than LOOP frequencies calculated for internal events.

However, AC power recovery may not be feasible for an extended time period, following a seismic event. This fact should be factored into the calculation of plant risk due to seismically-induced LOOP events.

ii). A small fraction of these LOOP events (at high seismic g values) will have additional SSC failures that would cause other initiating events, such as small loss-of-coolant accident (LOCA), large LOCA, etc.

iii). For the U.S. nuclear power plants east of the Rocky Mountains, an EXCEL workbook is used to calculate the seismically-induced LOOP frequencies for 61 sites. The EXCEL file can be found with ADAMS Accession No. ML11220A195 as well as in the RASP Tool Box website. The same generic ceramic insulator seismic fragility distribution is used for these calculations.

iv). For the three U.S. nuclear power plants west of the Rocky Mountains, plant-specific seismic event frequency distributions (seismic hazard curves) are obtained from licensees' submittals as part of the effort to address NRC NTTF Recommendation 2.1 in 2015. The seismic fragility distributions for LOOP are obtained from the Individual Plant Examination of External Events (IPEEE) submittals whenever available. If not available, generic ceramic insulator fragilities are used.

v). The calculations can be readily customized for plant-specific SSC fragilities (e.g., ceramic insulators) and/or hazard curves. The EXCEL workbook (ADAMS Accession No. ML11220A195) is available for this purpose.

Table 1 Frequencies of Seismically-Induced LOOP Events
(Based on Hazard Vectors in NTTF 2.1 submittals)

	Plant	Seismic IEV Frequency	Cond. Prob. of LOOP	Seismically-. Induced. LOOP Frequency	Plant Type	# of Units
		A	B	A*B		
1-2	ANO 1 & 2	1.22E-03	5.22E-02	6.36E-05	B&W/CE	2
3-4	Beaver Valley 1 & 2	7.68E-04	5.02E-02	3.85E-05	W	2
5-6	Braidwood 1 & 2	6.31E-04	5.90E-02	3.72E-05	W	2
7-89	Browns Ferry 1, 2 & 3	1.46E-03	5.79E-02	8.45E-05	BWR	3
10-11	Brunswick 1 & 2	8.00E-04	5.26E-02	4.21E-05	BWR	2
12-13	Byron 1 & 2	6.41E-04	8.23E-02	5.28E-05	W	2
14	Callaway	4.54E-03	8.17E-02	3.71E-04	W	1
15-16	Calvert Cliffs 1 & 2	2.81E-04	3.96E-02	1.11E-05	CE	2
17-18	Catawba 1 & 2	1.22E-03	7.11E-02	8.68E-05	W	2
19	Clinton	2.20E-03	4.09E-02	9.01E-05	BWR	1
20	Columbia	3.94E-03	1.04E-01	4.09E-04	BWR	1
21-22	Comanche Peak 1 & 2	7.27E-05	3.56E-02	2.59E-06	W	2
23-24	Cook 1 & 2	9.06E-04	6.06E-02	5.49E-05	W	2
25	Cooper	2.94E-04	5.43E-02	1.60E-05	BWR	1
26	Davis-Besse	4.14E-04	5.94E-02	2.46E-05	B&W	1
27-28	Diablo Canyon 1 & 2	2.30E-02	1.08E-03	2.48E-05	W	2
29-30	Dresden 2 & 3	7.21E-04	6.90E-02	4.97E-05	BWR	2
31	Duane Arnold	1.12E-04	5.99E-02	6.71E-06	BWR	1
32-33	Farley 1 & 2	7.25E-05	7.43E-02	5.39E-06	W	2
34	Fermi 2	3.91E-04	6.78E-02	2.65E-05	BWR	1
35	Fitzpatrick	2.91E-04	4.39E-02	1.28E-05	BWR	1
36	Fort Calhoun	6.95E-04	5.56E-02	3.87E-05	CE	1
37	Ginna	2.07E-04	5.78E-02	1.20E-05	W	1
38	Grand Gulf	2.31E-04	2.99E-02	6.91E-06	BWR	1
39-40	Hatch 1 & 2	6.87E-04	3.55E-02	2.44E-05	BWR	2
41	Hope Creek	4.46E-04	6.05E-02	2.70E-05	BWR	1
42-43	Indian Point 2 & 3	7.04E-04	1.31E-01	9.21E-05	W	2
44-45	LaSalle 1 & 2	1.98E-03	5.61E-02	1.11E-04	BWR	2
46-47	Limerick 1 & 2	4.47E-04	6.95E-02	3.11E-05	BWR	2
48-49	McGuire 1 & 2	9.66E-04	7.10E-02	6.86E-05	W	2
50-51	Millstone 2 & 3	4.13E-04	6.87E-02	2.84E-05	CE/W	2
52	Monticello	2.44E-04	7.56E-02	1.84E-05	BWR	1
53-54	Nine Mile Point 1 & 2	3.00E-04	4.42E-02	1.33E-05	BWR	2
55-56	North Anna 1 & 2	1.07E-03	1.67E-01	1.78E-04	W	2
57-59	Oconee 1, 2, & 3	1.31E-03	8.26E-02	1.08E-04	B&W	3
60	Oyster Creek	1.01E-03	3.64E-02	3.68E-05	BWR	1
61	Palisades	1.29E-03	5.90E-02	7.61E-05	CE	1
62-64	Palo Verde 1, 2, & 3	3.97E-04	5.32E-02	2.11E-05	CE	3
65-66	Peach Bottom 2 & 3	6.70E-04	1.27E-01	8.53E-05	BWR	2
67	Perry	3.86E-04	7.70E-02	2.97E-05	BWR	1

	Plant	Seismic IEV Frequency	Cond. Prob. of LOOP	Seismically-. Induced. LOOP Frequency	Plant Type	# of Units
		A	**B**	**A*B**		
68	Pilgrim	1.39E-03	1.15E-01	1.60E-04	BWR	1
69-70	Point Beach 1 & 2	3.69E-04	4.71E-02	1.74E-05	W	2
71-72	Prairie Island 1 & 2	5.48E-05	5.93E-02	3.25E-06	W	2
73-74	Quad Cities 1 & 2	3.21E-04	6.40E-02	2.05E-05	BWR	2
75	River Bend	1.80E-04	5.20E-02	9.36E-06	BWR	1
76	Robinson 2	3.72E-03	9.75E-02	3.63E-04	W	1
77-78	Saint Lucie 1 & 2	5.21E-05	5.04E-02	2.63E-06	CE	2
79-80	Salem 1 & 2	3.67E-04	5.72E-02	2.10E-05	W	2
81	Seabrook	1.11E-03	1.29E-01	1.44E-04	W	1
82-83	Sequoyah 1 & 2	2.39E-04	2.42E-02	5.79E-06	W	2
84	Shearon Harris	3.31E-04	3.38E-02	1.12E-05	W	1
85-86	South Texas 1 & 2	4.36E-04	2.67E-02	1.16E-05	W	2
87-88	Surry 1 & 2	4.36E-04	2.67E-02	1.16E-05	W	2
89-90	Susquehanna 1 & 2	2.17E-04	6.34E-02	1.38E-05	BWR	2
91	TMI-1	4.60E-04	8.52E-02	3.92E-05	B&W	1
92-93	Turkey Point 3 & 4	2.65E-05	5.50E-02	1.46E-06	W	2
94	V.C. Summer	1.44E-03	7.80E-02	1.12E-04	W	1
95-96	Vogtle 1 & 2	4.04E-03	1.07E-01	4.34E-04	W	2
97	Waterford	2.47E-04	4.29E-02	1.06E-05	CE	1
98-99	Watts Bar 1 & 2	1.56E-03	7.57E-02	1.18E-04	W	2
100	Wolf Creek	1.18E-03	6.09E-02	7.18E-05	W	1
			Average =	**6.72E-05**	**Sum =**	**100**

Note:
Bold numbers in the first column identify the three sites to the West of Rocky Mountains.

Table 2 LOOP Frequency Comparisons - Power Operation

		Mean Frequency	95%	Mean Duration (hrs)	95% Duration
1	Plant-centered	2.23E−03	4.49E−03	1.6	6.2
2	Switchyard-centered	1.41E−02	3.40E−02	3.2	12.3
3	Grid-related	1.17E−02	5.39E−02	4.1	14.4
4	Severe-weather-related	5.08E−03	2.61E−02	31.9	111.9
5	Seismically-induced	6.72E-05			

Table 3 LOOP Frequency Comparisons - Shutdown Operation

		Mean Frequency	95%	Mean Duration (hrs)	95% Duration
1	Plant-centered	4.88E−02	1.47E−01	1.6	6.2
2	Switchyard-centered	7.02E−02	2.70E−01	3.2	12.3
3	Grid-related	1.17E−02	2.09E−02	4.1	14.4
4	Severe-weather-related	3.76E−02	1.92E−01	31.9	111.9
5	Seismically-induced	6.72E-05			

Source = INL/EXT-15-34443, February 2015

Attachment A - Calculations

This attachment documents the calculational details of the frequencies of seismically-Induced LOOP events given in the main body of the Appendix.

A-1 Input-1: Seismic Event Frequencies

The seismic event frequencies for all 61 U.S. nuclear power plants are obtained from licensees' submittals as part of the effort to address Near-Term Task Force (NTTF) Recommendation 2.1 in 2014 and 2015. The submittals are available at the following NRC SharePoint site:

http://epm.nrc.gov/environmental/jlltg/Seismic/Forms/AllItems.aspx?RootFolder=%2Fenvironmental%2Fjlltg%2FSeismic%2FSeismic%202%2E1%20Reeval%2FSeismic%202%2E1%20Site%20Specific%2F01%20Seismic%20Reevaluation%2FFull%20Seismic%20Hazard%20Submittals

A-2 Input-2: SSC Fragilities leading to LOOP

Generally, the ceramic insulators with the lowest fragilities among the SSCs modeled in the PRAs govern the occurrence of LOOP following a seismic event. The generic fragility data for ceramic insulators is taken from NUREG-6544 (April 1998) as shown in Table A-1. The mean failure probabilities at different g-level earthquakes are calculated by using the equation:

$P_{fail}(a) = \Phi\ [\ \ln(a/a_m)\ /\ \mathrm{sqrt}(\beta_r^2 + \beta_u^2)]$

Where Φ is the standard normal cumulative distribution function and

a = median acceleration level of the seismic event;
a_m = median of the component fragility (or median capacity);
β_r = logarithmic standard deviation representing random uncertainty;
β_u = logarithmic standard deviation representing systematic or modeling uncertainty.

Fragilities of SSCs that would cause LOOP for the plants west of the Rocky Mountains can also be calculated by using the information taken from the plant-specific Individual Plant Examination of External Events (IPEEE).

Table A-1 contains the 4 types of SSC seismic fragilities used for calculating the conditional LOOP probabilities, given the occurrence of a seismic event at a certain g level. An example of these probabilities for a plant is given in the column named LOOP Probability in Table A-2

A-3 Calculation of LOOP Frequency

Once the initiating event frequencies at different g levels and their corresponding conditional LOOP probabilities are known, the frequency of seismically-induced LOOP event can be calculated as a weighted average of frequencies at different g intervals. A sample calculation is shown in Table A-2.

A-4 Summary of Results

Table 1 of Appendix 1 provides the summary of these information for all 61 U.S. nuclear power plants:

1. Seismic initiating event frequencies
2. Conditional probability of LOOP given seismic event
3. Frequency of seismically-induced LOOP event

The calculations can be readily customized for plant-specific SSC fragilities and/or hazard curves.

The seismically-induced LOOP frequency calculations for all 61 U.S. nuclear power plants are performed in a MS EXCEL workbook, which can be found with ADAMS Accession No. ML11220A195 as well as in the RASP Tool Box website.

Table A-1 Fragilities of SSCs causing seismically-induced LOOP

	median capacity	β_r	β_u	HCLPF	
Generic Ceramic Insulators	0.3	0.3	0.45	0.1	used for all sites except those West of the Rocky Mountains
Switchyard Fragility	0.31	0.25	0.43	0.1	Columbia
Offsite Power	1.40	0.2200	0.2	0.7	Diablo Canyon
Generic Ceramic Insulators	0.3	0.3	0.45	0.1	Palo Verde

Table A-2 Clinton SI-LOOP Calculation Using NTTF 2.1 Data

	PGA[g]	Mean Frequency per year	LOOP Probability at g	SE g interval - begin	SE g interval - end	Interval IEV Frequency	Interval Conditional LOOP Probability	Weighted Average
	a	**H(a)**						
1	0.0005	9.59E-02	1.40E-32					
2	0.001	8.14E-02	2.64E-26					
3	0.005	3.38E-02	1.86E-14					
4	0.01	1.87E-02	1.60E-10					
5	0.015	1.24E-02	1.52E-08					
6	0.03	5.15E-03	1.03E-05					
7	0.05	2.20E-03	4.62E-04	0.050	0.075	1.21E-03	1.55E-03	1.87E-06
8	0.075	9.94E-04	5.18E-03	0.075	0.10	4.54E-04	1.05E-02	4.75E-06
9	0.1	5.40E-04	2.11E-02	0.100	0.15	3.24E-04	4.59E-02	1.49E-05
10	0.15	2.16E-04	1.00E-01	0.150	0.30	1.75E-04	2.24E-01	3.92E-05
11	0.3	4.09E-05	5.00E-01	0.300	0.50	2.97E-05	6.43E-01	1.91E-05
12	0.5	1.12E-05	8.28E-01	0.500	0.75	7.49E-06	8.89E-01	6.66E-06
13	0.75	3.71E-06	9.55E-01	0.750	1.00	2.10E-06	9.71E-01	2.04E-06
14	1	1.61E-06	9.87E-01	1.000	1.50	1.15E-06	9.93E-01	1.14E-06
15	1.5	4.61E-07	9.99E-01	1.500	3.00	4.18E-07	9.99E-01	4.18E-07
16	3	4.30E-08	1.00E+00	3.000	5.00	3.71E-08	1.00E+00	3.71E-08
17	5	5.92E-09	1.00E+00	5.000	7.50	4.90E-09	1.00E+00	4.90E-09
18	7.5	1.02E-09	1.00E+00	7.500	10.00	7.55E-10	1.00E+00	7.55E-10
19	10	2.65E-10	1.00E+00	> 10		2.65E-10	1.00E+00	2.65E-10
				Sum =		2.20E-03		9.01E-05

Summary of Results Overall Seismic LOOP frequency for events with PGA >0.05g	
Seismic Event Frequency =	2.20E-03
Seismically induced LOOP probability =	4.09E-02
Seismically induced LOOP frequency =	9.01E-05