19I Seismic Margins Analysis

19I.1 Introduction

A seismic margins analysis (SMA) has been conducted for the ABWR using a modification of the Fragility Analysis method of Reference 19I-1 to calculate high confidence low probability of failure (HCLPF) accelerations for important accident sequences and accident classes. HCLPF values were calculated for components and structures using the relationship

$$\mathrm{HCLPF} = A_m * \exp(-2.326 * \beta_c)$$

where:

A_m = the median peak ground acceleration corresponding to 50% failure probability,

β_c = the logarithmic standard deviation of the component or structure fragility.

The resulting HCLPF acceleration corresponds essentially to the 95th percent confidence level that at that acceleration the failure probability of a particular structure or component is less than 0.05 (5%). HCLPFs for accident sequences were evaluated through use of event trees, and seismic system analysis was performed with fault trees to determine HCLPFs of systems.

The seismic margins analysis evaluates the capability of the plant and equipment to withstand a large earthquake of 2 times the safe shutdown earthquake (2*SSE). In this analysis, two alternative methods were used to evaluate the seismic accident sequences—a “convolution” method and a “min-max” method.

In the convolution method, accident sequences are evaluated by combining input fragility curves according to the Boolean expression for each sequence. Seismic and random/human failure probabilities are calculated and combined (convolved) for discrete intervals of ground acceleration, and then integrated over the range of interest.

In the min-max method, input fragilities are combined by using the lowest (minimum) HCLPF value of a group of inputs operating in an OR logic, and by using the highest (maximum) HCLPF value of a group of inputs operating in an AND logic. Random/human failure probabilities are reported in combination with HCLPFs for each accident sequence.

Analysis of the effects beyond core damage (Level 2 PRA analysis) was not a part of this seismic margins analysis. However, event trees were constructed to examine the possibility of loss of containment isolation resulting in a large release given the earthquake and a resulting core damaging accident.

Because of the inclusion of a rupture disk in the ABWR design as an ultimate means of containment heat removal, and because an earthquake would not prevent rupture of the disk, failure of containment heat removal is not modeled in the seismic margins analysis. (There are no Class II sequences in the analysis.) There are two valves in line with the rupture disk; however, these valves are left in an open position, and the earthquake would not cause these valves to close.

19I.2 Component and Structure Fragility - A_M, $ß_C$

Component and structure fragility values have been established for selected structures and components that have been identified as potentially important to the seismic margins analysis. For more information regarding the development of these fragilities and capacities, refer to Appendix 19H.

19I.3 Event Tree Analysis

The event trees used in the ABWR Level 1 seismic margins analysis were Seismic Support State, Loss of Off-site Power (LOOP) with Scram, and ATWS with LOOP. The individual paths through the event trees represent the accident sequences which are input to the HCLPF analysis.

The event trees show large random failure probabilities and min-max HCLPFs for each top event. Human error probabilities are included in the random failure probabilities.

19I.3.1 Support State Event Tree

The seismic support state event tree starts with the spectrum of seismic events, considers whether or not there is a structural failure (node SI), whether or not offsite power is lost (node LOP) and continues from there. Because of the ground rules of the analysis and the relative values of seismic fragilities, loss of structural integrity results in core damage, and survival of offsite power results in successful event termination. Thus, all remaining accident sequences are for cases of no structural failure, but always with loss of offsite power.

The success or failure of emergency DC power (station batteries) (node DP), and the emergency AC power and/or service water (node APW) are taken into consideration to account for support system dependencies. Failure of all DC power results in a high-pressure core melt since all control is lost, the high-pressure systems fail, and the reactor cannot be depressurized. The condition of successful emergency DC and AC power and successful scram is included in the LOOP with scram evaluation. The condition of successful emergency DC and AC power, but with failure to scram is considered by the ATWS event tree.

For successful emergency DC and failure of emergency AC, the next question is whether or not there is a failure to scram. Failure to scram is considered as a Class IV core melt. With successful scram, RCIC and firewater are the only available means of water injection into the RPV since all AC power is lost. Since station batteries will eventually discharge resulting in loss of RCIC, or if RCIC fails, the reactor must then be depressurized to allow firewater injection. The loss of emergency DC power (station batteries) results in a high-pressure core melt.

The firewater system has a diesel driven pump and all needed valves can be accessed and operated manually. No support systems are required for firewater operation. See Subsection 19.9.21 for COL license information pertaining to housing of ACIWA equipment. The random failure probability of firewater is dominated by operator failure to initiate the system. Where RCIC is successful, the operator has 8 hours before the station batteries expire and RCIC trips. The human error probability (HEP) for this case is very small. Where RCIC fails, the operator has only 30 minutes in which to depressurize the reactor and initiate firewater injection. For this case, the HEP is moderate. In the event that the firewater diesel fails to start, the operator could make use of a fire truck, but this was not modeled.

If the RHR heat exchanger fails (node HX) due to the earthquake, it is presumed that the failure could include a pipe break that could partially drain the suppression pool into the RHR pump room. Fission product scrubbing would still be effective in preventing a large release. The effects of possible flooding on equipment operation beyond the RHR room were considered and found to be relatively insignificant because of the relatively high HCLPF of the heat exchangers, the ability of the operator to isolate the break, and the presence of the independent ACIWA (firewater) system.

19I.3.2 LOOP with Emergency Power and Scram Event Tree

If there is a stuck-open valve, the reactor will eventually depressurize causing loss of RCIC steam supply. The probability of having a stuck-open valve is based on operating experience. If both high-pressure injection systems fail, the reactor must be depressurized rapidly for low-pressure system use.

19I.3.3 ATWS Event Tree

ATWS represents failure to scram, and requires standby liquid control (automatic) and operator action to control reactor water level with the injection system(s) that are available. The HEP for this action is small. In this ATWS analysis, if high-pressure systems fail, core damage results. No credit is given to low-pressure injection. For an ATWS, the probability of a stuck-open SRV was conservatively increased on the basis of increased SRV activity.

19I.4 System Analysis

The seismic system analysis calculates the probability of seismic failure and corresponding system HCLPFs of each of the important systems throughout the seismic ground acceleration spectrum. The system HCLPFs are then input to the event trees and combined with random system failure probabilities and human errors. The seismic fault trees contain only those components that might be subject to seismic failure. Random system failure probabilities are taken from the internal events analysis and include all other components. One of the important ground rules of the seismic margins analysis is that all like components in a system always fail together.

The reactor protection system, control rod drive system, and alternate rod insertion system were not modeled since the failure of control rods to insert is dominated by the relatively low seismic fragility of the fuel assemblies, control rod guide tubes, and housings. The fuel assemblies are the most fragile component.

Failure of the standby liquid control system is dominated by failure of two components: the pump and boron supply tank.

Since the most fragile essential component in the plant is the ceramic insulator in the switchyard, the loss of offsite power dominates the analysis and the availability of emergency power becomes very important. The more fragile AC components are the diesel generator, transformers, motor control centers, inverter and circuit breaker. The DC power fault tree has two elements: batteries and cable tray.

Systems and equipment which require offsite power, such as the feedwater system and condensate injection system, are not modeled since offsite power is presumed to be not available for the core damage sequences.

Essential service water is as important as emergency power, and its loss would have much the same effect as the loss of emergency AC power. The more fragile components in this system are the service water pump, heat exchanger, and room air conditioning unit. The service water pump house is also included in this fault tree.

In this analysis, any one or more of the structural failures that could contribute to seismic core damage are conservatively presumed to result in core damage. The structures having the lowest seismic capacity are the reactor building and control building.

The more fragile components in the core cooling systems are the pumps, heat exchangers, and the firewater supply tank. The condensate storage tank (CST) is not modeled since the ECCS systems that take suction from the CST have automatic switchover to the suppression pool if CST level is low. Valves for the switchover are included in the fault trees.

The ACIWA (firewater) system is designed to inject water into the reactor if the ECCS systems are not available. It is also the only means of water injection in case of a station blackout beyond 8 hours. Although firewater is not a Class 1E safety system, because of the safety function described above, the firewater diesel-driven pump, the firewater tank, valves, and related piping will have seismic margin above the SSE.

Because of the importance of RCIC in station blackout sequences, differences between the seismic RCIC fault tree and the internal events fault tree are explained below:

(1) The internal events fault tree contains basic events that would not be affected by an earthquake, e.g., test and maintenance unavailability. These events contribute to the random failure probability during the seismic event and are included in the random failure part of the seismic analysis. They are deleted from the RCIC seismic fault tree.

(2) The internal events fault tree contains common-cause failure events. These are deleted from the RCIC seismic fault tree since a basic rule of the seismic analysis is that all like components within a system fail together.

(3) The internal events RCIC fault tree contains separate events for the turbine and for the pump. The seismic fault tree uses a combined event, “turbine-driven pump”, since that is the assembly for which there is a seismic capacity.

19I.5 Accident Sequence HCLPF Analysis

Seismic fragility of a structure or component is defined as the conditional probability of its failure as a function of peak ground acceleration. The probability model adopted for each component fragility is the log-normal distribution. The density function for the component fragility, f(g), can be written

$$f(g) = \frac{1}{\sqrt{2\pi}*\beta_c*g}\exp\left(-\frac{1}{2}\left[\frac{\ln\left(\frac{g}{A_m}\right)}{\beta_c}\right]^2\right) \text{for} g > 0$$

where:

A_m = median capacity of the component,

β_c = logarithmic standard deviation of the fragility function,

g = peak ground acceleration.

The cumulative distribution of the component fragility, F(g), will then be

$$F(g) = \int_0^g \frac{1}{\sqrt{2\Pi}*\beta_c*g_1}\exp\left\{-\frac{1}{2}\left[\frac{\ln\left(\frac{g_1}{A_m}\right)}{\beta_c}\right]^2\right\}dg_1$$

19I.5.1 Convolution Analysis

If a system, S, (or sequence) contains two components (A, B) operating in OR logic, the failure of either component will fail the system (S = A + B), and the cumulative fragility distribution of the system is one minus the product of their complementary cumulative fragility distributions:

$$F_s(g) = 1-(1-F_A(g))*(1-F_B(g))$$

On the other hand, if two elements operate in AND logic, only the failure of both components will fail the system (S = A * B), and the cumulative fragility distribution of the system is the product of their cumulative fragility distributions:

$$F_s(g) = F_A(g)*F_B(g)$$

Using the two principles above, the distribution function of each system fragility is obtained by combining its component fragility functions based on its Boolean expression derived from the system fault tree.

Then the OR logic methodology is used to convolve the seismic and random/human failure probability of the systems. The combined cumulative fragility distribution of a system, $F_c(g)$, is the OR logic combination of the cumulative seismic fragility distribution, $F_s(g)$, and the cumulative random/human failure distribution, F_r, as follows:

$$F_c(g) = 1-(1-F_s(g))*(1-F_r)$$

Similarly, the distribution for each accident sequence is derived from the combined system fragility functions by using the Boolean expression obtained from the seismic accident sequence event trees. The fifth and fiftieth percentiles of the combined cumulative distribution of each accident sequence are used to obtain the A_m and β_c for the corresponding sequence. Then, the HCLPF of each accident sequence is obtained by using the formula presented in Subsection 19I.1 as follows:

$$HCLPF = A_m*\exp(-2.326*\beta_c)$$

where the parameters A_m and β_c are the median capacity and logarithmic standard deviation of the lognormal distribution of the accident sequence.

19I.5.2 Min-Max Analysis

If a system, S, (or sequence) contains two components (A,B) operating in OR logic, the failure of any component will fail the system (S = A + B), and the cumulative fragility distribution of the system is governed by the fragility distribution of the weakest component. This principle is applied to the system fault trees, which generally are made up of OR gates.

If two elements operate in AND logic, only the failure of both components will fail the system (S = A * B), and the cumulative fragility distribution of the system is governed by the fragility distribution of the strongest component. This principle is applied to accident sequences, which are composed of ANDed elements.

Significant random/human failure probabilities are combined with HCLPFs for elements in an accident sequence as follows:

$(\mathrm{HCLPF1} + \mathrm{RHP1})*(\mathrm{HCLPF2} + \mathrm{RHP2}) =$

HCLPF1*HCLPF2,

HCLPF1*RHP2,

HCLPF2*RHP1,

RHP1*RHP2,

where:

HCLPF1 = the HCLPF of one event,

RHP1 = the random/human failure probability of that event,

HCLPF2 = the HCLPF of a second event, and

RHP2 = the random/human failure probability of the second event.

The resulting combinations are reduced according to min-max rules.

19I.6 Results of the Analyses

The results of the convolution analysis are that the HCLPF values for all accident sequences are greater than 0.60g, which is twice the safe shutdown earthquake (SSE) of 0.30g.

For the accident sequences obtained from the min-max analysis, no accident sequence has a HCLPF lower than 0.60g.

For most accident sequences, the min-max method of analysis provided lower (more conservative) HCLPF values. However, the use of either method of analysis produced HCLPFs greater than twice the safe shutdown earthquake for all potential accident sequences.

19I.7 Containment Isolation and Bypass Analysis

In the seismic margins analysis there were no cutsets leading to core damage with low HCLPF values. A supplemental analysis was conducted to evaluate the HCLPF values for containment isolation for events that could cause containment bypass as a result of an earthquake, with potential for large releases to the environment.

Based on the results of the bypass analysis discussed in Subsection 19E.2.3.3, the events selected for evaluation in this analysis are:

(1) Main steam lines

(2) Feedwater or SLC injection lines

(3) Reactor instrument, CUW instrument, LDS instrument/sample or containment atmosphere monitoring lines

(4) RCIC steam supply or CUW suction lines

(5) Post accident sampling lines

(6) Drywell sump drain line

(7) SRV discharge lines

(8) ECCS lines

(9) Drywell inerting/purge lines

(10) Wetwell/drywell vacuum breaker lines

The bypass paths for atmospheric control system crosstie lines are protected by air operated valves. The seismic-induced bypass analysis for these lines is the same as that described for the drywell inerting/purge lines.

In the bypass analysis of Subsection 19E.2.3.3, several potential bypass pathways were excluded from detailed analysis on the basis of various reasons. The reasons are discussed in Subsection 19E.2.3.3.2 and Table 19E.2-1. These reasons were reviewed to determine whether they remain valid in regard to seismic events. All but one of the reasons are based on configuration details that would not be affected by an earthquake. RHR wetwell and drywell spray lines were excluded on the basis that the pipes are designed for higher internal pressures than will be seen in actual operation and would thus have a very low probability of breaking. In this case, the seismic event could increase the probability of a break in these lines. However, these pipes have very high seismic capacity with very low probability of breaking due to a seismic event.

An event tree was constructed for each of the above events. All event trees start with the earthquake as the initiating event followed by a core-damaging accident. If there is no core damage there is no large release. The HCLPF and random failure probability are shown for each branch point, and the sequence HCLPFs using convolution and min-max methods are also shown on the figures.

For suppression pool bypass via main steam lines following the earthquake and accident, the question is asked whether or not there is a break in a main steam line outside containment. If there is a break, the question is asked whether or not at least one MSIV in each steam line closes to isolate the break. For the case where there is no break, there could still be a bypass release to the main condenser if a turbine bypass valve is open—unless the MSIVs are closed to isolate the break.

Regarding bypass via feedwater or standby liquid control lines, these lines inject into the RPV and are protected from reverse flow by redundant check valves. These check valves provide isolation of upstream breaks provided that one of the valves closes in the line with the break.

For bypass via reactor instrument, CUW instrument, LDS instrument, LDS sample or containment atmosphere monitoring lines, these lines are also protected by check valves, a single valve in each line.

For bypass via either the RCIC steam supply line or the CUW suction line, both of these lines are protected by motor operated isolation valves which require power. Since offsite power is lost due to the earthquake, emergency power is required.

For bypass via the post accident sampling lines, these lines are also isolated by motor operated valves.

For bypass via the drywell sump drain line, this line is protected by a motor operated isolation valve and a check valve.

For bypass via the SRV discharge lines, if there is a break in an SRV discharge line during a core-damaging accident, and that SRV is open, a bypass pathway will exist. In this analysis, it is assumed that the SRV will be open during the accident.

For bypass via any of the ECCS lines, the lines of concern are the HPCF and LPFL warm-up and discharge lines. These lines are protected by motor operated isolation valves and check valves.

For bypass via drywell inerting/purge lines, these lines are protected by air operated valves.

Bypass via wetwell/drywell vacuum breaker lines requires an inadvertent opening of a vacuum breaker (check valve) to initiate a bypass during a severe accident.

19I.8 References

19I-1 R.P. Kennedy, et al., "Assessment of Seismic Margin Calculation Methods", NUREG/CR-5270, Lawrence Livermore National Laboratory, March 1989.

The following tables are not used in the DCD:

Tables 19I-1 through 19I-4

The following figures are not used in the DCD:

Figures 19I-1 through 19I-25