19.55 Seismic Margin Analysis

19.55.1 Introduction

In accordance with Section II.N, Site-Specific Probabilistic Risk Assessments and Analysis of External Events, of SECY-93-087 (Reference 19.55-1), the U.S. Nuclear Regulatory Commission (NRC) approved the following staff recommendations:

> "PRA insights will be used to support a margins-type assessment of seismic events. A PRA-based seismic margin analysis will consider sequence-level High Confidence, Low Probability of Failures (HCLPFs) and fragilities for all sequences leading to core damage or containment failures up to approximately one and two-thirds the ground motion acceleration of the Design Basis SSE."

The PRA based seismic margin analysis (SMA) and the methodology described in this section is consistent with the recommendation of SECY-93-087.

Seismic margins methodology is employed to identify potential vulnerabilities and demonstrate seismic margin beyond the design-level safe shutdown earthquake (SSE). The capacity of those components required to bring the plant to a safe, stable condition is assessed. The structures, systems, and components identified as important to seismic risk are addressed. For this PRA-based seismic margin analysis, HCLPFs are calculated and reported at the sequence level. In addition, insights related to random and/or human failures are reported, as deemed appropriate, for each sequence.

19.55.2 Calculation of HCLPF Values

19.55.2.1 Seismic Margin HCLPF Methodology

The seismic margin analysis is based on established criteria, design specifications, existing qualification test reports, established basic design characteristics and configurations, and public domain generic data.

The seismic margin assessment is used to demonstrate margin over the SSE of 0.3g. Consistent with SECY-93-087 (Reference 19.55-1), the goal of the SMA is therefore to demonstrate that the plant HCLPF is at least 0.5g peak ground acceleration (pga). This is also called the review level earthquake (RLE). The AP1000 seismic response spectra are included in Tier 1, Chapter 5 (see Tier 1, Figures 5.0-1 through 5.0-4). It will be necessary for a COL (combined operating license) applicant to demonstrate that the seismic response for the applicant's plant is equal to or less than that used in the calculation of the HCLPF values, and to evaluate the potential for soil liquefaction using the applicant's site specific conditions. This will ensure a reserve margin that exceeds a 0.5g seismic level.

19.55.2.2 Calculation of HCLPF Values

A seismic margin analysis is made up of two major tasks:

1. A PRA-based model to determine the plant HCLPF
2. Determination of the plant structure and component HCLPFs

The second task, determination of HCLPF seismic acceleration values for plant structures and components, is discussed in this section; the PRA-based model is herein discussed as far as the seismic event trees and major assumptions associated with seismic fault trees development are concerned. The HCLPF values used in the analysis, which now include HCLPF values for hard-rock, high-frequency sites and soil sites, are summarized in Table 19.55-1.

19.55.2.2.1 Review of Plant Information

The assessment uses the following plant information:

- Structural and seismic design criteria and procedures
- Structural design calculations
- Layout and design drawings
- Test reports
- Piping and instrumentation diagrams
- Equipment design specifications
- Generic fragility data
- AP1000 plant response spectra.

19.55.2.2.2 System Analysis

Section 7.4 of the AP1000 Design Control Document provides a discussion of the systems required for safe shutdown. The structures and components associated with these systems are considered in the seismic margin assessment. It is noted that the same success criteria as in the AP1000 PRA sensitivity case where no credit is taken for non-safety related systems, is used as the starting point for the AP1000 PRA-based seismic margins analysis. This success criterion is not necessarily defined in terms of reaching specific plant modes, but rather on reaching a sustainable safe plant state. The bases for these success criteria are given in the AP1000 PRA report (Reference 19.55-5).

19.55.2.2.3 Analysis of Structure Response

The purpose of a seismic fragility analysis is to define the maximum limit, seismic capacity, of functional capability or operability with the associated uncertainty for plant components and structures that could have an effect on safe shutdown of the plant following a seismic event. Capacity in the seismic margin assessment, expressed in terms of the free field peak ground level acceleration, is the level of the seismic event that results in failure of a given component or structure to perform its safety-related function. Failures leading to loss of safety function could result from such things as: loss of a pressure boundary; significant inelastic deformation; partial collapse; loss of support functions; or a combination of failure modes. In the calculation of the

HCLPF value for a system, structure, or component, the governing failure mode is established by examining the different potential failure modes possible. Each failure mode has different reserve margin. As an example, ductility may be very large for tension failure, whereas, for buckling, ductility generally does not contribute to reserve margin.

A fragility evaluation is made for the key structures and components. The HCLPF for the equipment and structures is established using one of the following:

- Probabilistic fragility analysis
- Conservative deterministic failure margin (CDFM) method
- Test results
- Deterministic approach
- Generic fragility data

These methods are briefly discussed below.

Probabilistic Fragility Analysis

This method is used to define HCLPF values for structures such as:

- Steam generator supports
- Reactor pressure vessel supports
- Pressurizer supports
- Containment vessel

There are many sources of conservatism and variability in the estimation of seismic peak ground acceleration capacity for seismic margin assessment. HCLPF values reflective of the seismic capacity are derived from median capacity using formulas based on the log-normal distribution. The HCLPF values reflect a 95-percent confidence (probability) of not exceeding a 5-percent probability of failure (Reference 19.55-2).

The HCLPF is defined by a lognormal probability distribution that is a function of median seismic capacity and composite standard deviation, βc:

$$\text{HCLPF} = \text{Median Capacity x } e^{[-2.3 \text{ x } \beta c]}$$

The median seismic capacity is related to the mean seismic capacity by the expression:

$$\text{Median Capacity} = \text{Mean Capacity x } e^{[-(\beta c\text{^}2)/2]}$$

The mean peak seismic ground capacity, A_m, is related to the stress and strength design margin factors by the following expression:

$$A_m = (\Pi_i \, [X_i] \,)A_o$$

where:

A_m = Mean peak seismic ground capacity
X_i = i^{th} design mean margin factor
Π_i = Product notation
A_o = Nominal seismic peak ground capacity

It is noted that the composite standard deviation is equal to the root mean square of the composite standard deviation associated with each of the margin factors. That is:

$$\beta_c = \sqrt{[\Sigma_i \ (\beta_c)_i^2]}$$

The conservatisms and variability identified and considered in this assessment are associated with stress and strength margin factors. The basic grouping of margin factors are: deterministic strength factor; variable strength factors; material; damping; inelastic energy absorption, ductility; and analysis or modeling error.

Conservative Deterministic Failure Margin Method

The HCLPF values for the shield building and the exterior walls of the Auxiliary Building were calculated using the conservative deterministic failure margin approach. A finite element analysis was performed of the structures that considered cracking of the concrete and redistribution of the loads. Deterministic margin factors were defined for three items: strength; inelastic energy absorption; and damping.

The polar crane HCLPF is calculated using the Westinghouse's design specification of Polar Crane and the vendor structural qualification calculation. The CDFM approach is used allowing the stress to reach yield and using a ductility factor of 1.25.

In addition, the HCLPF values for the Reactor Coolant Pump external heat exchanger and for the Passive Containment Cooling System are calculated with the CDFM approach.

Test Results

For the electrical equipment where documented test results are available, the HCLPF value is defined from comparison of required response spectra (RRS) and test response spectra (TRS). The method employed follows a deterministic approach using existing test data for similar types of equipment.

The existing test data was reviewed to determine a lower bound seismic capacity.

When the natural frequency of the equipment is not known, it was assumed that the natural frequency coincided with the required response spectra peak acceleration so that the lowest HCLPF value was calculated. It is noted that where equipment frequencies are known, and are used for comparing the RRS and TRS, these frequencies will be included in the design specification for the equipment to assure that the dynamic characteristics are the same as those expected.

Relay Chatter

Solid-state switching devices and electro-mechanical relays will be used in the AP1000 protection and control systems. Solid-state switching devices are inherently immune to mechanical switching discontinuities such as contact chatter. Robust electro-mechanical relays are selected for AP1000 applications such that inherent mechanical contact chatter is within the required system performance criteria. Therefore, contact chatter has no effect on system operation and was, therefore, not included in the seismic margin analysis. The COL must confirm the use of seismically robust electro-mechanical relays in the engineered safety features actuation and control systems.

Moreover, the loss of offsite power event has a very low HCLPF value (0.09g). The control rod motor generator sets are powered by AC load centers that are de-energized on loss of offsite power sources. When the control rod motor generator sets are de-energized, current to the magnetic jack mechanisms stops and the gripper coils open, allowing the rods to drop into the core. Therefore, relay chatter is not an issue for reactor trip.

Finally, passive residual heat removal (PRHR) and core makeup tank (CMT) system valves automatically fail open upon loss of instrument air due to loss of seismically induced loss of offsite power. Thus, relay chatter is not an issue for PRHR and CMT system functions.

Deterministic Approach

A lower bound estimate of the HCLPF is obtained for selected structures or equipment based on margin to design limit for the appropriate load combination defined by the fault tree logic. Where applicable, the increased capacity due to inelastic energy absorption is defined using the recognized and recommended ductility factor of 1.25.

This approach was used for the primary components to verify that their supports would control the HCLPF value. It was also used for a few cases to define the HCLPF when it was apparent that its seismic capacity would not control the plant HCLPF value. This approach was used for: containment baffle plate supports; Interior Containment Structure and IRWST; PRHR heat exchanger; core makeup tank; and valves.

Generic Fragility Data

Generic fragility data was used when insufficient information was available to define the HCLPF value using one of the methods described above. Those cases where this approach was use were:

- Reactor internals and core assembly that includes fuel
- Control rod drive mechanism (CRDM)
- Reactor coolant pump
- Accumulator tank
- Piping
- Cable trays
- Valves
- Ceramic insulators

The Utility Requirements Document for Advanced Light Water Reactor, Reference 19.55-3, was used for all of the components listed above except ceramic insulators, which used recognized industry low seismic capacity data.

19.55.2.2.4 Evaluation of Seismic Capacities of Components and Plant

Table 19.55-1 provides the HCLPF values for the equipment, structures, and systems considered in the seismic margin evaluation. Also shown in this table is the approach used to define the HCLPF value, as described in subsection 19.55.2.2.3. The evaluation considers the effect of uplift and sliding of the nuclear island basemat foundation. The nuclear island seismic response has been evaluated at 1.1 times the Review Level Earthquake (RLE) and was found to retain its stability against sliding and overturning.

In the design of the AP1000, careful consideration is given to those areas that are recognized as important to plant seismic risk. In addition to paying special attention to those critical components that have HCLPF values close to the review level earthquake, the design process considers potential interaction with both safety-related and nonsafety-related systems or structures, as well as adequate anchorage load transfer and structural ductility. The seismic margin evaluation provides a means of identifying specific equipment and/or structures that are vulnerable to beyond design basis seismic events.

Equipment qualification is the generation and maintenance of evidence to ensure that safety systems and equipment will operate on demand to meet system performance requirements during normal/abnormal and accident environmental conditions. The methodology for qualification of safety-related electrical and mechanical equipment is defined in Appendix 3D of the AP1000 DCD and further expanded for seismic high frequency considerations in Appendix 3I. The intent of the qualification process defined in these Appendixes is to ensure a high reliability for equipment and system safety. Qualification by test, analysis or a combination of test and analysis is performed to verify the safety-related electrical and mechanical equipment will operate as intended under normal/abnormal and accident environmental conditions over the installed life. Details on the qualification process are provided to the equipment vendors in specifications and qualification methodology documents during procurement under a 10CFR50 Appendix B quality assurance program.

19.55.2.2.5 Verification of Equipment Fragility Data

The AP1000 safety-related equipment is designed to meet the safe shutdown earthquake requirements defined in Chapter 3 of the AP1000 DCD. This seismic margin evaluation has focused on demonstrating that the design of the nuclear island structures, safety-related equipment, and equipment supports can carry the loads induced by the review level earthquake discussed here. This evaluation incorporates as-specified equipment data. After the plant has been built, it will be necessary to perform a verification of the seismic margin assessment for the installed conditions.

19.55.2.2.6 Turbine Building Seismic Interaction

As part of the seismic margin assessment, the seismic interaction between the turbine building and the nuclear island was evaluated according to guidance provided in Reference 19.55-4. It was determined that:

- To protect the adjacent nuclear island auxiliary building the first bay of the turbine building has been classified as seismic category II.

- It is not likely that the size and energy of debris from the turbine building will be large enough to result in penetration through the auxiliary building roof structure.

Even though it is not likely that penetration of turbine building debris could be large enough or have sufficient energy for penetration through the auxiliary building roof structure, this event was evaluated. The consequences of damage to the safety-related equipment in the auxiliary building were investigated. It was determined from this investigation that should an event occur that causes the failure of equipment in the upper elevations of the auxiliary building, the results of the seismic margin assessment, the plant HCLPF value, and the insights derived from the seismic margin assessment are not affected. Moreover, the steam line break events, which would result from the damage of equipment in the upper elevations, are not dominant contributors to the core damage frequency. Further, the loss of equipment in the upper elevations will not affect the passive safety systems that would be used to put the plant in a safe shutdown condition should an event occur.

19.55.3 Seismic Margin Model

In this section, the AP1000 Risk-Based Seismic Margins Model is summarized and the plant HCLPF for AP1000 is determined.

HCLPFs are calculated for the seismic Category I safety-related systems that are called upon via the seismic event trees to mitigate an accident caused by the initiating seismic event.

19.55.3.1 Major SMA Model Assumptions

In this section, the general characteristics and major assumptions of the AP1000 SMA model are discussed.

1. The seismic event is assumed to occur while the plant is operating at full power.

2. A review level earthquake equal to 0.5g is used for the seismic margin analysis.

3. It is assumed that the seismic event would result in loss of offsite power since the AC power equipment is not seismic Category I. (The offsite insulators on the feed lines from the offsite power grid fail such that a loss of offsite power occurs.) No credit is taken for onsite emergency AC power (diesel generators).

4. No credit is taken for non-safety related systems. They are assumed to have failed or be non-functional due to the seismic event. This includes all equipment in the turbine building and

the turbine building itself; as discussed in Section 19.55.3.3, structural failure of the turbine building is assumed not to impact the structural integrity of the adjacent auxiliary building.

5. The seismically induced SMA initiating event categories and their event trees are taken from the AP600 PRA model. For each initiating event, the PRA logical modeling (i.e., seismic event and fault trees) developed for AP600 structures, systems, and components have been used as the starting point and their applicability to the AP1000 design has been assessed and confirmed. The applicability of the base AP600 to the AP1000 has been addressed in a supporting calculation. Cutsets associated with each sequence are generated and then the min-max method is used to calculate the plant HCLPF value.

19.55.3.2 Seismic Initiating Events

The first step in Seismic Margins Model is to evaluate which initiating events could occur as a result of a seismic event. For this purpose, a Seismic Initiating Event Hierarchy Tree is constructed. This event tree is given in Figure 19.55-1 and discussed below. Based on this hierarchy event tree, seismic initiating event categories are defined and their event tree models are constructed (as discussed in subsection 19.55.3.3).

Given that a seismic event occurs, the hierarchy event tree is constructed such that the seismically-induced initiating event with the most challenge to the plant safety systems is considered first: gross structure collapse. This category is labeled as EQ-STRUC and is the first initiating event category to be modeled and quantified.

If gross structure collapse does not occur, next the reactor coolant system (RCS) loss-of-coolant-accident (LOCA) category in excess of emergency core cooling system (ECCS) capacity (also termed as "Vessel Failure") is considered. This category is labeled as EQ-RVFA.

If vessel failure does not occur, then large RCS LOCAs are considered. This category is labeled as EQ-LLOCA.

If EQ-LLOCA does not occur, then small RCS LOCAs are considered. This category is labeled as EQ-SLOCA. Steam generator tube rupture (SGTR) and large secondary line break (SLB) events are folded into the small LOCA category, as discussed in subsection 19.55.3.3.

Next considered is the seismically induced anticipated transient without scram (ATWS) event. This event is labeled as EQ-ATWS.

Finally, all other transients are considered in the category labeled EQ-LOSP. The seismically induced LOSP event occurs at low HCLPF values (e.g., lower than the SSE at 0.3g) and does not affect the plant HCLPF, as discussed in subsection 19.55.4.2. The cutsets for this event are all "mixed cutsets," containing seismically induced initiating event coupled with random failures leading to core damage. This event is included in the model for additional insights and completeness.

Thus, the hierarchy tree defines six initiating event categories. Each of these is discussed and an event tree for each is constructed in subsection 19.55.3.3.

The PRA-based seismic margins analysis does not consider seismic hazard curves. Therefore, initiating event frequencies are not calculated for each seismically generated initiating event category. Although seismically generated initiating event frequencies are not calculated, it is important to evaluate the seismic vulnerability of the components and systems that contribute to the initiating event categories. This is done by estimating a HCLPF for each seismic initiating event category, as discussed in subsection 19.55.3.3.

19.55.3.3 Seismic Event Trees

The six seismically induced initiating event categories defined by the hierarchy event tree model of subsection 19.55.3.2 are further discussed to model seismically induced failures that will determine the HCLPF for each of these initiating events. The six categories considered are:

1.	EQ-STRUC	Gross structural collapse
2.	EQ-RVFA	LOCA in excess of emergency core cooling system capacity
3.	EQ-LLOCA	Large LOCA
4.	EQ-SLOCA	Small LOCA
5.	EQ-ATWS	ATWS
6.	EQ-LOSP	Loss of offsite power

The small LOCA category also covers SGTR and SLB events. As discussed later in the success paths, the SLOCA success path used for SMA is also applicable (conservatively) to the SGTR and unisolated SLB events given that only safety-related systems are credited and considered in the PRA-based SMA.

The last event, LOSP, is postulated at 0.09g. This event may also be viewed to represent a larger family of transients associated with loss of main feedwater, loss of compressed air, turbine trip, reactor trip, loss of service water/component cooling water, etc, following a seismic event and LOSP since no credit is taken for these non-safety systems in the SMA models. Moreover, a seismically induced transient containing LOSP, becomes a station blackout (SBO) event since no credit is taken for diesel generators that are not seismically qualified.

Each of the SMA events are further discussed below.

1. EQ-STRUC (Gross Structural Collapse)

   This event includes seismically induced failures of AP1000 structures that may result in core damage and large fission product release.

   The AP1000 structures are classified in 5 groups:

   1. Nuclear Island

      This consists of the containment, shield building, and auxiliary building.

      Nuclear island is structurally designed to meet seismic Category I.

2. Turbine Building

   The first bay of the turbine building is classified as Seismic Category II, and the remaining bays are designed to meet the uniform building code (UBC). For the SMA model, it is assumed to have failed. Thus no credit is taken for systems in this building.

3. Annex Building

   The high rise portion of the annex building is designed to meet seismic Category II. For the SMA model, it is assumed to have failed. Thus, no credit is taken for systems in this building.

4. Diesel Generator Building

   The diesel generator building is designed to meet the UBC. For the SMA model, it is assumed to have failed. Thus, no credit is taken for systems in this building.

5. Radwaste Building

   The radwaste building is designed to meet the UBC. For the SMA model, it is assumed to have failed. Thus, no credit is taken for systems in this building.

Thus, only the nuclear island is considered for the SMA model; the interaction between the other buildings and the nuclear island is assumed to have no detrimental effect on the nuclear island structures. This assumption needs to be verified by a plant walkdown when an AP1000 plant is built.

The failures of the nuclear island structures are modeled in terms of the driving structures of the steel containment vessel, the shield building, and the auxiliary building.

The EQ-STRUC event tree is shown in Figure 19.55-2; HCLPF value for EQ-STRUC is calculated in Section 19.55.4.

2. EQ-RVFA (LOCA in Excess of ECCS Capacity)

This event represents the "vessel failures" where the event leads to excessive loss of RCS inventory that can not be made up by the ECCS capacity. In this case, core damage is postulated. A complete dependency between seismic induced failures of SSCs that share basic characteristics (i.e., component type, location/elevation, etc.), the "vessel failure" event comprises the following types of structural and component failures:

1. Seismically induced failures of the reactor vessel
2. Seismically induced failures of the steam generators
3. Seismically induced failures of the other RCS components
4. Seismically induced failures of two direct vessel injection (DVI) lines
5. Seismically induced failures of fuel.

The EQ-RVFA event tree is shown in Figure 19.55-3; HCLPF value for EQ-RVFA is calculated in Section 19.55.4.

3. EQ-LLOCA (Large LOCA)

Seismically induced large LOCA initiating event category, EQ-LLOCA, contains RCS breaks with break sizes greater than 9 inches. Since the seismic event failures assume that if one pipe breaks by a seismic event, all redundant similar pipes will break at the same time, all major RCS pipe breaks are conservatively included in this category; thus, no medium LOCA is defined in the initiating event hierarchy tree. Also included in this category are the failures of the PRHR heat exchanger by a seismic event.

The EQ-LLOCA event tree is shown in Figure 19.55-4; HCLPF value for EQ-LLOCA is calculated in Section 19.55.4.

4. EQ-SLOCA (Small LOCA)

Seismically induced small LOCA initiating event category, EQ-SLOCA, contains RCS breaks with break sizes less than 2 inches of equivalent diameter. Since the seismic event failures assume that if one pipe breaks by a seismic event, all redundant similar pipes will break at the same time, all major RCS pipe breaks are conservatively included in the large LOCA category. For the small LOCA category, RCS leaks from instrument lines are used as the representative event. The small LOCA category also includes and bounds events such as

- Steam Generator Tube Rupture (SGTR)
- Large Steam Line Breaks (SLB) (due to generation of SI signal and RCS inventory shrinkage)

For SGTR events, breaks of one or more (up to 5) tubes have been considered for the AP1000 design. An event with 5 steam generator tubes rupturing has an equivalent LOCA break flow area of a 1.46 inch diameter hole. The rupture of more than 5 tubes by a seismic event is conservatively bounded by the structural failure of a steam generator, which is included in the EQ-RVFA initiating event.

Due to the modification of the Reactor Coolant Pump (RCP) Heat Exchanger (HX) from the AP600 design to the AP1000 design, an additional entry is added to the seismic induced Small LOCA. This reflects the possibility that in the event of a RCP HX pipe break, a small LOCA will be induced. Flow from the RCS inventory will be restricted by the labyrinth seal surrounding the RCP motor shaft; tolerances on the labyrinth seal allow for a maximum flow area of $1.389 in^2$. This corresponds to approximately a 1.3 inch pipe break. A postulated seismic induced break of all eight tubes does not change the equivalent break flow rate for each pump and when considering the break in all pumps, a total of approximately 2.7 inch pipe break equivalent LOCA needs to be considered. This is judged to be consistent with the definition of seismically induced small LOCA given above.

The EQ-SLOCA event tree is shown in Figure 19.55-5; HCLPF value for EQ-SLOCA is calculated in Section 19.55.4.

5. EQ-ATWS (Anticipated Transients without Scram)

The EQ-ATWS event addresses the seismically induced ATWS initiating event related to the failure of the core assembly or guide tubes or the control rod drive systems to remain functional so that the rods can not fall into the core. The fuel is still intact and can be cooled. The failure mode associated with seismically induced fuel failure has been already addressed in EQ-RVFA event.

Because offsite power is postulated to have been lost, the control rod motor generator sets would be de-energized even if the reactor trip function failed. If the core assembly or the control rod system failed, the rods are postulated to fail to insert into the core.

The EQ-ATWS event tree is shown in Figure 19.55-6; the HCLPF value for EQ-ATWS is calculated in Section 19.55.4.

6. EQ-LOSP (Loss of Offsite Power)

The EQ-LOSP event addresses the seismically induced loss of offsite power. This event occurs at relatively low intensity earthquakes. The driving failure for loss of offsite power is represented by failure of ceramic insulators in the switchyard. The HCLPF value for these insulators is 0.09g, which is lower than the review level earthquake of 0.5g, and the plant SSE of 0.3g. Such an earthquake does not challenge any of the safety-related systems that are built to withstand the SSE and have margin for higher g levels. Thus, this event does not lead to purely seismically driven failure combinations for a core damage sequence. This event model contains only "mixed cutsets" for core damage; these are failure combinations of seismically induced initiating event coupled with random failures of safety-related systems.

The EQ-LOSP event tree is shown in Figure 19.55-7; this event does not contribute to plant HCLPF.

19.55.3.4 Seismic Fault Trees

System fault trees for mitigation functions have been modified to account for seismically-induced failures. The AP600 system seismic fault trees have been reviewed for applicability to the AP1000 and only limited and minor changes have been deemed necessary.

19.55.4 Calculation of Plant HCLPF

This section presents the SMA calculations based on the model developed in subsection 19.55.3.

The initiating event HCLPFs are calculated in subsection 19.55.4.2. The plant HCLPF is calculated in subsection 19.55.4.3.

The analysis demonstrates that all structures and components required to maintain the plant in a safe stable state are expected to function following a seismic event of 0.5g acceleration.

19.55.4.1 HCLPFs for Basic Events

The HCLPF values for various AP1000 structures and components were determined in a supporting calculation and are given in Table 19.55-1. The basic events defined in the SMA model for seismic failures are assigned their own HCLPF values, as shown in Table 19.55-2. These HCLPF values are taken from Table 19.55-1. When not self-evident, the "Source" column in Table 19.55-2 explains how the information Table 19.55-1 has been used.

For reasons beyond the development of the PRA-based AP1000 SMA, Table 19.55-1 groups all the electrical equipment into two major categories: "Non-Sensitive to High Frequency Excitation" and "Sensitive to High Frequency Excitation". For the purposes of the PRA-based SMA, all electrical equipment has been assumed to be from the limiting categories among the two, which has an HCLPF value of 0.5; this assumption is for the purposes of this analysis only and is conservative for this purpose.

19.55.4.2 Calculation of Initiating Event HCLPFs

Initiating event HCLPFs are calculated by assigning the HCLPF values from Table 19.55-2 to the seismically induced failures modeled in subsection 55.3.3 for initiating events. The HCLPF associated to the initiating events will be the minimum among those for each of the potential initiator; the results of these calculations are given in Tables 19.55-3 through 19.55-7; results are presented for the AP1000 before and after this modification for DCD Revision 17. EQ-IEV-LOSP is already assigned a HCLPF 0.09g, representing the failure of ceramic insulators but it does not contribute to plant HCLPF since it has only mixed cutsets (seismic and random failures combined in cutsets).

The initiating event HCLPFs are summarized below:

Initiating Event	HCLPF	Dominated by
EQ-IEV-STRUC	0.55g	Polar crane
EQ-IEV-RVFA	0.50g	Fuel and pressurizer failure
EQ-IEV-LLOCA	0.81g	RCS piping
EQ-IEV-SLOCA	0.54g	Steam generator tube failure
EQ-IEV-ATWS	0.50g	Core assembly failures
EQ-IEV-LOSP	0.09g	Ceramic insulator failure

When the min-max method is used, the HCLPF of seismic sequences resulting from an initiating event can not be less than the initiating event HCLPF since it appears in every cutset. If the initiating event is postulated to lead directly to core damage, the IE HCLPF is used in the determination of the plant HCLPF.

Since both EQ-STRUC and EQ-RVFA events are postulated to lead to core damage, and EQ-STRUC is postulated to go to large early release as well, plant HCLPF can be determined at this point to be at least 0.50g for core damage and at least 0.55g for large, early release consequences.

19.55.4.3 Calculation of AP1000 Plant HCLPF

The final AP1000 plant HCLPF calculation also considers the mitigation portion of the PRA logic. Even though this is not going to change the values identified in section 19.55.4.2, the complete calculation provides further insights on the seismic margin of the AP1000 design.

All basic events in the AP1000 SMA model (listed in Table 19.55-2) are assigned a dummy probability value of 0.5; the model is then quantified and cutsets are generated. The min-max approach is then applied to the obtained cutsets at each failure sequence level to evaluate the sequence HCLPF value, the event tree HCLPF value and the overall plant HCLPF value.

The cutset generated from the SMA model are listed and analyzed through the min-max approach discussed above in a supporting calculation. Sequence level results are presented in Table 19.55-8 where also the plant level HCLPF value is presented.

19.55.5 Sensitivity Analyses

A 99% confidence associated with the test response spectra is expected for all the HCLPF extracted from tests (method [6] in Table 19.55-1). To address this expectation a sensitivity case was run to the AP1000 PRA-based SMA.

Since electrical equipment is tested and qualified to the SSE (i.e., 0.30g), the HCLPF values in Table 19.55-1 for all tested equipment are set to 0.3g. While the selected values are extremely conservative due to the engineering margins normally adopted for the qualification tests, such values would not change either the overall AP1000 plant HCLPF value or any sequence or event tree level HCLPF value.

The Polar Crane HCLPF value dominates the plant level HCLPF for the Gross Structural Collapse initiating event. Therefore, the fragility analysis of the polar crane was performed using both CDFM and PRA-based fragility analysis. It was demonstrated that the calculated HCLPF values from these two methods are above 0.5g and have a difference of less than 5%.

19.55.6 Results and Insights

19.55.6.1 AP1000 SMA Results

The AP1000 PRA-based SMA has demonstrated that for structures, systems, and components required for safe shutdown, the HCLPF magnitudes are equal to or greater than 0.50g. This HCLPF is determined by various structures, systems, and components with an HCLPF value of 0.5g.

Thus, the AP1000 plant can meet or exceed the requirement to withstand a review level earthquake of 0.5g. It is observed that electrical equipment qualification consistent with the Certified Seismic Design Response Spectra (CSDRS) at 0.3g (with a 99% confidence associated to the Test Response Spectra – TRS) supports the overall plant HCPLF value of 0.5g.

The success paths used for the SMA are taken conservatively in many cases, and credit for operator actions for events at 0.5g review level earthquake has been avoided. Thus, the results are valid without operator intervention, which indicates a strong point of the AP1000 design to mitigate seismically induced core damage and large release sequences.

All SMA sequences are evaluated with loss of offsite power and loss of onsite AC power leading to a station blackout event. The plant design is shown to be robust against seismic event sequences each of which contain station blackout coupled with other seismic or random failures.

19.55.6.2 AP1000 SMA Insights

The SMA results also point out the following insights:

1. Design Features

   The AP1000 design provides some aspects that make the plant more robust against the review level earthquakes. Namely:

   - Reactor trip is ensured without the actuation signal due to the loss of offsite power occurring and rods inserting by gravity.

   - PRHR system valves fail open without actuation signal following loss of power/loss of instrument air. Thus, PRHR cooling is immediately available.

   - CMT system valves fail open without actuation signal following loss of power/loss of instrument air. Thus, CMT injection is immediately available.

   Thus, three key mitigating systems, reactor trip, PRHR cooling, and CMT injection are available with high confidence and low probability of failure, without dependence on actuation signals immediately after a review level seismic event.

   Moreover, the passive containment cooling system air operated valves also fail open in a review level earthquake, due to loss of offsite power/instrument air. As a result, the passive containment cooling system is automatically actuated and has enough water inventory to last for 72 hours.

2. DC System Fragility

   Control rods, PRHR, CMT, and passive core cooling systems would be operational after potential loss of protection and safety monitoring system (PMS) or DC control power. Thus, the plant can successfully mitigate a transient event even with a failure of PMS or DC control power. However, the DC control power system HCLPF is the same as the plant HCLPF (0.50g). This HCLPF has the potential to become a driving failure, if it were to be coupled with a LOCA event with low HCLPF. However, no such low HCLPF LOCA events are identified in the current model.

3. Importance of Valve Room Fragilities

   Fragility of certain valve rooms, where the passive core cooling system valves are concentrated, becomes an important factor; the SMA model depends on the successful functioning of these valves to mitigate LOCA accidents. These rooms are labeled as 11206/11207 and contain CMT, accumulator, IRWST injection, and cavity recirculation valves. Since the HCLPF of these rooms is relatively high, compared to the plant HCLPF value, the seismic failure of many passive core cooling system valves does not become a contributor to plant HCLPF.

4. Operator Actions

Operator actions are not credited in the SMA model for the 0.50g review level events. Inclusion of operator actions in the models would provide additional success paths, such as manual actuation of the automatic depressurization system (ADS) after failure of CMTs to inject. However, this inclusion would not affect the plant HCLPF or the major conclusions of the SMA. Thus, the AP1000 design is already robust with respect to its response to seismic events, even without taking credit for operator actions.

5. IRWST Failure

This failure is modeled to render PRHR, gravity injection, and recirculation systems inoperable. Thus, it becomes a single point failure that affects both the transient (e.g. LOSP events) and LOCA success paths. Failure of IRWST is modeled as a part of gross structural failure, as well as in PRHR and gravity injection system fault trees. The IRWST HCLPF is 0.71g and therefore significantly above the plant level HCLPF.

Additionally, an argument can be made that when the IRWST fails, its inventory would end up in the containment cavity and can be used to recirculate cavity water back into the RCS, leading to successful core cooling. Although this scenario is plausible and credible, such success sequences (e.g. sequences where gravity injection is skipped, directly going into cavity recirculation) are not analyzed in the AP1000 PRA. For this purpose, no credit for such a success path is taken in the present model.

6. Large Fission Product Release

The large fission product release is driven by the same seismic sequences that dominate the plant core damage. This is due to either the nature of the initiating event (such as gross structural failure initiating event, EQ-STRUC), or postulated containment failure following a reactor vessel failure (RVFA) (such as EQ-RVFA initiating event or some ATWS sequences leading the RVFA). Failure of containment isolation or containment cooling system due to their system components or system actuation failures does not dominate the plant large release HCLPF.

19.55.7 References

19.55-1 "SECY-93-087 - Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," USNRC Memorandum, July 21, 1993, Chilk to Taylor.

19.55-2 Budnitz, R. J., et al., "An Approach to the Quantification of Seismic Margins in Nuclear Power Plants," NUREG/CR-4334, UCID-20444, August 1985.

19.55-3 Advanced Light Water Reactor Utility Requirements Document, Volume III, ALWR Passive Plant, Chapter 1, Appendix A, PRA Key Assumptions and Groundrules, Revisions 5 & 6, Issued December 1993.

19.55-4 "A Methodology for Assessment of Nuclear Power Plant Seismic Margin," Electric Power Research Institute, EPRI NP-6041, October 1988.

19.55-5 APP-GW-GL-022, Revision 8, AP1000 Probabilistic Risk Assessment, Westinghouse Electric, LLC, August 2007.

Table 19.55-1 (Sheet 1 of 2)

SEISMIC MARGIN PARAMETERS AND HCLPF VALUES

Description	Median pga[1]	βc	HCLPF Value[1]	Basis
Buildings/Structures				
Shield Building – Tension Ring	-	-	0.73	[2]
Shield Building – Air Inlet	-	-	0.71	[2]
Shield Building – Conical Roof	-	-	0.71	[2]
Shield Building – PCS Tank	-	-	0.81	[2]
Shield Building – SC/RC Connection	-	-	>0.67	[2]
Shield Building – RC Cylindrical Wall	-	-	0.67	[2]
Steel Containment Vessel – Buckling	1.94	0.42	0.73	[3]
Steel Containment Vessel – Overturning	5.74	0.62	1.38	[3]
Containment Baffle – Support Failure	-	-	0.91	[4]
Interior Containment Structure & IRWST Tank	-	-	0.71	[4]
Exterior Walls of Auxiliary Building – Wall 1	-	-	0.97	[2]
Exterior Walls of Auxiliary Building – Wall 11	-	-	0.88	[2]
Primary Components				
Reactor Pressure Vessel	-	-	0.56	[4]
Reactor Pressure Vessel Supports	1.58	0.35	0.71	[3]
Reactor Internals and Core Assembly (includes fuel)	1.5	0.51	0.5	[5]
Control Rod Drive Mechanism (CRDM)	2.2	0.51	0.7	[5]
Steam Generator	-	-	0.54	[4]
Steam Generator Support Column Buckling	1.14	0.33	0.54	[3]
Steam Generator Lower Lateral Support	1.23	0.34	0.57	[3]
Steam Generator Intermediate Supports	1.17	0.30	0.59	[3]
Pressurizer	-	-	0.58	[4]
Pressurizer Upper Support Weld[10]	1.02	0.31	0.50	[3]
Pressurizer Upper Support Strut	1.11	0.29	0.56	[3]
Pressurizer Lower Support Strut	1.41	0.29	0.72	[3]
Reactor Coolant Pump[9]	2.2	0.51	0.68	[5]
Reactor Coolant Pump Heat Exchanger[9]	-	-	0.55	[2]
Mechanical Equipment				
Polar Crane	-	-	0.55	[2]

Table 19.55-1 (Sheet 2 of 2)

SEISMIC MARGIN PARAMETERS AND HCLPF VALUES

Description	Median pga[1]	βc	HCLPF Value[1]	Basis
Piping – Support Controlled	3.3	0.61	0.81	[5]
Cable trays – Support Controlled	2.2	0.61	0.54	[5]
Accumulator Tank	2.2	0.46	0.76	[5]
Core Make Up Tank	-	-	0.87	[4]
Heat Exchanger (PRHR)	-	-	1.11	[4]
Valves				
Higher than El. 100′	3.3	0.61	0.81	[5]
Equal to or Lower than El. 100′	-	-	1.02	[4]
Passive Containment Cooling System	-	-	0.67	[2]
Electrical Equipment				
Non-Sensitive to High Frequency Excitation	-	-	0.5	[6]
Sensitive to High Frequency Excitation	-	-	0.52	[6]
Ceramic Insulators[7]	0.2	0.35	0.09	[8]

Notes of Table 19.55-1:

[1] pga is the free field peak ground acceleration level for the seismic event.
[2] HCLPF based on conservative deterministic fragility margin approach.
[3] HCLPF based probabilistic fragility analysis.
[4] HCLPF based on deterministic approach.
[5] HCLPF based on URD recommended generic fragility data.
[6] HCLPF based on design margin, code requirements and test margins inherent to the seismic qualification testing. Qualification testing with 99% confidence on the TRS will be limited to 0.3g.
[7] The capacity of the ceramic insulators is less than the review level earthquake of 0.5g. The failure of the ceramic insulators is considered in the PRA analysis.
[8] HCLPF based on recognized generic fragility data
[9] Both the Reactor Coolant Pump Support and Reactor Coolant Pump External Heat Exchanger HCLPF values are controlled by Steam Generator Support.
[10] The HCLPF value of the Pressurizer Upper Support Weld is calculated as 0.6 g using conservative deterministic failure margin method. The value of 0.5 g in the table is used in the PRA/SMA and is more conservative.

Table 19.55-2 (Sheet 1 of 5)

BASIC EVENTS HCLPF VALUES

BE ID	BE Description	HCLPF (g)	Source
EQ-AB-EXTWALL	Failure of Auxiliary Building Exterior Wall	0.88	Exterior walls of auxiliary building, limiting values between *wall 1* and *wall 11*
EQ-AB-FLOOR	Failure of Auxiliary Building Floor	0.88	Same as auxiliary building exterior wall
EQ-AB-INTWALL	Failure of Auxiliary Building Interior Wall	0.88	Same as auxiliary building exterior wall
EQ-ACC-CV28	Accumulator Check Valves 28A and 28B Fail	1.02	In rooms 11206/11207, below elevation 100′
EQ-ACC-CV29	Accumulator Check Valves 29A and 29B Fail	1.02	In rooms 11206/11207, below elevation 100′
EQ-ACC-TANKS	Accumulator Tanks Fail	0.76	
EQ-ACDISPANEL	120 Volt AC Distribution Panels Fail	0.5	Limiting value among those provided for electrical equipment
EQ-ADS-S1MOVS	ADS Stage 1 MOVs RCS-PL-V001A/B and RCS-PL-V011A/B Fail	0.81	In rooms 11603/11703, above elevation 100′
EQ-ADS-S2MOVS	ADS Stage 2 MOVs RCS-PL-V002A/B and RCS-PL-V012A/B Fail	0.81	In rooms 11603/11703, above elevation 100′
EQ-ADS-S3MOVS	ADS Stage 3 MOVs RCS-PL-V003A/B and RCS-PL-V013A/B Fail	0.81	In rooms 11603/11703, above elevation 100′
EQ-ADS-S4VALVES	ADS Stage 4 Squib Valves 4A/B/C/D Fail	0.81	In rooms 11301/11302, above elevation 100′
EQ-BAF-SUPP	Failure of Containment Baffle Support	0.91	
EQ-BAT-RACK	Battery Racks Fail	0.5	Limiting value among those provided for electrical equipment.
EQ-BATTERY	250 Vdc Batteries Fail	0.5	Limiting value among those provided for electrical equipment.

Table 19.55-2 (Sheet 2 of 5)

BASIC EVENTS HCLPF VALUES

BE ID	BE Description	HCLPF (g)	Source
EQ-CABINETS	PMS Cabinet Fail	0.5	Limiting value among those provided for electrical equipment.
EQ-CABLETRAY	Cable Trays Fail	0.54	
EQ-CAS-AOV-1415	Containment CAS Isolation Valves AOV 14 and 15 Fail	0.81	In rooms 12405/11400, above elevation 100′
EQ-CER-INSULATOR	Seismically induced failure of ceramic insulators	0.09	
EQ-CMT-AOV	CMT AOV 14A/B and 15A/B Fail by Seismic Event	1.02	In rooms 11206/11207, below elevation 100′
EQ-CMT-CV	CMT CV 16A/B or 17A/B Fail by Seismic Event	1.02	In rooms 11206/11207, below elevation 100′
EQ-CMT-LEVELSWT	CMT Level Switch Fails	0.5	Limiting value among those provided for electrical equipment.
EQ-CMT-TANKS	CMT Tanks Fail by Seismic Event	0.87	
EQ-CONTPR-SENSOR	Containment Pressure Sensor or Transmitter Fails	0.5	Limiting value among those provided for electrical equipment.
EQ-CORE-ASSEMBLY	Failure of Core Assembly	0.5	
EQ-CRDM	Failure of Control Rod Drive Mechanism	0.7	
EQ-CV-BUCKLE	Containment Vessel Buckling	0.73	
EQ-CV-INTER	Failure of the Interior (concrete) Structure of Containment	0.71	
EQ-CV-OVERT	Containment Vessel Overturning	1.38	
EQ-DCDISPANEL	250 Vdc Distribution Panel Fails	0.5	Limiting value among those provided for electrical equipment.
EQ-DCMCC	DC Motor Control Centers Fail	0.5	Limiting value among those provided for electrical equipment.

Table 19.55-2 (Sheet 3 of 5)

BASIC EVENTS HCLPF VALUES

BE ID	BE Description	HCLPF (g)	Source
EQ-DC-SWBRD	250 Vdc Switchboard Fails	0.5	Limiting value among those provided for electrical equipment.
EQ-DVI-PIPES	Seismically Induced Failure of Both DVI Lines	0.81	
EQ-ELECTRONICS	PMS Electronic Fail	0.5	Limiting value among those provided for electrical equipment.
EQ-INSTR-PIPES	Failure of RCS Instruments Lines	0.81	
EQ-INVERTER	250 Vdc Inverters Fail	0.5	Limiting value among those provided for electrical equipment.
EQ-IRW-INJCV	IRWTS Injection CV 122A/B and 124A/B Fail by Seismic Event	1.02	In rooms 11206/11207, below elevation 100′
EQ-IRW-INJSQ	IRWTS Injection Squib Valves 123A/B and 125A/B Fail by Seismic Event	1.02	In rooms 11206/11207, below elevation 100′
EQ-IRW-RECCV	Sump Recirculation Check valves 119A/B Fail by Seismic Event	1.02	In rooms 11206/11207, below elevation 100′
EQ-IRW-RECMOV	Sump Recirculation MOVs 117A/B Fail by Seismic Event	1.02	In rooms 11206/11207, below elevation 100′
EQ-IRW-RECSQ	Failure of Recirculation Squib Valves 118A/B and 120A/B by Seismic Event	1.02	In rooms 11206/11207, below elevation 100′
EQ-IRWST-TANK	Failure of IRWST	0.71	
EQ-MSL-SENSOR	Main Steam Line Pressure Sensor or Transmitter Fails	0.5	Limiting value among those provided for electrical equipment.
EQ-PCC-TANK	Passive Containment Core Cooling Tank Fails	0.81	
EQ-POL-CRANE	Failure of the Polar Crane	0.55	
EQ-PRHR-AOV	Passive RHR AOVs PXS-PL-V108A and B Fail by Seismic Event	0.81	In room 11300, above elevation 100′
EQ-PRHR-HX	Failure of Passive RHR Heat Exchanger	1.11	

Table 19.55-2 (Sheet 4 of 5)

BASIC EVENTS HCLPF VALUES

BE ID	BE Description	HCLPF (g)	Source
EQ-PRZR-FAILS	Seismically Induced Failures of the Pressurizer	0.5	Pressurizer upper support weld (limiting HCLPF among pressurizer components)
EQ-PRZR-LVTRANS	Seismically Induced Failure of Pressurizer Level Transmitter	0.5	Limiting value among those provided for electrical equipment.
EQ-PRZR-SENSOR	Pressurizer Sensor Or Transmitter Fails	0.5	Limiting value among those provided for electrical equipment.
EQ-PRZR-SV	Pressurizer Safety Valves RCS-PL-V005A/B Fail Seismically	0.81	In rooms 11603/11703, above elevation 100′
EQ-RCP-FAILS	Reactor Coolant Pumps Fail	0.54	Same as SG due to connection between RCP & SG.
EQ-RCP-HX	Seismically Induced RCP HX Failure Inducing a LOCA	0.55	
EQ-RCS-PIPES	Failure of RCS Piping	0.81	
EQ-RV-FAILS	Reactor Pressure Vessel Fails	0.56	
EQ-RV-FUEL	Fuel in Reactor Vessel Fails	0.5	
EQ-RV-HDPK	Reactor Vessel Integrated Head Package Fails	0.7	Same as CRDM due to physical location
EQ-SG-FAILS	Seismically Induced Failures of the Steam Generators	0.54	
EQ-SGTR	Seismically Induced SGTR	0.54	Same as SG failure
EQ-SHBLD-ROOF	Shield Building Roof Fails	0.71	
EQ-SHBLD-WALL	Shield Building Wall Fails	0.71	Same as roof
EQ-SLB	Failure of Feed and Steam Pipes on Secondary Side	0.81	
EQ-TRSFSWITCH	Transfer Switches Fail	0.5	Limiting value among those provided for electrical equipment.

Table 19.55-2 (Sheet 5 of 5)

BASIC EVENTS HCLPF VALUES

BE ID	BE Description	HCLPF (g)	Source
EQ-VFS-AOV-0304	Containment Air Filtration System Containment Air Supply Isolation Valves AOV 03 and 04 Fail	0.81	In rooms 12452/11400, above elevation 100′
EQ-VFS-AOV-0910	Containment Air Filtration System Containment Air Exhaust Isolation Valves Fail (009, 010, 800A/B, and 803A/B)	0.81	In rooms 12452/11400, above elevation 100′
EQ-WLS-AOV-5557	WLS Cont. Sump Isolation Valves AOV 55 and 57 Fail	0.81	In rooms 11300/12244, above elevation 100′

Table 19.55-3

EQ-IEV-STRUC (EQSTR-02) HCLPF

		Original AP1000	Updated AP1000
1	EQ-AB-FLOOR	0.51g	0.88g
2	EQ-AB-EXTWALL	0.51g	0.88g
3	EQ-AB-INTWALL	0.51g	0.88g
4	EQ-BAF-SUPP	1.30g	0.91g
5	EQ-PCC-TANK	0.51g	0.81g
6	EQ-SHBLD-ROOF	0.51g	0.71g
7	EQ-SHBLD-WALL	0.51g	0.71g
8	EQ-CV-INTER	0.50g	0.71g
9	EQ-CV-BUCKLE	0.66g	0.73g
10	EQ-CV-OVERT	1.11g	1.38g
11	EQ-IRWST-TANK	0.50g	0.71g
12	EQ-POL-CRANE	0.77g	0.55g
	IE HCLPF=	0.50g	0.55g

Table 19.55-4

EQ-IEV-RVFA (EQRVF-02) HCLPF

		Original AP1000	Updated AP1000
1	EQ-DVI-PIPES	0.81g	0.81g
2	EQ-SG-FAILS	0.54g	0.54g
3	EQ-RCP-FAILS	0.68g	0.54g
4	EQ-PRZR-FAILS	0.55g	0.50g
5	EQ-RV-FUEL	0.50g	0.50g
6	EQ-RV-HDPK	0.70g	0.70g
7	EQ-RV-FAILS	0.64g	0.56g
	IE HCLPF =	0.50g	0.50g

Table 19.55-5

EQ-IEV-LLOCA HCLPF

		Original AP1000	Updated AP1000
1	EQ-PRHR-HX	0.76g	1.11g
2	EQ-RCS-PIPES	0.81g	0.81g
	IE HCLPF =	0.76g	0.81g

Table 19.55-6

EQ-IEV-SLOCA HCLPF

		Original AP1000	Updated AP1000
RCS Instrumentation Pipe Breaks	EQ-INSTR-PIPES	0.81g	0.81g
Secondary Line Breaks	EQ-SLB	0.81g	0.81g
SGTR	EQ-SGTR	0.54g	0.54g
RCP HX	EQ-RCP-HX	-	0.55g
	HCLPF =	0.54g	0.54g

Table 19.55-7

EQ-IEV-ATWS HCLPF

		Original AP1000	Updated AP1000
1	EQ-CORE-ASSEMBLY	0.50g	0.50g
2	EQ-CRDM	0.70g	0.70g
	HCLPF =	0.50g	0.50g

Table 19.55-8

SEQUENCE AND PLANT HCLPF

ET	Original AP1000	Updated AP1000
EQ-STRUC	EQSTR-02	0.55
	EQ-STRUC HCLPF	*0.55*
EQ-RVFA	EQRVF-02	0.50
	EQ-RVFA HCLPF	*0.50*
EQ-LLOCA	EQLLO-02	0.81
	EQLLO-03	0.81
	EQLLO-05	0.81
	EQLLO-06	0.81
	EQLLO-08	0.81
	EQLLO-09	0.81
	EQLLO-10	0.81
	EQLLO-11	0.81
	EQ-LLOCA HCLPF	*0.81*
EQ-SLOCA	EQSLO-02	0.54
	EQSLO-03	0.54
	EQSLO-04	0.54
	EQSLO-05	0.87
	EQ-SLOCA HCLPF	*0.54*
EQ-ATWS	EQATW-02	0.50
	EQATW-03	0.50
	EQATW-04	0.50
	EQATW-05	0.87
	EQATW-06	0.81
	EQATW-07	0.71
	EQ-ATWS HCLPF	*0.50*
EQ-LOSP	*All mixed cut sets (IE HCLP =0.09)*	*N/A*
	Plant HCLPF	***0.50***

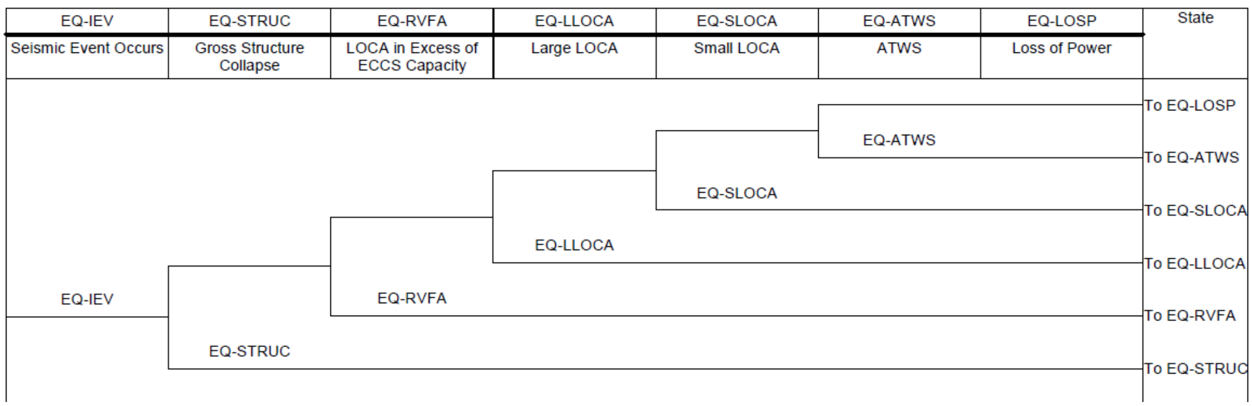

Figure 19.55-1

Seismic Initiating Event Hierarchy Tree

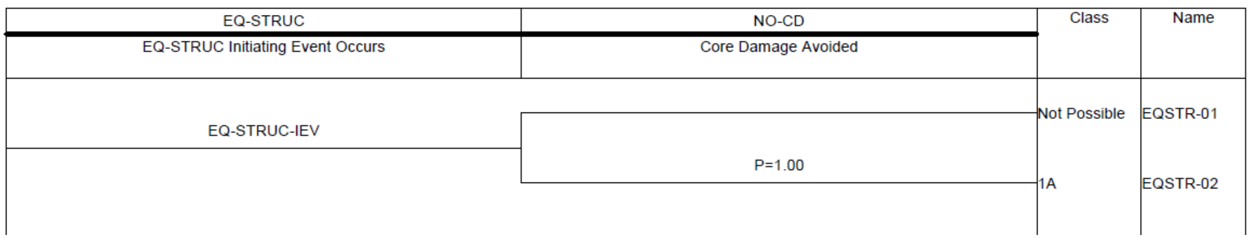

Figure 19.55-2

Seismic Induced Gross Structural Collapse Event Tree

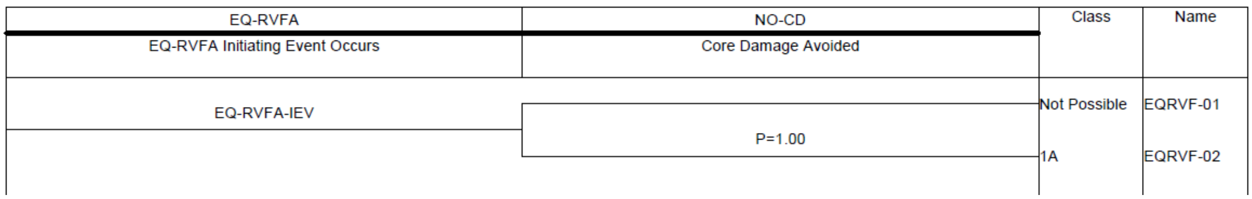

Figure 19.55-3

Seismic Induced Excessive LOCA Event Tree

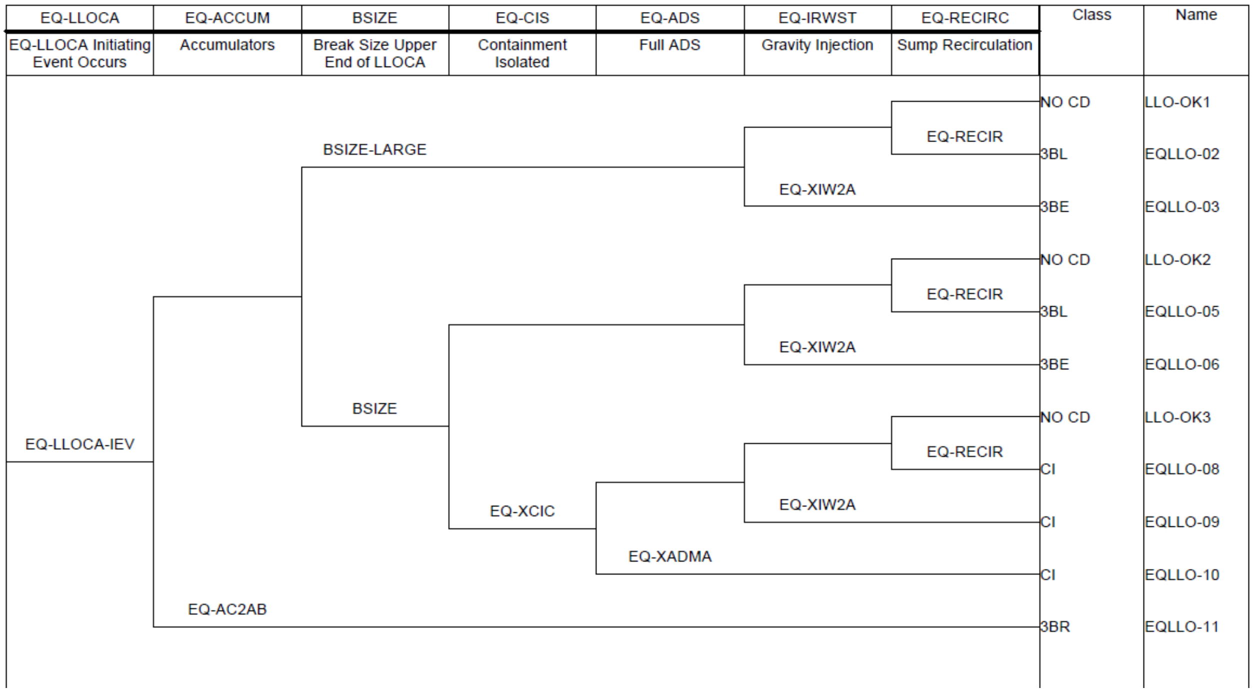

Figure 19.55-4

Seismic Induced Large LOCA Event Tree

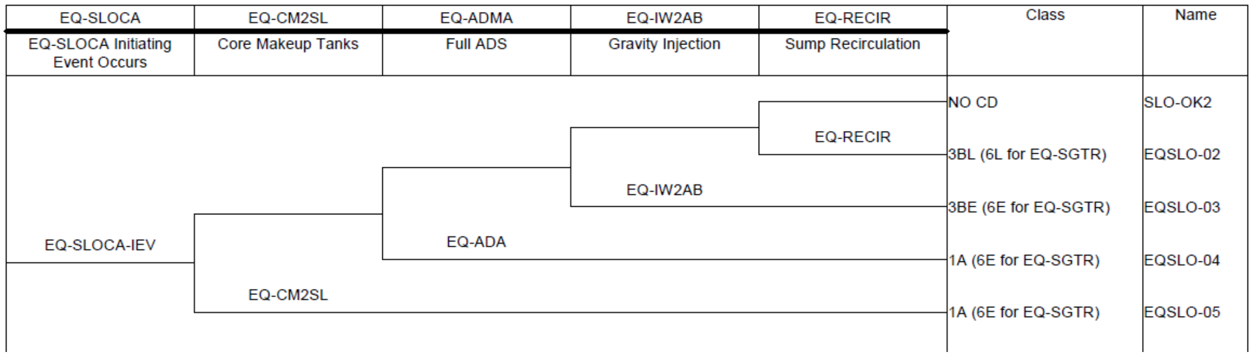

Figure 19.55-5

Seismic Induced Small LOCA Event Tree

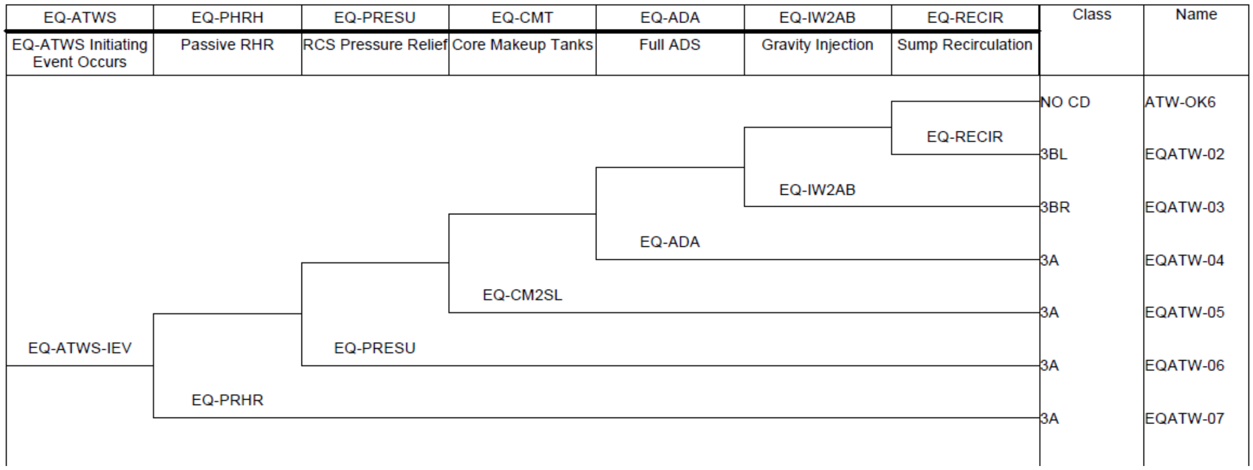

Figure 19.55-6

Seismic Induced ATWS Event Tree

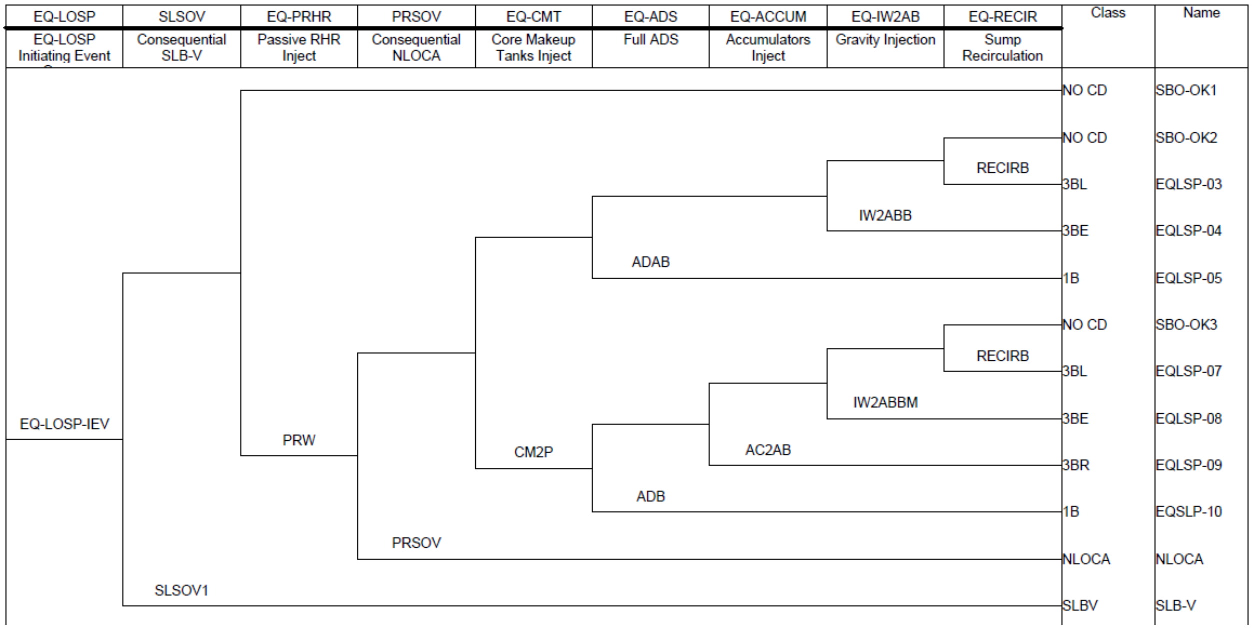

Figure 19.55-7

Seismic Induced LOSP Event Tree

19.56 PRA Internal Flooding Analysis

The design certification of the AP1000 included consideration by the NRC of the topic referred to in this section.

19.57 Internal Fire Analysis

The design certification of the AP1000 included consideration by the NRC of the topic referred to in this section.

19.58 Winds, Floods, and Other External Events

19.58.1 Introduction

External events considered in the AP1000 PRA are those events whose cause is external to all systems associated with normal and emergency operations situations. Some external events may not pose a significant threat of a severe accident. Some external events are considered at the design stage and have a sufficiently low contribution to core damage frequency or plant risk.

Based upon the guidelines provided in References 19.58-1 and 19.58-2, the following is a list of six external events that are included for AP1000 analysis:

- High winds and tornadoes
- External floods
- Transportation and nearby facility accidents
- Seismic events
- Internal fires
- External fires

The first three external events are addressed in this section. Seismic events and internal fires are addressed in the AP1000 PRA. Based on site-specific information, the COL applicant should reevaluate the qualitative screening of external fires. Accordingly, based on the criteria to screen out external hazards in the PRA, a risk evaluation should be performed if it cannot be demonstrated that the frequency of hazard is less than 1E-7/yr. If any site-specific susceptibilities are found, the site-specific PRA performed to address COL Holder Item 19.59.10-2 should include external fires.

Chapter 2 defines the site characteristics for which the AP1000 is designed. A site is acceptable if the site characteristics fall within the AP1000 site interface parameters.

19.58.2 External Events Analysis

19.58.2.1 Severe Winds and Tornadoes

The overall methodology recommended by NUREG-1407 for analyzing plant risk due to high winds and tornados is a progressive screening approach. This approach is modified to consider determining the acceptability of hazard frequency and risk. High winds (including tornadoes) can affect plant structures in at least two ways: (1) if wind forces exceed the load capacity of a building or other external facility, the walls or framing might collapse or the structure might overturn from the excessive loading; and (2) if the wind is strong enough, as in a tornado or hurricane, it may be capable of lifting materials and thrusting them as missiles against the plant structures that house safety-related equipment. Critical components or other contents of plant structures not designed to resist missile penetration might be damaged and lose their function.

The NUREG-1407 criterion for high winds and tornados states that "these events pose no significant threat of a severe accident because the current design criteria for wind are dominated by tornadoes having an annual frequency of exceedance of about 10^{-7}." This is interpreted to mean that events with an annual frequency of exceedance less than 1.0E-07 may be removed from further consideration and events with an annual frequency of exceedance greater than 1.0E-07 must be further evaluated. However, the NUREG-1407 criterion was developed for currently operating plants.

High winds and tornados tend to behave as a loss of offsite power (LOSP) since the site switchyard is unprotected and not designed against high wind velocities. For wind velocities greater than the design basis, additional structures, systems, and components (SSC) may also fail. Therefore, two analyses are performed, one considering only a LOSP, and another considering a LOSP with failure of the standby nonsafety systems. This analysis considers not only excessive wind forces, but also missile generation. A conditional core damage probability will be calculated for each of those scenarios. Risk due to the event can be estimated using the following equation:

$$CDF = IEF * CCDP \qquad \text{(Equation 19.58-1)}$$

Where CDF is annual core damage frequency, IEF is the initiating event frequency, and CCDP is the conditional core damage probability. If this evaluation indicates an acceptably small contribution to risk (e.g., less than 10% of the total plant CDF), then the progressive screening is complete and no detailed PRA will be necessary.

A sensitivity study is performed for the above two cases with a loss of component cooling water/service water considered also because those systems may not be available following above design basis winds.

The analysis for winds and tornadoes is site-specific. It is anticipated that a high wind or tornado event would result in a loss of offsite power because the switchyard is likely to become unavailable during the event.

The analysis for high winds and tornados begins with an examination of the design basis for the plant, which is documented in Chapter 2.

The AP1000 design basis wind speed for tornados is 300 mph as discussed in Chapter 2. This value is assumed to be the maximum wind speed that will not challenge the safety-related structures. The AP1000 operating basis wind speed is 145 mph as discussed in Chapter 2. This value is assumed to be the maximum wind speed that will not challenge the nonsafety-related structures.

The structures protecting safety-related features of the AP1000 are designed for extreme winds and missiles associated with these winds. As long as the external event winds are less than these design basis winds, the safety features of the AP1000 will be unaffected. If the winds exceed the design values, then the integrity of the safety-related structures may be compromised.

The structures protecting nonsafety-related features of the AP1000 are designed according to uniform building code and have some level of protection against seismic and high wind events. As long as the external event winds are less than the operating basis winds (145 mph, per Chapter 2), the nonsafety features of the AP1000 will be unaffected. If the winds exceed the operating basis values, then the integrity of the nonsafety relates structures may be compromised.

In summary of the design against high winds, the plant is designed against 300 miles per hour (mph) winds. The operating basis of the plant is winds up to 145 mph. This means that the safety structures are protected against winds up to 300 mph and nonsafety system (NSS) structures are protected against winds up to 145 mph. Per the Enhanced Fujita Scale for Tornados (Table 19.58-1), no tornados are expected to exceed 300 mph; however, EF3, EF4, and EF5 tornados do exceed the operating basis of the AP1000. Per the Saffir-Simpson Scale for Hurricanes (Table 19.58-2), no hurricanes are expected to reach 300 mph winds; however, Category 3, Category 4 and Category 5 hurricane winds do exceed the operating basis of the AP1000.

Three studies are performed to evaluate the high wind events. The Case 1 study is a LOSP induced by each of the events, with no other equipment unavailable. A conditional core damage probability (CCDP) is developed for this scenario, which may be multiplied by the high wind event frequency. All tornados and hurricanes are considered in this Case 1 as they may challenge the AP1000 switchyard. Extratropical cyclones are normal storms and thunderstorms with winds expected to fall below the operating basis for the AP1000. They are also included in the Case 1 analysis.

As stated above, the EF3, EF4, and EF5 tornados and Category 3, Category 4 and Category 5 hurricanes may challenge the nonsafety-related structures in the AP1000. Therefore, these events will be evaluated with the loss of additional SSCs. The Case 2 study is created by modifying the Case 1 analysis for the EF3, EF4, and EF5 tornados, and Category 3, Category 4 and Category 5 hurricanes to have a LOSP with additional failures of nonsafety systems unavailable. A CCDP is developed for this scenario, which may be multiplied by the high wind event frequency.

The final Case 3 is a conservative study where all high wind events are evaluated as a LOSP with failure of the nonsafety systems. This case is created to represent the worst case scenario. In this analysis, events are considered of low risk importance if their initiating event frequency is less than 1.0E-07 or if their estimated CDF is less than 1.0E-08 events/yr.

The results of the CDF calculation are shown in Table 19.58-3. Equation 19.58-1 was used to determine the resultant CDF.

In Table 19.58-3, none of the initiating event frequencies were sufficiently low to be removed from further consideration. Therefore, the CDF calculation was performed. In each case, the resultant CDF is less than 1.0E-08 events/yr. The Category 4 and Category 5 hurricane frequency is considered to be extremely conservative at 1.00E-02 events/yr. An event with the conservative initiating event frequency, and the worst case sensitivity study (Case 3), the resultant CDF is still less than the CDF criterion of 1.0E-08 events/yr. Case 2 is considered to be the representative model for high winds, with Case 1 and Case 3 being treated as sensitivity studies on the baseline. Case 3 is conservative in that it assumes total failure of the standby non-safety systems (CVS, RNS, SFW, automatic DAS, and diesel generators) for all high wind events. As AP1000 non-safety structures have been designed to a building code that offers an added level of protection, the above failures are considered extreme and conservative. Therefore, while the total Case 3 CDF does fall above the 1.0E-08 events/yr CDF screening criteria, the results are considered very conservative for the above reasons. Therefore, no further detailed PRA is necessary for the AP1000 high winds and tornados analysis.

19.58.2.2 External Floods

An external flooding analysis is performed to verify that any significant contribution to core damage frequency resulting from plant damage caused by storms, dam failure, and flash floods is accounted for as follows:

> The analysis for external floods begins with an examination of the design basis for the plant, which is documented in Chapter 2 of the AP1000 DCD. The AP1000 is protected against floods up to the 100′ level. The 100′ level corresponds to the plant ground level. From this point, the ground is graded away from the structures. Thus, water will naturally flow away from the structures. Additionally, all seismic Category I SSCs are designed to withstand the effects of flooding. The seismic Category I SSCs below grade (below ground level) are protected against flooding by a water barrier consisting of water stops and a waterproofing system. None of the non-safety SSCs were found to be important based on flooding considerations.
>
> The basic steps involved in an external flooding analysis are similar to those followed for internal flooding in the individual plant examination. However, the focus of attention is on areas, which due to their location and grading, may be susceptible to external flood damage. This requires information on such items as dikes, surface grading, locations of structures, and locations of equipment within the structures. Information such as meteorological data for the site, historical flood height, and frequency data, is also needed.

Only one site indicated susceptibility to external floods due to hurricane surge water. That site is located at an elevation of 45 feet above sea level. Therefore, the AP1000 100′ level, for this site, corresponds to 45′ above sea level. Per DCD subsection 3.4.1.1, the ground will be graded away from the structures beginning at the 100′ level and sloping downward away from the structures.

Category 5 hurricanes, per the Saffir-Simpson scale, are capable of storm surges greater than18 feet. The storm surge of record for a hurricane is 27.8 feet recorded for Katrina (2005). Based on historical information, a hurricane storm surge above the 28-foot level may be classified as an extremely rare event. Engineering judgment is used to establish that the frequency of this type of flood is significantly less than the 10^{-7} per year criterion for initiating event frequency.

As a sensitivity study, the 1.0E-07/yr initiating event frequency is taken as the frequency of an event that may challenge the nonsafety structures in the plant. This sensitivity study also considers failure of the switchyard due to flooding. LOSP with failure of the nonsafety systems CCDP was developed. Equation 1 was used to determine the resultant CDF.

As expected, the risk due to a flooding event is low for the AP1000. The resultant CDF of 5.85E-15/yr is an insignificant contribution to total plant CDF.

For other sites, the AP1000 is designed to site characteristics described in Chapter 2. The site selection criterion provides that for an accident that has potential consequences serious enough to affect the safety of the plant to the extent that 10 CFR 50.34 guidelines are exceeded, the annual frequency of occurrence is less than 1.0E-06 per year. This criterion should be extended to an annual frequency of occurrence less than 1.0E-07 per year for the AP1000 design. As none of the surveyed sites indicated susceptibility to floods due to dam failure and/or flash floods, those events should be considered on a site-by-site basis.

19.58.2.3 Transportation and Nearby Facility Accidents

These events consist of accidents related to transportation near the nuclear power plant and accidents at industrial and military facilities in the vicinity. The following modes of transportation are considered:

- Aviation (commercial/general/military)
- Marine (ship/barge) and nearby facility
- Pipeline (gas/oil)
- Railroad
- Truck

19.58.2.3.1 Aviation Accidents

For limiting event frequency of 1.21E-06/year with most of that frequency for small aircraft, and with commercial aircraft contribution 9.40E-09/year, then the following discussion is applicable.

A conservative analysis was performed to evaluate the risk due to small aircraft accidents onsite. This analysis assumes a LOSP and loss of component cooling water/service water event, and conservatively fail a set of standby nonsafety systems. This is acceptable because it is unlikely that a small aircraft accident would challenge the passive safety systems inside containment. This leaves only the nonsafety systems outside containment as vulnerable. However, this evaluation is conservative because it is unlikely that a small aircraft would have the capacity to fail such a large area of the AP1000.

Equation 19.58-1 is used to determine the resultant CDF. A CDF of 7.08E-14/yr is calculated and is an insignificant contribution to total plant CDF of approximately 5.08E-07/yr. Therefore, sites that can demonstrate an aviation event frequency less than or equal to 1.21E-06/yr for small aircraft accidents are bounded by this evaluation.

Larger commercial aircraft may have the capacity to challenge SSCs within the AP1000 containment. However, the containment structure and safety systems are designed to withstand various earthquake levels so that many of the safety system SSCs will still be available following the accident. To consider the already low risk of the AP1000 design, the 1.0E-07 events/yr criterion for event frequency is applicable for larger commercial aircraft. Sites that can demonstrate a commercial aircraft aviation event frequency less than the 1.0E-07/yr criterion are also bounded by this analysis. For this current evaluation, the highest initiating event frequency reported for large commercial aircraft is 9.40E-09 events/yr. This value falls below the 1.0E-07 events/yr screening criteria. Therefore, no further evaluation is necessary.

19.58.2.3.2 Marine and Nearby Facility Accidents

Only sites with large waterways with ship and/or barge traffic that goes through or near the site need to consider marine accidents.

Marine (ship/barge) accidents and nearby land-based facility accidents pose a potential hazard to a nuclear power plant due to two possibilities:

1. Release of hazardous material towards the plant
2. Explosion with resulting damage to the plant

The potential exists for a marine (or any other mode of transportation) or nearby facility accident that leads to a release of toxic materials into the atmosphere. This type of event may compromise the safety of the plant operators, resulting in reduced operator reliability. However, the toxic release does not directly lead to any failure of plant equipment. To evaluate the risk impact of this scenario, a CCDP is developed that models a reactor trip followed by the guaranteed failure of all PRA credited operator actions. Failure of all PRA credited operator actions obviates the need to evaluate specific toxic release events with respect to differences in the type and amount of material released and duration of the release. The resulting CCDP is 6.26E-08.

Equation 19.58-1 (CDF = IEF * CCDP) is used to determine the maximum frequency for toxic releases, from all sources combined, that would keep the resulting CDF below the 1.0E-08 screening threshold. That maximum value is (1.0E-08/6.3E-08) or 0.15 events per year. This initiating event frequency represents hazardous chemical releases that exceed the assumptions and screening criteria described in U.S. NRC Regulatory Guide 1.78 for screening out release events that need not be considered in the evaluation of control room habitability. The number of events to consider could be determined by the COL applicant contacting the county public safety or emergency management departments and requesting a list of chemical spills that occurred within 5 miles of the plant and required HAZMAT intervention. Only these cases would need to be screened in accordance with Regulatory Guide 1.78 to determine if each event warranted the classification of a toxic release initiating event. If the frequency of toxic releases from all possible sources is demonstrated to be less than 0.15 events per year, the toxic release event is screened out from the need to do additional detailed PRA analyses.

The above analysis is conservative. The AP1000 has an additional level of defense against toxic airborne material. With advanced warning, the operators may actuate passive control room habitability. This system isolates the control room from normal HVAC and actuates a separate system supplied from compressed air containers. The compressed air slightly pressurizes the control room above atmospheric pressure, preventing the entrance of toxic material in the control room. This system is available for 72 hours, which is adequate time to withstand the event.

There is also a potential for marine explosion accidents. The AP1000 is not designed with a service water intake structure. Therefore, loss of service water events as a consequence of marine explosions are not a concern for the AP1000 design. As long as Regulatory Guide 1.91 acceptance criterion is met, marine explosion accidents do not need to be considered further for the AP1000 PRA.

19.58.2.3.3 Pipeline Accidents

Pipeline accidents could pose a hazard to the AP1000 due to the release of hazardous material or the possibility of an explosion and resulting damage to the plant. For a site with a 30-inch gas line approximately 5800 feet away, a semi-quantitative evaluation is performed.

Considerations for the evaluation are as follows:

- Gas pipe rupture frequency
- Gas cloud formation probability
- Gas cloud transportation and nondispersion probability
- Gas cloud ignition probability onsite

Figure 19.58-1 is considered to further evaluate the probability of this accident. When considering the probability of forming a dense gas cloud, and the probability of the wind speed and direction to be in the ranges necessary to transport the gas cloud 5800 feet to the site, without dispersing the gas, including ignition of the gas cloud onsite in a location that may challenge the plant, this probability becomes very low.

Site habitability is also a concern for toxic materials. However, the AP1000 has an additional level of defense against toxic airborne material. With advanced warning, the operators may actuate passive control room habitability. This system isolates the control room from normal HVAC and actuates a separate system supplied from compressed air containers. The compressed air slightly pressurizes the control room above atmospheric pressure, preventing the entrance of toxic material in the control room. This system is available for 72 hours, which is adequate time to withstand the event. The expected frequency value is expected to be below the initiating event criterion of 1.0E-07 events/year. Therefore, no further quantitative evaluation is necessary.

19.58.2.3.4 Railroad and Truck Accidents

Railroad accidents could pose a hazard to the AP1000 due to the release of hazardous material or the possibility of an explosion and resulting damage to the plant. Toxic material releases were evaluated in the marine accident evaluation as to not be important to AP1000 plant risk. Significant damage to the AP1000 plant was evaluated in the aviation accident evaluation. No railroad accidents are expected to result in the amount of damage that may be seen from an aviation accident. This is especially true considering the increased security barriers established at U.S. nuclear power plants.

The AP1000 is designed to site characteristics described in Chapter 2. The site selection criterion provides that, for an accident that has potential consequences serious enough to affect the safety of the plant to the extent that 10 CFR 50.34 guidelines are exceeded, the annual frequency of occurrence is less than 1.0E-06 per year. This criterion should be extended to an annual frequency of occurrence less than 1.0E-07 per year for the AP1000 design.

19.58.2.4 Malevolent Aircraft Impact

Malevolent aircraft impact is discussed in Appendix 19F.

19.58.3 Conclusion

The risk due to external hazards is low for the AP1000 design for the participating sites listed in Section 3.2. The AP1000 design is shown to be highly robust against the external events discussed in this section. The design is resilient against high winds, external floods, and other external events that challenge various equipment in the plant.

Based on site-specific information, the COL applicant should reevaluate the qualitative screening of external fires. Accordingly, based on the criteria to screen out external hazards in the PRA, a risk evaluation should be performed if it cannot be demonstrated that the frequency of hazard is less than 1E-7/yr. If any site-specific susceptibilities are found, the site-specific PRA performed to address COL Holder Item 19.59.10-2 should include external fires.

The following conclusions and insights are derived from the AP1000 external events assessment for events at power:

1. High winds and tornados were quantitative evaluated to be of low risk to the AP1000 design for each of the participating sites. A bounding assessment is provided to show that the expected CDF due to any one of these events does not exceed 1.0E-08 events/year. The same is true for the aggregate results. Sensitivity studies were performed to determine that there is low risk for more limiting scenarios. No further analysis is suggested.

2. The AP1000 is designed to flooding levels described in Chapter 2. The site selection criterion provides that, for an accident that has potential consequences serious enough to affect the safety of the plant to the extent that 10 CFR 50.34 guidelines are exceeded, the annual frequency of occurrence is less than 1.0E-06 per year. This criterion can be extended to an annual frequency of occurrence less than 1.0E-07 per year for the AP1000 design. No further analysis is suggested.

3. Transportation and nearby facilities accidents are qualitatively evaluated to be of low risk importance and do not warrant further evaluation.

A site-specific review of the generic PRA should be conducted to verify that the assumptions in the PRA bound the site-specific conditions for the applicant's site.

19.58.4 References

19.58-1 "Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities - 10 CFR 50.54(f)," Generic Letter 88-20, Supplement 4, June 28, 1991.

19.58-2 NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," June 1991.

19.58-3 National Weather Service, "The Enhanced Fujita Scale," February 2, 2007, http://www.spc.noaa.gov/efscale/.

19.58-4 National Weather Service, “The Saffir-Simpson Hurricane Scale,” June 22, 2006, http://www.nhc.noaa.gov/aboutsshs.shtml.

19.58-5 U.S. Nuclear Regulatory Commission Regulatory Guide 1.91, “Evaluation of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plants,” Revision 1, February 1978.

Table 19.58-1

DESCRIPTION OF THE ENHANCED FUJITA SCALE (TORNADOS)
(Reference 19.58-3)

Scale Number	Intensity Phrase	Wind Speed	Type of Damage Done
EF0	Gale tornado	65-85 mph	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
EF1	Moderate tornado	86-110 mph	Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads.
EF2	Significant tornado	111-135 mph	Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
EF3	Severe tornado	136 - 165 mph	Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
EF4	Devastating tornado	166-200 mph	Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
EF5	Incredible tornado	>200 mph	Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 meters (109 yds); trees debarked; incredible phenomena will occur.

Table 19.58-2

DESCRIPTION OF SAFFIR-SIMPSON SCALE (HURRICANES)
(Reference 19.58-4)

Category Number	Wind Speed	Category Description
1	74-95 mph	Storm surge generally 4-5 ft above normal. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage.
2	96-110 mph	Storm surge generally 6-8 feet above normal. Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of the hurricane center. Small craft in unprotected anchorages break moorings.
3	111-130 mph	Storm surge generally 9-12 ft above normal. Some structural damage to small residences and utility buildings with a minor amount of curtain wall failures. Damage to shrubbery and trees with foliage blown off trees and large trees blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Flooding near the coast destroys smaller structures with larger structures damaged by battering from floating debris. Terrain continuously lower than 5 ft above mean sea level may be flooded inland 8 miles (13 km) or more. Evacuation of low-lying residences with several blocks of the shoreline may be required.
4	131-155 mph	Storm surge generally 13-18 ft above normal. More extensive curtain wall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of structures near the shore. Terrain lower than 10 ft above sea level may be flooded requiring massive evacuation of residential areas as far inland as 6 miles (10 km).
5	>155 mph	Storm surge generally greater than 18 ft above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of all structures located less than 15 ft above sea level and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5-10 miles (8-16 km) of the shoreline may be required.

Table 19.58-3

HIGH WINDS AND TORNADOS RESULTS

Category	Event	Limiting Initiating Event Freq. (/yr)	CDF (/yr)		
			LOSP (Case 1) (/yr)	LOSP with Nonsafety Systems Unavailable for Select Events (Case 2) (/yr)	LOSP with Nonsafety Systems Unavailable for All Events (Case 3) (/yr)
High Winds	EF0 Tornado	1.00E-03	9.81E-12	9.81E-12 (1)	5.85E-11
	EF1 Tornado	1.00E-03	9.81E-12	9.81E-12 (1)	5.85E-11
	EF2 Tornado	1.00E-03	9.81E-12	9.81E-12 (1)	5.85E-11
	EF3 Tornado	1.00E-03	9.81E-12	5.85E-11	5.85E-11
	EF4 Tornado	1.00E-03	9.81E-12	5.85E-11	5.85E-11
	EF5 Tornado	1.00E-03	9.81E-12	5.85E-11	5.85E-11
	Cat. 1 Hurricane	1.00E-01	9.81E-10	9.81E-10(1)	5.85E-09
	Cat. 2 Hurricane	5.00E-02	4.91E-10	4.91E-10(1)	2.93E-09
	Cat. 3 Hurricane	3.00E-02	2.94E-10	1.76E-09	1.76E-09
	Cat. 4 Hurricane	1.00E-02	9.81E-11	5.85E-10	5.85E-10
	Cat. 5 Hurricane	1.00E-02	9.81E-11	5.85E-10	5.85E-10
	Extratropical Cyclones	3.00E-02	2.94E-10	2.94E-10(1)	1.76E-09
Totals			2.32E-09	4.90E-09	1.38E-08

Note:

1. CDF values from Case 1 were used to illustrate the winds from these events will not challenge additional plant SSCs.

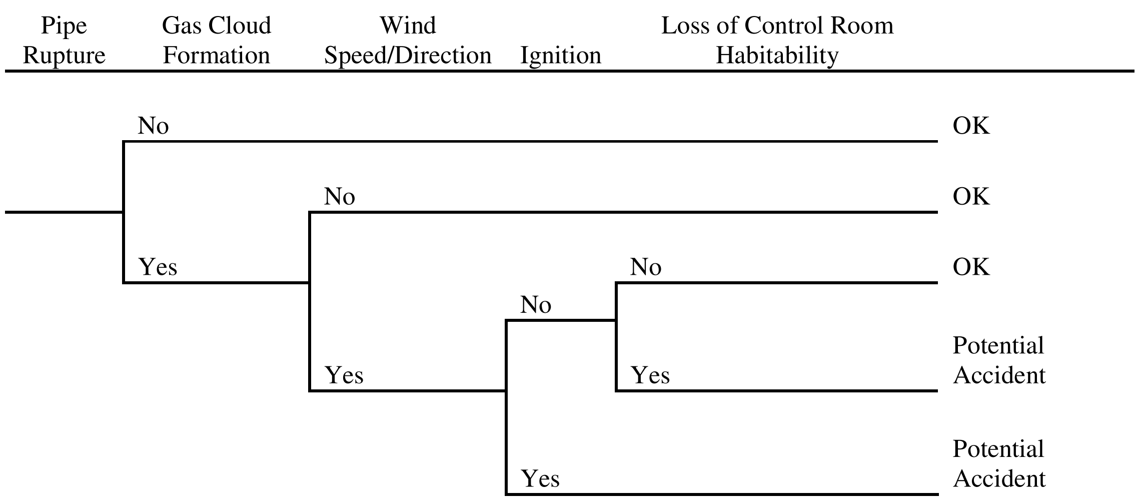

Figure 19.58-1

Pipeline Accident Model