Probabilistic Accident Analysis of the Pebble Bed Modular Reactor for Use with Risk Informed Regulation

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Abstract

One of the major challenges to the successful deployment of new nuclear plants in the United States is the regulatory process, which is largely based on water-reactor technology. While ongoing and expected efforts to license new LWR designs are based primarily on current regulations, guidance, and past licensing experience, the pre-application review of the gas-cooled Pebble Bed Modular Reactor (PBMR) has shown that efforts are being made to provide additional "risk-informed" improvements to the licensing process.

The work presented herein was completed as part of the DOE Nuclear Energy Research Initiative project on a new "highly risk-informed" design and regulatory process. This study concentrates on the application of the risk-informed principles to a new plant design such as the PBMR. The purpose of this work is to provide selected examples of PRA applications, including development of Master Logic Diagram (MLD) for the selection of accident-initiating events and safety classification systems and components, as well as evaluating the risk significance of design features responsible for preventing and mitigating accidents.

An implementation example chosen for a detailed analysis concentrates on the investigation of potential failure modes where performance of the novel design features such as water-based Reactor Cavity Cooling System (RCCS) is critical for the plant safety. The role and importance of the PBMR safety features is investigated by evaluating the risks from the most important external event: earthquake with a subsequent loss of offsite power.

The scope includes specifying design configurations and using PRA techniques to evaluate the design, then iterating with subsequent design changes that improve the overall level of safety and system reliability.

The viability of the new risk-informed process is demonstrated. Technical results, consistent with the known inherent safety features of such a reactor design, indicate that a pressure-tight containment similar to those for today's operating reactors may not be required for the PBMR.

Acknowledgements

This work was supported by the U.S. Department of Energy as a part of the Nuclear Energy Research Initiative (NERI) project Risk – Informed Assessment of Regulatory and Design requirements for future Power Plants. The Department of Nuclear Engineering at Massachusetts Institute of Technology also received support from the Westinghouse Electric Company, Technology Insights Consulting and Framatome ANP in completing this work.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

1.0 Background

The major impediment to a long term competitiveness of new nuclear plants in the U.S. is the capital cost component which may need to be reduced on the order of 35%. Achieving cost savings of this magnitude, while maintaining or improving upon current levels of protection of the public health and safety, will require a fundamental re-evaluation of the design options, industry standards, and regulatory bases under which nuclear plants are designed and licensed. It is expected, therefore, that the nuclear power plants of the future will differ substantially from the current generation of light water reactors (LWRs) in both their design and their safety evaluation methods.

The current collection of nuclear industry standards and NRC regulatory requirements and guidance is based largely on LWR technology and experience from the past forty years of design, operation, and regulation. The current experience base is a mix of deterministic methods and criteria, which are based mostly on non-quantitative risk concepts, and engineering judgment that evolved over the last forty years. Most of these criteria evolved one by one, as safety issues were recognized and resolved. There is also an increasing awareness that many of the existing regulatory requirements and industry standards are inconsistent with each other and may not be contributing significantly to plant safety and reliability. They are, therefore, unnecessarily adding to nuclear plant costs. The prescriptive nature of the current regulations has the potential to inhibit the deployment of non-LWR technologies for future nuclear power plants as well as the development of more advanced LWR designs. The design and licensing of new reactor technologies can no longer rely solely on the accumulation of past experience on which to base regulations for the new technologies. What the industry needs now is to (1) use more risk-informed design and regulation methods for new plant designs and (2) continue ongoing programs for implementing performance-based management of their operation.

2.0 Use of Probabilistic Risk Assessment for Design and Regulation

The primary focus of the regulators is to protect the public safety and health. The "state of the art" for probabilistic risk assessments (PRAs), including the database of operating experience, is now sufficiently mature that these PRAs should be able to be used more prominently to establish standards and regulatory requirements that truly maintain the reliability and safety of nuclear power plants regardless of the specific technologies. Thus, a highly risk-informed, performance-based process has been proposed for the design and licensing of future nuclear power plants[3].. Under this approach, the regulators would establish a set of high-level quantitative public safety criteria that the plant designers would need to meet. These criteria would be expressed in terms of "non-exceedance frequencies" (e.g., the probability of an early fatality due to an event at the plant shall not exceed 1.0E-06 per year). The designers would design the plant using the best available engineering practices, but would have significant leeway in the plant design as long as they can demonstrate that the design will meet the quantitative public safety criteria. Defense-in-depth and safety margin would continue to be used by both the designer and the regulator to assure adequate safety. The difference, however, would be that risk-informed (probabilistic) methods would be used more prominently to make an integrated assessment of a plant design. Defense-in-depth would be used to address uncertainties in equipment performance and modeling when those uncertainties could not otherwise be addressed via the probabilistic models.

The highly risk-informed design process is a parallel, top-down process with two key elements; the design and performance analysis process itself, and the risk assessment/cost-benefit evaluation process [2]. In this top-down process, the design proceeds by stages from a very generalized design to the final detailed design. At each stage there is a significant interaction between the design process and the risk assessment process with the risk assessment being used as a design decision tool. This is consistent with the recent ASME policy statement on the role of risk analysis in decision-making [1].

In this context, risk is defined to be the combination of the probability and consequences of adverse outcomes that can result from various courses of action or undesired occurrences. Plants are designed for a successful, controlled operation under a set of anticipated operating conditions and configurations. However, it is recognized that challenges to the successful, controlled operation of the plant can arise due to failure of equipment, unanticipated operating conditions, or external challenges and if unmitigated, these challenges can result in undesired outcomes. In the risk-informed design process, the risk analysts work with the designers to identify the set of potential challenges to plant operation, to determine the potential adverse outcomes and to quantify the associated risk. The quantified risks are compared to the design risk criteria. If the criteria are not satisfied, the design is altered and the evaluation process is repeated. This risk evaluation process may also be used as part of the cost benefit analyses to decide between various design alternatives.

Currently, significant efforts are being made to utilize PRA technology to support the design and licensing of the PBMRs that are planned for construction in South Africa and the United States. Exelon Power Corporation in the document "Proposed Licensing Approach for the Pebble-bed Modular Reactor in the United States" lists the following objectives of the PBMR PRA:

1. To be an integral part of the PBMR design process;
2. To confirm that the Top Level Regulatory Criteria are met;
3. To support the identification of licensing basis events;
4. To provide a technical basis for the development of regulatory design criteria;
5. To support the determination of safety classification and special treatment requirements of systems, structures, and components;
6. To support the development of emergency planning specifications;
7. To support the development of technical specifications;
8. To provide insight on the application of defense-in-depth strategies.

Current status of the PBMR PRA has been discussed in [6].

3.0 Objectives

This work concentrates on the application of the risk-informed principles to a new plant design such as the gas-cooled pebble bed reactor. The basis for the analysis is the conceptual design presented in the SAR, 2000. Since the PBMR conceptual design puts a premium on passive mechanisms of decay heat removal, it is important that the role of the PBMR passive systems in the accident prevention and mitigation is evaluated explicitly and adequately incorporated in the new regulatory framework. Therefore an example chosen for a detailed analysis concentrates on the investigation of potential failure modes where performance of the novel design features such as water-based Reactor Cavity Cooling System (RCCS) is critical for the plant safety.

The scope includes specifying design configurations and using PRA techniques to evaluate the design, then iterating with subsequent design changes to achieve the desired level of safety and reliability.

4.0 Methodology

The methodology employed includes standard features of PRA such as initiating event selection, event tree construction, fault tree, common mode failure, and uncertainty analyses leading to sequence probability quantification. A Master Logic Diagram (MLD) is developed to be used in taking a top-down approach to identify the safety functions, and systems, structures and components (SSCs) that are required to maintain safety and to identify the accident initiators and system response failures that could compromise safety. The data bank employed draws upon light water reactor and gas-cooled reactor power plant experience. It includes component operating failure rates, demand failure probabilities, common mode failure fractions, fragilities and uncertainty distributions. This information was used as an input to the SAPHIRE code.

The Beta factor method utilized for the assessment of common mode failures compensates for the lack of sufficient design detail to explicitly model system interactions. The event tree quantification appropriately utilizes the fault tree probabilities by accounting for conditional probabilities. The transient analysis considers the physical phenomena and the timing specific for the PBMR. For sequence frequency quantification, Monte Carlo uncertainty propagation technique is employed.

The work presented herein is only an example of the new highly risk-informed approach. The analyses use the best available information. While the technical results are promising and hopefully representative of what is expected, it is realized that more design work needs to be done, more analysis work needs to be completed, and regulatory review must be accomplished before firm conclusions can be drawn with respect to specific safety features.

5.0 Differences in the Risk-Informed Goals for a LWR and a PBMR.

The safety goals from using PRA strategies in the regulatory framework for a LWR reactor may apply differently to a PBMR reactor. The goals of limiting core damage and large release frequency may not be applicable to the PBMR since the coated fuel pebbles are designed to retain fission products in normal and accident conditions and the fuel can never credibly get hot enough to melt in the accident conditions. Other sources of radioactivity release may need to be addressed as well.

Therefore, the nature of PBMR specific "risk measures" or "accident classes" need to be defined as part of the PRA application. The Level 1/Level 2/Level 3 structure from the LWR PRAs is not useful for the PBMR risk analysis. The PBMR initiating event sequences terminate with very small releases from normal circulating activity or defective fuel particles. Design precludes significant releases from initially intact fuel particles as temperatures are maintained below levels that would cause thermal degradation. More than 99.994% of the radio-nuclide inventory resides within the intact fuel particles. The breakdown of the sources of radioactive material in the 268 MWt PBMR is provided in the following table, which tracks a key radio-nuclide I-131 [6]:

Source	**I-131 Inventory (Ci)**
Circulating primary coolant activity	<1
Plate out on internal HPB surfaces	16
Uranium contaminated fuel particles	73
Failed and defective fuel particles	365
Intact fuel particles	7.3×10^6

Table 5-1 Radioactive Sources in the PBMR

One type of safety goal that can be applied to any reactor type is expressed as a “frequency versus consequence” diagram. This idea was first proposed by Farmer [7] and has been expanded on by others over the years (Ballard, [8]). Farmer proposed performing multiple safety evaluations, producing a “spectrum of events with associated probabilities and associated consequences.” In Farmer’s example, the reactor-years between accidental releases of ^{131}I were plotted against Curies of ^{131}I released. However, the consequences of interest can also be selected to provide different performance measures that support other high level criteria. For example, the consequence could be Curies of particular radio-nuclides released (e.g., ^{131}I, ^{90}Sr, ^{137}Cs, noble gases, alpha-emitters with a half-life greater than 5 years, etc), or percentage release of particular radio-nuclides or dose to a worker or a member of the public.

The potential consequences of PBMR accidents are spread over a range of accidents that involve the release of very small sources of radioactivity over long periods of time. The timing and quantity of radioactive material release in a PBMR accident vary over a limited range and involves participation by several small components of the total radio-nuclide inventory of the PBMR (see the table above).

5.1 Release Categories for the PBMR

In the risk analysis of the PBMR a set of release categories needs to be defined. Those release categories would define accident sequences and determine magnitude of the source term. The parameter input to those release categories could include:

- time;
- status of the primary barrier (Fuel particle coatings);
- status of the helium pressure boundary;
- status of the reactor building.

5.2 Time

Magnitude of the release depends on whether the release occurs early or late after the fission reaction has stopped. Time parameter describes how much time have passed between the fission reaction termination and the moment of the release.

5.3 Status of the primary barrier

Three parameters have to be specified to define the primary barrier status:

- Fuel temperature;
- Corrosion level (specifies whether or not oxygen is present);
- Time-at-temperature (specifies how long the fuel has been at a particular temperature).

5.4 Status of the helium pressure boundary

This parameter distinguishes between the following four states:

- Intact helium pressure boundary;
- Small leak which does not lead to the opening of the building ventilation valves;
- Large break resulting in the opening of the building ventilation valves;
- Break resulting in the chimney effect.

5.5 Status of the reactor building

This parameter distinguishes between the following three states of the reactor building:

- Building intact;
- Building vented;
- Building damaged.

6.0 Pebble Bed Modular Reactor Overview

6.1 General Description

The PBMR concept is based on German high temperature helium cooled pebble-bed reactor technology, demonstrated in the AVR and THTR reactors. The PBMR is a modular, graphite moderated, helium-cooled reactor that uses Brayton direct gas turbine cycle to convert the heat into electrical energy by means of helium turbo-generator. The PBMR plant specifications are summarized in the table below [5]:

Maximum Power Output	268 MW Thermal/120 MW Electric
Continuous Stable Power Range	0-100%
Anticipated Cost	$1000/KWe
Construction Schedule	24 Months
Outage Rate	2% Planned and 3% Forced
O&M and Fuel Costs	$4-5/MWHr
Emergency Planning Zone	<400 Meters
Plant Operating Life Time	40 Years
Maximum Operating Temperature	900°C
Maximum Operating Pressure	7 MPa

Table 6-1 PBMR Plant Specifications

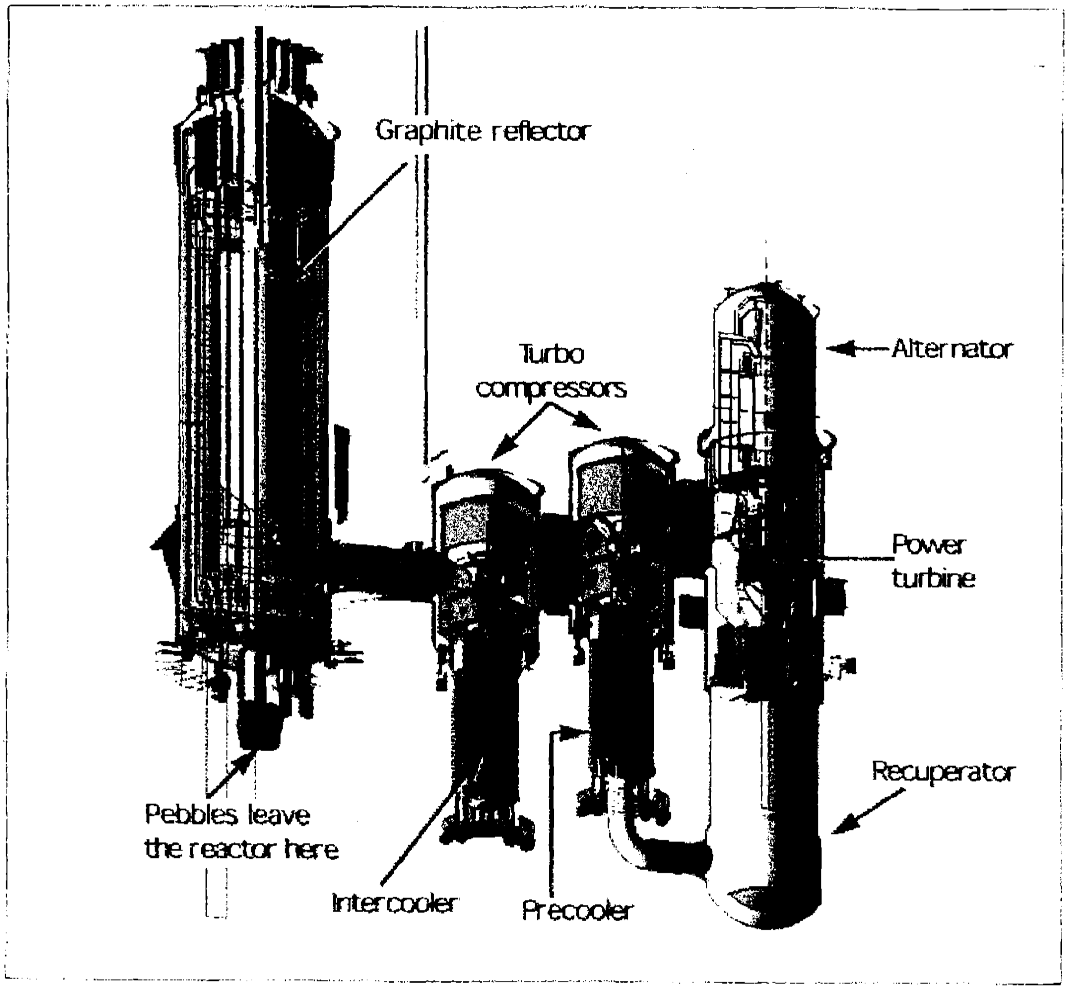
The PBMR Main Power System is illustrated in Figure 6-1 and the process flow is illustrated in Figure 6-2 [5]. The PBMR Main Power System includes a vertical steel pressure vessel, about 6 m (19.7 ft) in diameter and about 20 m (65 ft) high. It is lined with a 100-cm (39-in) thick layer of graphic bricks, which serve as a reflector and a passive heat transfer medium. The graphic brick lining is drilled with vertical holes to allow insertion of the control rods.

"The PBMR uses silicon carbide and carbon-coated particles of enriched uranium oxide encased in graphite matrix to form a fuel sphere, or pebble, about the size of a tennis ball. Helium is used as the coolant and energy transfer medium to a closed-cycle gas turbine and generator system. During normal operation, the PBMR core contains a load of 440,000 spheres, 330,000 of which are fuel spheres. The balance is solid nuclear-grade graphite spheres, which serve the function of an additional nuclear moderator. Graphite is used in nuclear applications because of its structural characteristics and its ability to slow down neutrons to the speed required for the nuclear reaction to take place. The graphite spheres are located in the center of the core and the fuel spheres in the annulus around it. This geometry limits the peak temperature in the fuel following a loss of cooling" [5].

To remove the heat generated by the nuclear reactor, helium coolant enters the top of the reactor vessel at a temperature of about 500°C and a pressure of 70 bar (7 MPa).

It then moves down between the hot fuel spheres, after which it leaves the bottom of the vessel having been heated to a temperature of about 900°C.

The hot gas then enters the first of three gas turbines in series, the first two of which drive compressors and the third of which drives the electrical generator. The coolant leaves the last turbine at about 530°C and 26 bar (2.6 MPa), after which it is cooled, recompressed, reheated and returned to the reactor vessel.



The Pebble Bed Modular Reactor (Source: PBMR [Pty] Ltd.)

Figure 6-1 Pebble Bed Modular Reactor System

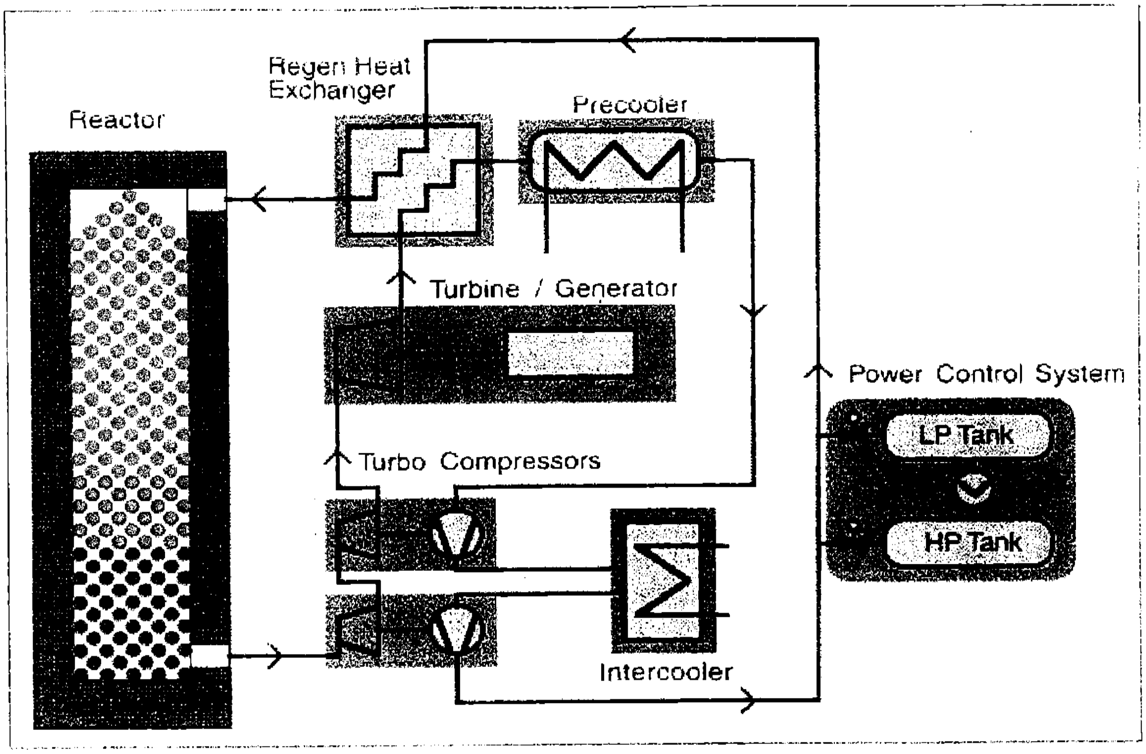


Figure 6-2 PBMR Process Flow

6.2 Fuel Design

This section is adapted from the Reference 5.

The PBMR fuel is based on the proven high-quality German molded graphite sphere and triple-coated particles (Triso). Essentially, the fuel elements are multi-layer spheres consisting of enriched uranium and various forms of carbon.

In the fabrication process, tiny beads of enriched UO2 are dropped to form microspheres, which are then gelled and calcined (baked at high temperature) to produce uranium fuel "kernels." The kernels are then run through a chemical vapor deposition (CVD) machine – typically using an argon environment at a temperature of 1000°C – in which layers of specific chemicals can be added with extreme precision.

For the PBMR fuel, the first layer deposited on the kernels is porous carbon, which allows fission products to collect without over-pressurizing the coated fuel particle. This is followed by a thin coating of pyrolitic carbon (a very dense form of heat-treated carbon), followed by a layer of silicon carbide (a strong refractory material), followed by another layer of pyrolitic carbon.

The porous carbon accommodates any mechanical deformation that the uranium oxide particle may undergo during the lifetime of the fuel. The pyrolytic carbon and silicon carbide layers provide an impenetrable barrier designed to contain the fuel and the radioactive decay products resulting from the nuclear reactions.

Some 15,000 of these fuel particles, now about a millimeter in diameter, are then mixed with graphite phenol powder and pressure into the shape of 50-mm-diameter balls. A 5-mm thick layer of highly pure carbon is then added to form a "non-fuel" zone, and the resulting spheres are then pressure, sintered and annealed to make them hard and durable.

Finally, the fuel elements are machined to a uniform diameter of 60 mm, about the size of a tennis ball. Each fuel sphere contains 9 g of uranium, which means that the total uranium in one fuel load is 2.97 metric tons. The total mass of a fuel sphere is 210 g.

Fuel particles are shown in Figure 6-3 [5].

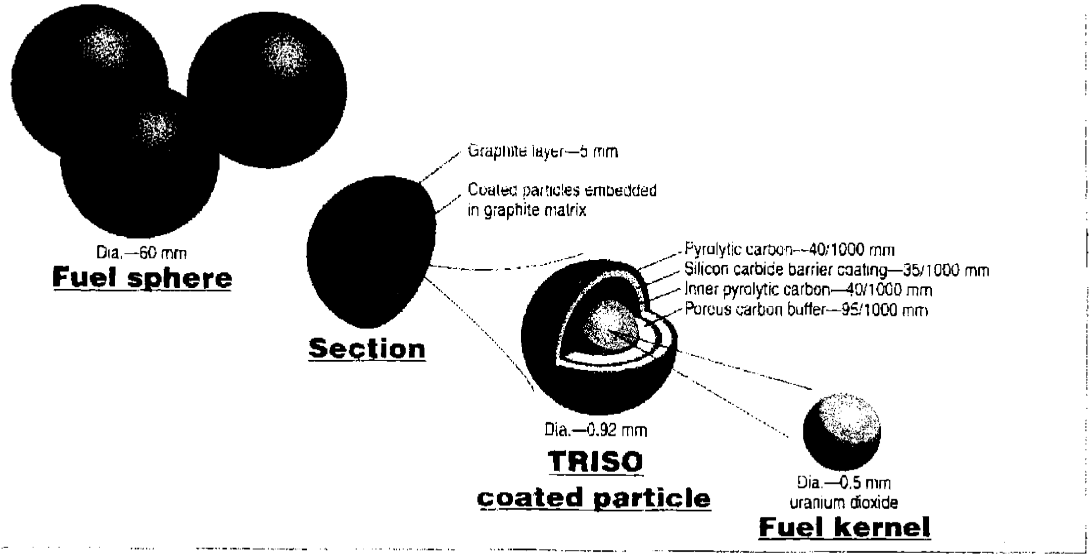


Figure 6-3 Fuel Element Design for the PBMR

6.3 Safety Features

The PBMR reactor concept is based on the well-tried and proven German AVR power plant which ran successfully for 21 years.

A unique aspect of PBMR is that design features and parameters have been selected so as to minimize the need for reliance on active safety components such as pumps, motors, valves, and associated safety systems. In particular, annular core geometry and low power density (1/30 of the power density of a PWR) have been selected ensure that decay heat can be removed solely by passive mechanisms of conduction, radiation and natural convection, thus eliminating heavy reliance on forced convection to prevent significant radionuclide release from occurring. Also, the fuel type and enrichment have been selected so as to favor an intrinsically strong negative temperature coefficient that shuts the chain reaction down in case of undercooling or overcooling transients. With this combination of features the required levels of safety can be achieved with a greatly simplified design, which gives notably advantageous economic performance when compared to existing reactor designs, which must rely upon extensive engineered safety systems to achieve acceptable levels of safety. Because of the potential for failure in these systems, they are duplicated to provide redundancy. Other systems, such as a containment building, are provided in the conventional reactor designs to mitigate the consequences of failure and provide a further barrier to radioactive release. Unlike LWR types, the PBMR conceptual design puts a premium on the inherent and passive safety features. Therefore the PBMR advocates argue that adoption of design requirements which are suitable for other reactor types should be avoided in the case of the PBMR. In particular, the necessity of the pressure-retaining containment building is questioned.

The Fundamental Safety Design Philosophy of the PBMR is based on the premise that the fuel adequately retains its integrity to contain radioactive fission products under normal and accident conditions. The size of the PBMR core is such that it has a high surface area-to-volume ratio. This means that the amount of heat that it loses through its surface is greater than the amount of heat generated by the decay of fission products in the core. The reactor, therefore, is not expected to reach a temperature at which significant degradation of the fuel can occur.

Safety tests conducted on the German AVR power plant demonstrated that even in case of complete cessation of forced cooling followed by withdrawal of control rods chain reaction shuts itself down within a few minutes and fuel temperature does not exceed design limit of 1600°C.

Preliminary analysis based on the PBMR conceptual design indicates that even in case of the most severe envisioned transient - withdrawal of all control rods followed by a fast depressurization and no scram fuel temperature limit is not exceeded.

The graph for a fuel failure fraction as a function of the temperature is presented in Figure 6-4 [5]. The calculated temperature distribution during a depressurized loss of forced cooling is presented in Figure 6-5 [5].

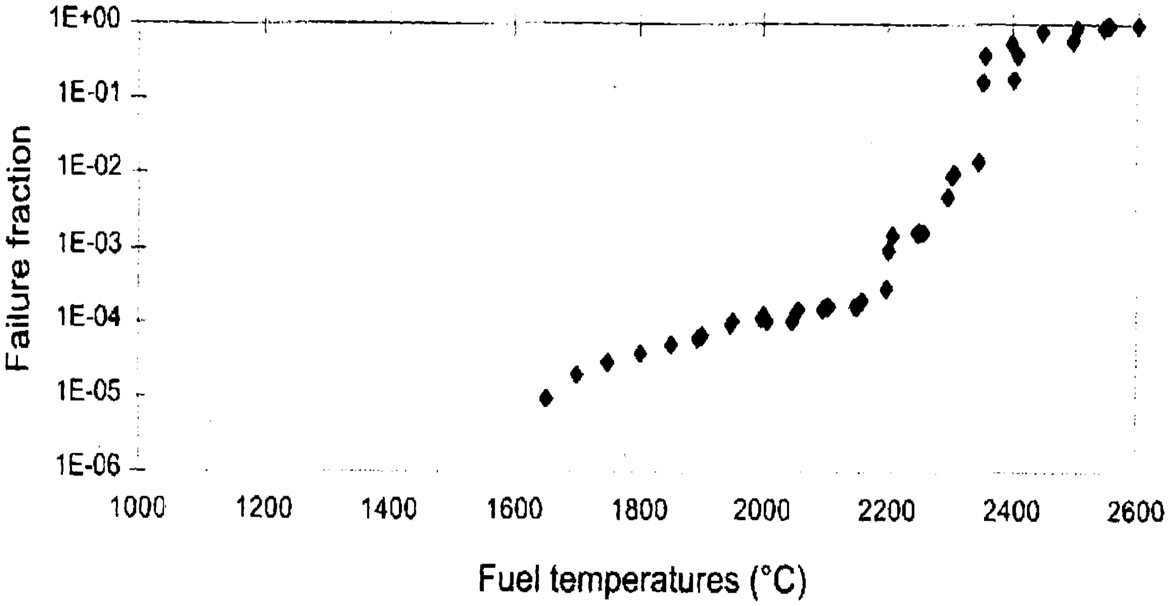


Figure 6-4 Fuel Failure Fraction vs. Temperature

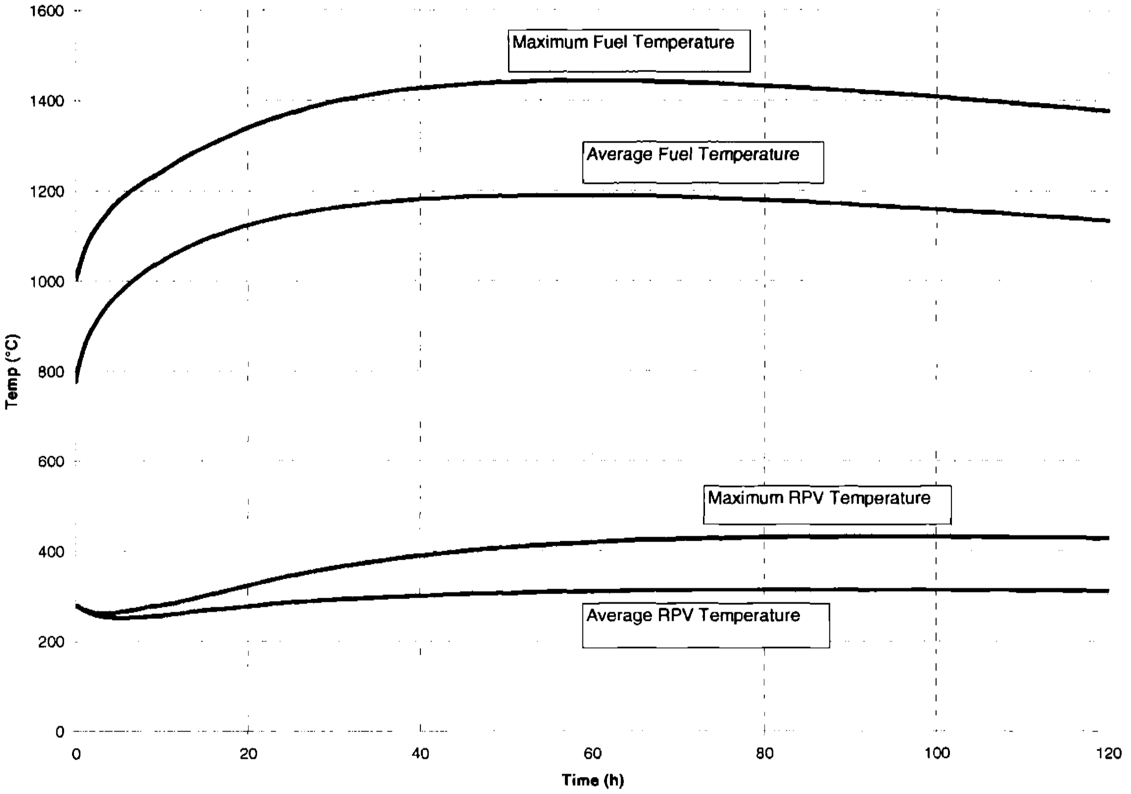


Figure 6-5 Temperature Distribution in Case of the Depressurized Loss of Forced Cooling

6.4 Safety Systems

This section summarizes the specifications of the design configuration of the systems most important for the purpose of our study.

6.4.1 Reactor Cavity Cooling System (RCCS)

The RCCS is designed to remove and dissipate to the sea (or to the atmosphere, when sea water is not available) the waste heat from the reactor cavity during all modes of reactor operation, including a Pressurized or Depressurized Loss of Forced Cooling. The heat from the reactor vessel walls is transported to the cooling chambers of the cavity cooling system by thermal radiation and convection thus protecting the concrete wall of the reactor cavity, and ensuring that the maximum allowable Reactor Pressure Vessel (RPV) and fuel temperatures are not exceeded.

The RCCS consists of three identical cooling trains, where each train is an independent, low-pressure, closed-loop, pump-driven, water-based cooling system sized to dissipate 50% of the maximum heat rejected by the reactor under a Depressurized Loss of Forced Coolant event.

The system consists of a series of low carbon steel water chambers arranged vertically around, and concentric to, the RPV. Three inlet and outlet headers are arranged around the top of the chambers. Each outlet header transports hot water to a heat exchanger situated outside the reator cavity, after which it is pumped back into the corresponding inlet header. From each inlet header, feed lines enter the top of every third chamber, and then run down the inside of the chamber to discharge cold water at the bottom. The entire structure is suspended from a support ring resting on the concrete wall of the reactor cavity, thereby allowing free expansion and contraction. Thermal shields close the gaps between the chambers to prevent hot spots from developing on exposed concrete. Anti-siphoning devices are fitted to prevent the chambers from being emptied in the event of a low-level break in the pipework outside of the reactor cavity. The arrangement of the RCCS water chambers and headers is presented at the Fig.2.1.2 (Appendix A).

All three cavity cooling systems are connected to the back-up cooling towers which automatically come on line if a fault is detected in any of the cavity cooling system pumps.

In the event of the failure of all the pumps and /or heat exchangers, including the loss of the cooling towers, the water in the chambers is allowed to heat up to the boiling point over a period of about 24 hours. Should the pump-heat exchanger fault persist, the hot water in the chambers is converted, over a period of about seven to nine days, to a low-pressure steam, which is released into the atmosphere from the roof of the module building. This ability of RCCS to remove heat from the reactor cavity without any external power source is one of the design characteristics that makes the PBMR an inherently safe design.

6.4.2 Core Conditioning System (CCS)

The CCS removes core heat when the Brayton cycle is not operational, in order to facilitate cool-down or start-up operations. It consists of two 50% systems, installed within their respective pressure vessels, which is in turn connected to the RPV by feed and return pipes. The pressure boundary of the CCS forms part of the PPB.

The CCS is a manually activated system designed to perform the following functions:

- Remove decay heat when the reactor is shut down and. the Brayton cycle is not operational. This is necessary in order to cool the reactor down to a temperature that will allow maintenance operations to take place.
- In the event of the plant trip, cool the reactor down to a temperature that will allow a restart.
- During start-up operations, the reactor will be made critical with only the CCS in operation before the Brayton cycle is initiated. In these conditions, the CCS is required to provide the required core mass flow, and to remove core fission heat.

The CCS consists of two separate but identical systems, each with a 50% capability. Each of these CCS systems is installed in its own pressure vessel that is connected to the RPV by a hot feed pipe, and to the Power Conversion Unit (PCU) by a cold pipe. The feed and return pipes of the CCS are contained inside their own pressure boundary.

6.4.3 Active Cooling System (ACS)

The ACS is a water-based system which has specifically designed and controlled components to cool the required higher level systems and components. The function of the ACS is to remove waste heat from the Power Conversion Unit, consisting of the Pre-cooler, Intercooler and Generator and from the various auxiliary systems including RCCS and CCS and to transfer this heat to the ultimate heat sink which, for the demonstration module, is the sea.

The ACS is made up of four subsections:

- The Open Circuit, which transfers heat from the main, auxiliary and RCCS heat exchangers to the ultimate heat sink.
- The Main Closed Circuit, which carries heat from the Power Conversion Unit to the main heat exchangers.
- The Auxiliary Closed Circuit, which carries heat from various small heat sources, to the auxiliary heat exchangers.
- The back-up cooling towers, which provide back-up cooling to the auxiliary heat sources.

7.0 Initiating event selection for the Pebble-Bed Modular Reactor

7.1 Methodology

The following method has been proposed for the event evaluation for the PBMR design:

1. Identify possible enveloping events for a range of initiating conditions, e.g., reactivity excursions, loss of coolant, etc.
2. Analyze the "enveloping" or limiting event using best estimate calculations.
3. Perform a PRA on these events to obtain a classification in terms of probability of occurrence and identify the full spectrum of events of interest.
4. Analyze a number of subordinate events with possibly higher frequency, using conservative calculation methods and assumptions.
5. Confirm that the enveloping event will be a worst-case event by searching for all possible contributors and ascertain that none exceeds the enveloping events for consequences and that no event will result in the regulatory requirements being exceeded.

An analytical tool used to organize the process of initiating event selection is the Master Logic Diagram (MLD). The Master Logic Diagram provides a logical framework to identify the safety functions, and systems, structures and components (SSCs) that are required to maintain safety and to identify the accident initiators and system response failures that could compromise safety. Beginning with the topmost level in the MLD, each succeeding level is constructed in a logical manner. This is accomplished by identifying all radionuclide sources in the plant and the barriers that can retain them, in the upper region of MLD. The lower levels of MLD are completed by incorporating the physical mechanisms capable of challenging the barriers identified in the upper portion of the diagram and transporting radionuclides to the environment. Ultimately various event sequences are postulated, each involving different combination of events, and resulting in a particular type of release. The probability of occurrence of each event along each of the event sequences in the event tree is computed using fault trees which use reliability data of the relevant Structures, Systems and Components.

By comparing estimates of the doses associated with each type of release, as well as likelihood that the various event sequences occur, the dominant safety risk event sequences are identified. The events, which initiate this dominant event sequences are then selected for detailed study in the PRA event trees. The consequences of the accident sequences are then estimated in terms of the effects on the health and safety of the public.

The MLD developed for this study employs Boolean logic in the manner of a fault tree (Fig. 7-1) A top-down approach ensures completeness in the process of identifying critical safety functions and initiating events specific to the pebble-bed reactor.

As the tree shows, there is a combination of two first-level functions that should be performed to control the offsite release of the radioactive material:

- To control the release of radioactive materials inside the containment
- To ensure containment/confinement capability to attenuate the release

Conventional reactor designs have placed considerable emphasis on control of the radioactivity transport from the reactor building. Accordingly, the performance or non-performance of the reactor building in conventional designs has a significant influence on assessed risks.

However, the safety philosophy of the PBMR has been to place a primary reliance on the achievement of the first function as a means to minimize the risks. It has been argued that the pressure-retaining containment is not necessary for the PBMR as the risk envelope of the PBMR is projected to be less sensitive to failures of the barriers beyond the primary barrier – the fuel particle coatings. This MLD, therefore, is focusing on initiators which pose a challenge to the fuel integrity.

Level two of the MLD identifies three functions that should be performed in order to control the release of radioactive material inside the reactor building.

- Control the release of activation materials from the processes (e.g, activated water spill, fuel handling accidents)
- Control the release of radioactivity from the storage facilities (Spent fuel criticality and heat removal design has to be analyzed as well as overpressure and mechanical failure accidents)
- Control the release of fission products from the Primary Pressure Boundary.

This MLD focuses on the search for the initiators that pose a significant risk to the public and personnel. Releases due to events taking place in the spent fuel storage and water-carrying systems will generally be much smaller than those due to primary circuit breach. There are three main reasons for this:

- Firstly, the amount of uncontained Radioactive-Material available for release from the Spent Fuel Storage Tanks is very small compared to that of the primary circuit
- Secondly, significant decay of the fuel have occurred, and therefore less radioactive material will be available for release
- Similarly, events involving water-carrying and fuel handling systems are expected to contribute a negligible amount to risk to the public, and should only be considered in terms of plant personnel risk.

Additionally, the design of the PBMR presents no unusual challenges to controlling the risks from these sources of activity.

The third level of the MLD identifies two functions associated with the barriers to fission product escape from the primary pressure boundary:

- Maintain fuel integrity
- Maintain primary pressure boundary integrity

Pressure boundary failure events include pipe breaks, seal leaks, valve malfunction, as well as vessel and vessel cross-duct damage in case of severe transients.

Level four of the MLD identifies that the activity releases from the fuel into the coolant gas are due to:

- The Fuel fraction which has initial damage to silicon carbide layers - primary barrier for fission product escape from the pebbles.
- Fuel damage during a transient.

The Fundamental Safety Design Philosophy of the PBMR is based on the premise that the fuel adequately retains its integrity to contain radioactive fission products under normal and accident conditions. Also, there is a presence of circulating radioactivity in the primary circuit due to a fraction of fuel particles having defective coatings. Therefore it is of major importance to maintain an adequate fuel quality control in order keep fraction of defective fuel particles within industry standards.

Level five of the MLD identifies two mechanisms responsible for fuel degradation:

- Exceeding the fuel design temperature limit;
- Chemical attack on the fuel.

Level six of the MLD identifies three functions which can be defined as critical to maintaining the fuel integrity:

- Control of excessive heat generation
- Control of insufficient heat removal
- Control of chemical attack on the fuel (such as water or air ingress).

7.1.1 Initiators Challenging Heat Generation.

In the PBMR, the following events may cause an undesired increase, over a relatively shorttime interval, of the core reactivity and the reactor power:

- Inadvertent withdrawal of control rods (due to errors in control system or mal-operation);
- An automatic trip failure (may be caused by instrumentation failure, control logic failure, or a mechanical failure which prevents the insertion of an adequate quantity of control material);
- Manual trip failure (due to instrumentation failures, mechanical failures or operator failure);
- Ingress of moderating material into the core (water);
- Inadvertent increase in primary coolant mass flow with consequent overcooling;
- Compaction of the pebble bed due to an earthquake;

Though it has been proposed that a distinction is to be made between reactivity excursions for the following conditions:

- Full-power operation;
- Partial power operation;
- Hot zero power;
- Cold critical,

it has been found that the full power operating mode is limiting for the PBMR. This is because the reliability of cooling systems is not significantly affected by the plant operating states. The PBMR design relies highly on passive safety features such as RCCS which is always operational. Furthermore, since the safety philosophy of the PBMR has been to maintain the integrity of the fuel particle coatings, operating mode changes have less impact upon safety.

The event which results in the largest reactivity insertion into the core is the control rod bank withdrawal event, the consequences of which would be generally worse under normal operating conditions. The severity of such an event as well as of failure to trip is generally limited by a strong negative temperature coefficient. The negative temperature coefficient, however, does not reduce power levels to normal decay heat levels and thus fuel and coolant temperatures above those encountered in decay heat removal scenarios will be encountered in the core.

Though considered very unlikely, the withdrawal of all control rods followed by a fast depressurization with no subsequent scram is proposed for the use as design criteria by the PBMR design team.

7.1.2 Initiators Challenging Heat Removal.

Loss of forced cooling can be caused by the following events:

- Interrupt or bypass valve malfunctioning;
- Turbine compressor failure;
- Brayton cycle upsets;
- Fast depressurization due to a pipe break or similar size failure elsewhere of diameter greater than 65 mm in the coolant loop.

The CCS is intended to take over the cooling of the core with the reactor scrammed by the control system. The absence of active core cooling will result in an increase in the average core temperature, with a redistribution of the stored heat and the eventual transfer of the decay and stored heat to the RPV wall, from where conduction, convection and direct radiation will transfer the heat to the RCCS. The CCS cooling may be disrupted by the following events:

- Loss of power;
- Valve malfunctioning;
- Pipe breaks and mechanical failures.

The PBMR design intentionally places primary reliance on natural processes of thermal radiation and convection to transport the heat from the non-insulated reactor vessel walls to the sea via the intermediate heat sink (RCCS) and the surroundings during all modes of reactor operation. The RCCS consists of three identical cooling trains, where each train is sized to dissipate 50% of the maximum heat rejected by the reactor under a Depressurized Loss of Forced Cooling (DLOFC) event. The RCCS is needed for medium and long-term protection of the fuel and the reactor cavity structures. When active operation of the RCCS has ceased and cannot be reintroduced, the RCCS may dry out, and alternative ways to fill the RCCS will have to be found.

A cessation of active operation of the RCCS with the following dry-out can be caused by the event of a long-term failure of the power supply, both normal and emergency which, in turn, may be introduces by a large seismic event.

7.1.3 Initiators Challenging Control of Chemical Attack.

Large-scale air or water ingress may cause fuel corrosion. A limited amount of water in the system rules out the possibility of the massive fuel damage due to water ingress.

Air ingress can only occur when the PBMR is in a depressurized condition caused by a leak, or possibly during maintenance. Even then the air will have to displace the helium left in the core, and how this can take place depends on the size and position of the opening. Possible, though unlikely, initiators of massive air ingress are:

- Cold gas return pipe break;
- Conditions of hermetical sealing are broken during the maintenance and not restored.

The complete severance of the manifold with the hot and cold gas pipes has been postulated for the analysis by the PBMR design team as a limiting event. Preliminary analysis has demonstrated [5] that even if such an event should happen, it would lead only to less than 10^{-6} (one millionth) of the radioactivity in the core being released per day. That means that the amount of activity released in 24 hours under this very severe (and recoverable) situation would be some 10,000 times less than that requiring any offsite emergency actions.

7.2 Summary.

Based on the MLD, the following critical Safety Functions are identified for the PBMR:

- Control of excessive heat generation
- Control of insufficient heat removal
- Control of chemical attack on the fuel (such as water or air ingress)
- Control of the release from the spent fuel storage
- Quality control of the fuel arriving at the plant
- Maintaining primary pressure boundary integrity.

The following initiating events can be proposed for detailed evaluation:

- Reactivity excursions;
- Loss of Forced Cooling;
- Fast Depressurization;
- Air Ingress;
- Earthquake;
- Internal disturbances (Core);
- Internal Disturbances (Spent Fuel);
- Primary Pressure Boundary Leaks;
- Station Blackout.

In terms of consequences, the following limiting events can be postulated to be challenges to the safety functions responsible for maintaining fuel integrity:

- Withdrawal of all control rods without scram followed by a fast depressurization and failure to take mitigating action for at least 72 hours;
- The complete severance of the manifold with the hot and cold gas pipes;
- Loss of the Intermediate Heat Sink (RCCS) and failure to take mitigating action for 185 hours

These limiting events are regarded as extremely implausible, and analyzing these will create confidence that there are no credible events which are of such severity and constricted timescales that public could be endangered without mitigation action being possible.

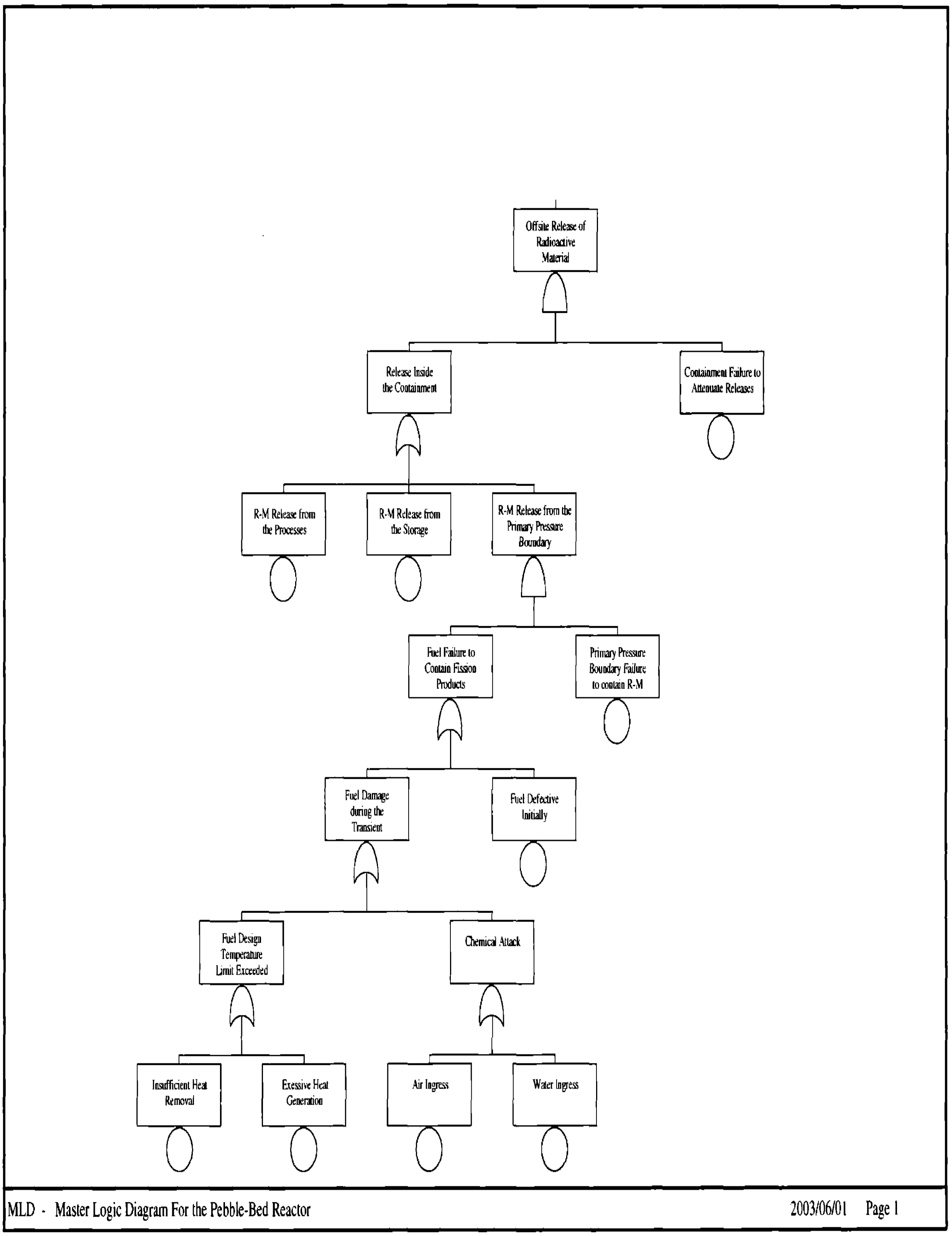


Figure 7-1 Master Logic Diagram for the Pebble-Bed Reactor

8.0 Event Analysis

8.1 Earthquake -Induced Failures.

Seismic events have been chosen for consideration in this study because they (1) simultaneously challenge active and redundant equipment and (2) pose one of the few potential risks to passive equipment. It is most likely that the limiting event such as Loss of the Intermediate Heat Sink (RCCS) and failure to take mitigating actions for at least 185 hours can be initiated by a significant earthquake.

The Pebble-bed reactor is designed to be able to rely solely on passive heat transfer mechanisms such as conduction and radiation to RCCS water chambers. Even in case of loss of RCCS function, hundreds of hours are available to take recovery actions. Based on the design information available, two RCCS failure modes have been identified:

1. Loss of water in the RCCS chambers resulting from the RCCS structural failure;
2. Boil-off of the RCCS water resulting from the prolonged loss of power.

Several studies conducted on this subject suggest that in case of the total loss of power RCCS water heats up and boils off to the atmosphere over the period of 3-7 days. After that, if RCCS water has not been restored, the reactor cavity concrete and the vessel start to heat up until, over a period of hours, a loss of the structural strength occurs. After vessel loses its structural integrity, fuel spheres and graphite reflectors become exposed to an air and start to oxidize. For this case, the following scenarios should be investigated:

1. The possibility of damage to SiC layers via oxidation;
2. The possibility of a graphite fire, leading to fuel damage via overheating.

A large degree of uncertainty is present in both cases. First of all, the oxidation rate depends on the amount of oxygen available for the reaction. Therefore, possible flow paths for the air convection should be considered. Also, in the first case, a lack of experimental data concerning the SiC temperature-dependent susceptibility to oxidation does not provide an adequate basis for assigning appropriate release categories. Detailed design information is not available at this conceptual design stage to permit a reliable evaluation of this scenario. Analysis of this event can be conduced as additional design information becomes available.

8.2 Event Tree Construction and Quantification

In performing the seismic analysis of the conceptual PBMR design, several preliminary assumptions are necessary. First, it is necessary to assume site seismic characteristics.

For the purpose of our study, site parameters of the Seabrook Station have been selected as a reference for the seismic hazard curve. Secondly, assumptions have been made regarding the fragility of the plant. Since only a very limited accounting for plant specific variations for plant conceptual design can be made, it was assumed that the plant will be constructed in a manner comparable to existing Light Water Reactors (LWRs). Available data has been reviewed and after accounting for design differences between LWR and PBMR, representative equipment and structure fragility values have been selected.

The fragility data in the literature is developed primarily from the analysis and engineering judgment supported by limited test data. Such fragility estimates contain considerable uncertainty, which is usually represented by two factors in the literature. One accounts for the random variability in a particular earthquake's characteristics, and the second accounts for uncertainty in measuring a particular component's seismic response. The first factor was included in this assessment by assuming the random variability follows a logarithmic relationship in which the median values listed in Table 7.4 correspond to peak ground acceleration causing 50% of the components to fail. The second factor was included by utilizing a Latin Hypercube selection process from each component's fragility uncertainty distribution. Thus, component fragilities were statistically combined with the probability of a particular ground acceleration to estimate plant system response following an earthquake.

8.3 Modeled Accident

A limiting event chosen for the analysis involves Loss of the Intermediate Heat Sink (RCCS) and failure to take mitigating action for ≥185 hours. The event tree is presented in Figure 8-1.

Various event sequences corresponding to different plant responses are depicted in the event tree. Each sequence's frequency has been assessed by evaluating the initiating event frequency and branch point conditional probabilities within an event tree utilizing the fault tree quantification methodology. Uncertainty quantification employed s Monte Carlo method of error propagation. This section discusses the likelihood of event sequences corresponding to possible plant response scenarios.

8.3.1 EIE (Earthquake Initiating Event)

Preliminary studies disclose that above approximately 0.2g, main loop cooling may be disrupted due to spurious signals from electrical system equipment. Earthquakes are not, however, expected to impact the RCCS structures or the control system reliability at intensities below 0.8g.

8.3.2 PPB (Primary Pressure Boundary Integrity)

The event named PPB considers whether the primary pressure boundary remains intact following an earthquake. In general, plant response varies depending on the peak ground acceleration and primary coolant pressure. Failure branch corresponding to the Primary Pressure Boundary Failure represents the possibility for the release of circulating and plateout activity inside the reactor building. The amount of radioactive material released to the atmosphere is calculated depending on the size of the leakage area and potential flow path configuration. The detailed methodology is described in the MHTGR PRA [28]. In this study, we'll be focusing on the case where Primary Pressure Boundary remains intact and no helium pumpdown is available to reduce load on the reactor vessel thus increasing vessel failure probability as temperatures grow high.

8.3.3 TRIP (Reactor Trip)

Here we consider whether the reactor trip has been performed successfully. Success of Failure of the reactor trip has been evaluated as a combination of the following events:

Reactor Trip with Rods

PPIS initiates the reactor trip based on the signals from the vibration sensors, or in case PPIS is disabled, the control rods can be inserted by gravitational forces (if power is lost) or manually by operator.

Reactor Trip with Reserve shutdown Mechanism

In the unlikely event that the Reactor Trip with Control Rods fails, the reserve shutdown material (boronated pellets) is dumped into the core. Failure of the PPIS, common mode failure of several RSCE (Reserve Shutdown Control Equipment) hoppers or the loss of the ac or dc power supply could cause failure of automatic insertion of SAS. In case of ac power failure, operator can still manually insert reserve shutdown material into the core.

8.3.4 CCS (Core Conditioning System Performance)

Event CCS considers whether or not CCS is successfully started and if it is started, whether it runs successfully. The failure of the CCS following an earthquake was calculated as the combination of earthquake-induced failures and the conditional probability of failure due to other mechanisms.

8.3.5 RCCS (RCCS Performance)

Following the loss of power, the RCCS gradually heats up over a period of approximately 24 hours. Should the fault persist, the hot water in the RCCS chambers is converted, over a period of 87 hours[9], into a low-pressure steam, which is released into the atmosphere from the roof of the module building. After period of approximately 87 hours water in the RCCS chambers boils off [9] and vessel temperatures start to rise.

8.3.6 RCCS-R (RCCS Cooling Restored Prior to Vessel Damage)

The PBMR reactor vessel is made of SA 508 steel. Yield strength and modulus of elasticity of carbon steel vary with temperature. At elevated temperatures (>600°C) its yield strength is greatly reduced [9]. If the vessel temperature were to become too high, rupture of the vessel and subsequent damage to the fuel would become possible.

Preliminary analysis indicates that after the RCCS system loses its water supply without being refilled, the vessel temperatures will gradually rise to above 900°C [9]. The strain rates of vessel material also increase with the vessel temperature and a fracture could result. This fracture would lead to a primary system depressurization thus reducing the vessel internal pressure. The vessel stress will become compressive. Ductile failure would likely continue near the point of fracture possibly leading to a catastrophic failure of the vessel since the fracture would act as a stress concentrator [9]

It is assumed that a large earthquake could disable the electrical power to the primary and backup pumps for the RCCS. The Reactor Cavity Cooling System could operate for approximately three days without being re-filled with water. For this accident to have an effect on the PBMR safety, operators would fail to refill the RCCS for at least 100 hours. The first variable in this accident is the time required for operators to take the necessary actions. The operators could fail to take the appropriate actions for one of two reasons. First, the earthquake could have restricted access to the PBMR site or RCCS piping. Second, the operators could make an improper diagnosis related to the RCCS operation. The longer it takes for operators to respond correctly, the higher is the possibility of damage to the PBMR vessel.

Preliminary analysis based on the design information available at this point estimates the meantime for boil-off to be 87 hours. A mean time for the catastrophic failure of the vessel is estimated to be 185 hours, which corresponds to an 850°C vessel temperature (Reference 9). In order to prevent the catastrophic failure of the vessel, the operators should respond before this time. In estimating the likelihood of restoring RCCS function general data for human errors were used. The situation may be aggravated due to a general confusion following a large earthquake and possible personnel injuries.

The next event in the modeled accident is possible damage to the fuel pebbles that could result in a release of the fission products. This event is not shown separately in the event tree since it is difficult to determine the degree of the fuel damage at this conceptual design stage and further analysis is needed. Several factors affect the degree of the fuel damage and the magnitude of the release. Following the failure of the vessel, the fuel could be damaged by a mechanical shock, a thermal shock, or a chemical attack. The fuel temperature in this case is extremely high thus favoring a rapid oxidation. The degree of the damage depends on the possible air flow paths in the reactor cavity.

8.3.7 BLDG (Building Failure)

The last event describes the possibility of the fission product transport outside of the PBMR building. The fission products could be mixed with helium in the cavity and carried out via the pressure relief system. If pressure does not become high enough, fission products are expected to settle inside the reactor building with the possibility of a leakage due to a building failure.

Detailed design information is not available at this conceptual design stage for a reliable evaluation of some initiating). Analysis of such events can be conduced as additional design information becomes available.

8.4 Release Categories

Four release categories are defined from the failure sequences: RC-A (Sequence 4), RC-B (Sequence 8), RC-C (Sequence 12) and RC-D (Sequence 16). Any release is based on the failure of the RCCS system and the building confinement. Different release categories are modeled based on the following functions:

- success of the trip
- success of the core conditioning system

Is can be assumed that only releases RC-B (conduction cooldown with scram successful) and RC-D (conduction cooldown with no scram) can pose significant risk to public.

Determining a size of the source term for each release category would require additional experimental data on the SiC temperature-dependent susceptibility to oxidation and detailed design information. For this example, a rough estimate is given of the time available for the corrective action before the release occurs, based on the work presented in Reference 9.

The release categories are defined in Table 8-1.

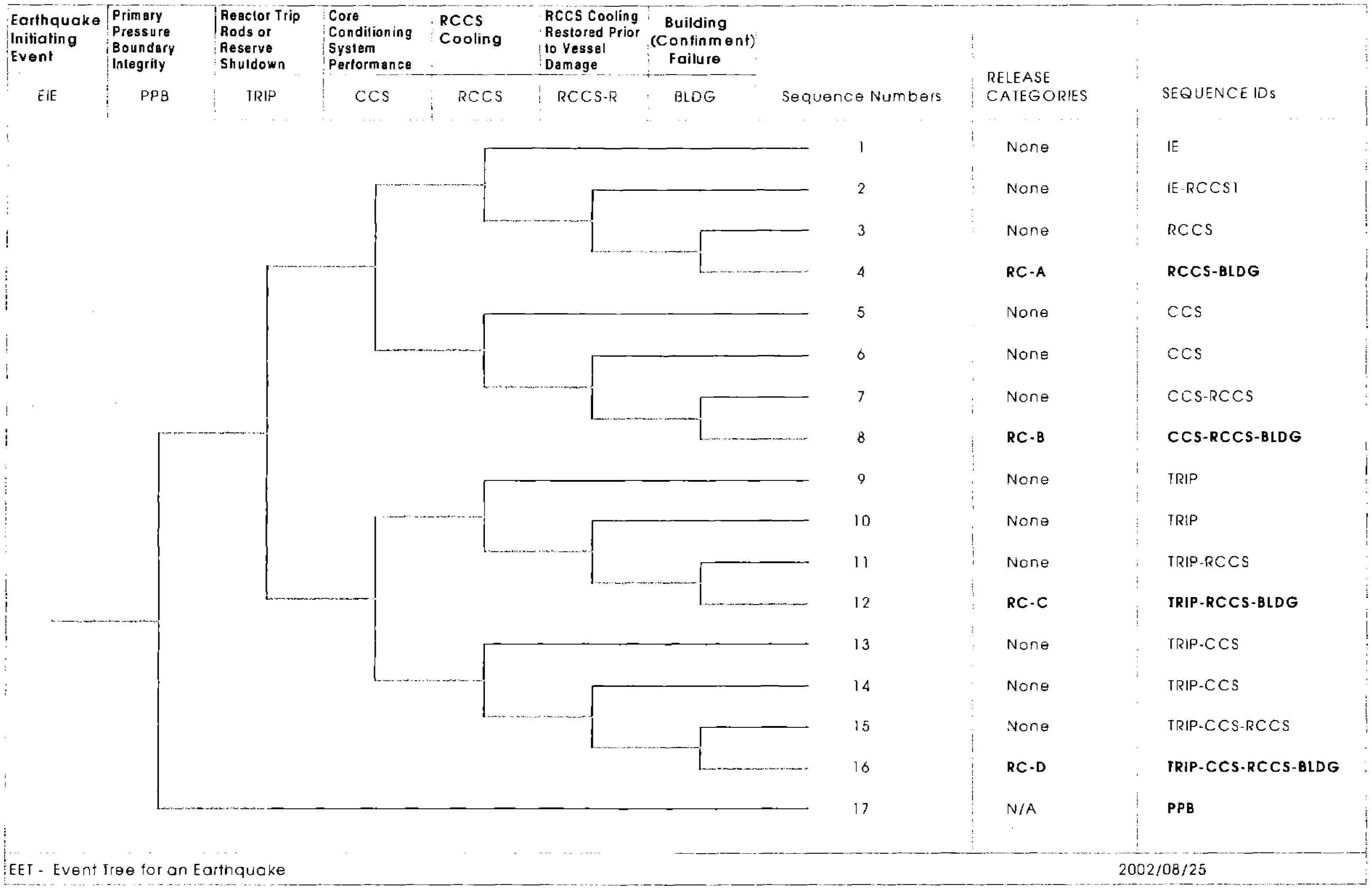


Figure 8-1 PBMR Seismic Event Tree

TRIP Success	Core Conditioning System Successful	RCCS & Recovery	Confinement	Time Before Release	Sequence Number	Release Category
YES	YES	NO	NO	>10 days	4	A
YES	NO	NO	NO	10 days	8	B
NO	YES	NO	NO	>5 days	12	C
NO	NO	NO	NO	5 days	16	D

Table 8-1 Release Categories, Corresponding Event Sequences and Attributes

9.0 Fault Trees

The fault trees used in the analysis are defined in Table 9-1. A few trees are broken into the subtrees defined in Table 9-2. Even single event top events are presented in the form of a fault tree. All fault trees and subtrees are illustrated in Figures 9-1 through 9-12.

Top Event	Description	Model	Fault Tree Figure
EIE	Earthquake Initiating Event	Initiating Event	Figure 1-2
PPB	Primary Pressure Boundary Integrity	Undeveloped Event	Figure 1-3
TRIP	Reactor Trip with Rods or Reserve Shutdown System	Fault Tree	Figure 1-4
CCS	Core Conditioning System Performance	Fault Tree	Figure 1-5
RCCS	RCCS Performance	Fault Tree	Figure 1-6
RCCS-R	RCCS Cooling Restored Prior to Vessel Failure	Human Action	Figure 1-12
BLDG	Building (Confinement) Failure	Undeveloped Event	Figure 1-13

Table 9-1 Fault Trees Corresponding to PBMR Seismic ET Top Events

Subtree	Description	Top Event/Fault Tree	Subtree Figure
TRIP-RODS	Failure to Trip With Rods	TRIP	Figure 1-4
LOOP1	Failure of RCCS Loop 1	RCCS	Figure 1-7
LOOP3	Failure of RCCS Loop 2	RCCS	Figure 1-8
EL-POWER	Loss of Electrical Power	RCCS and COOLING-TOWERS	Figure 1-9
COOLING-TOWERS	Loss of Cooling Towers	CCS and RCCS	Figure 1-10
OPEN-CIRCUIT	Loss of Open Circuit	CCS and RCCS	Figure 1-11

Table 9-2 Organization of the PBMR Seismic Subtrees in SAPHIRE

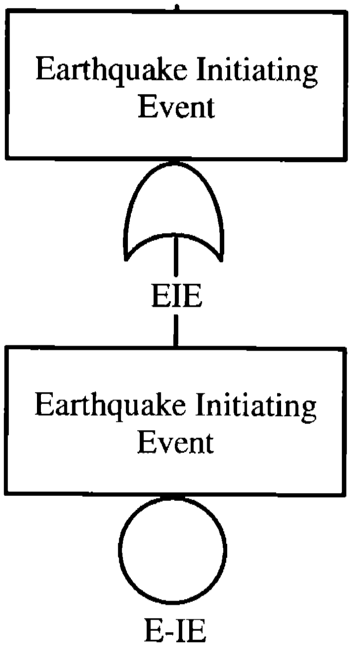


Figure 9-1 Earthquake Initiating Event Fault Tree (EIE)

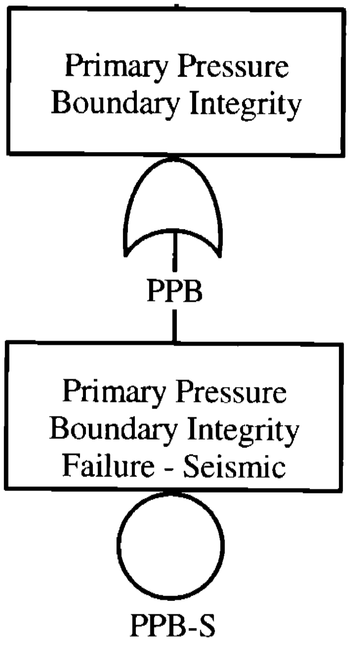


Figure 9-2 Primary Pressure Boundary Integrity Fault Tree (PPB)

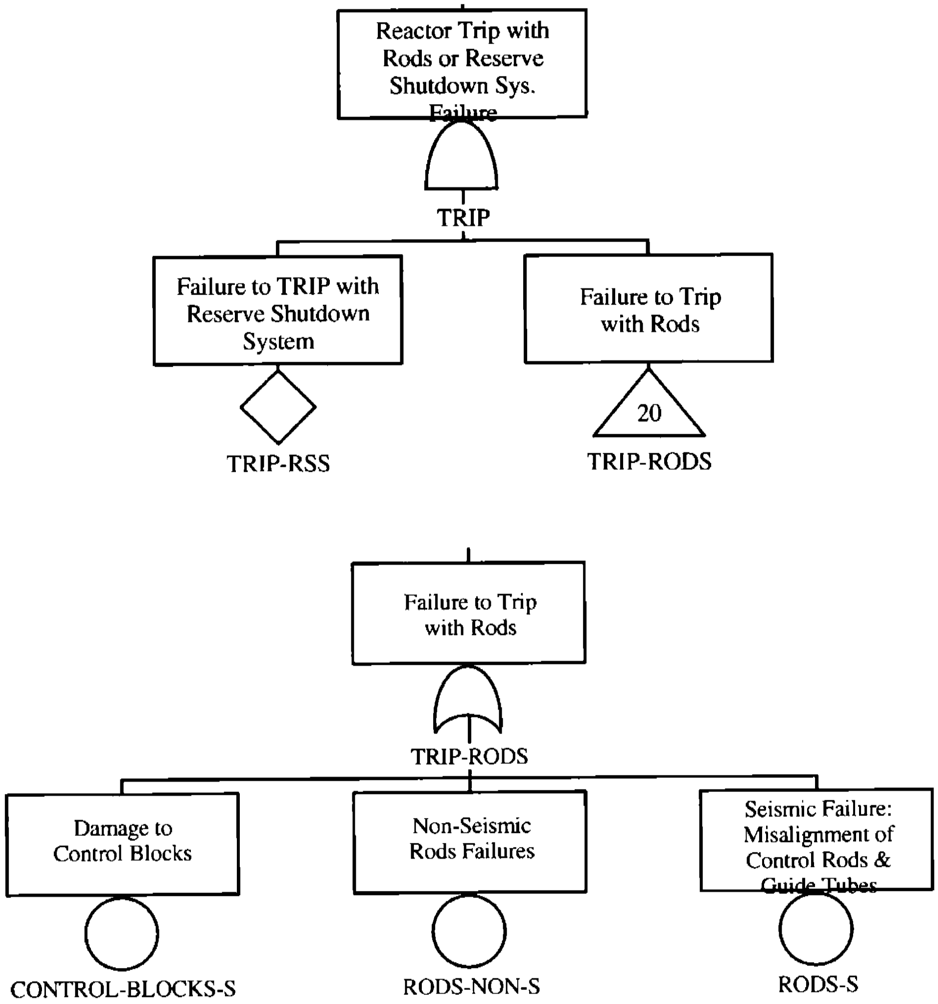


Figure 9-3 Reactor Trip With Rods or Reserve Shutdown System Fault Tree (TRIP)

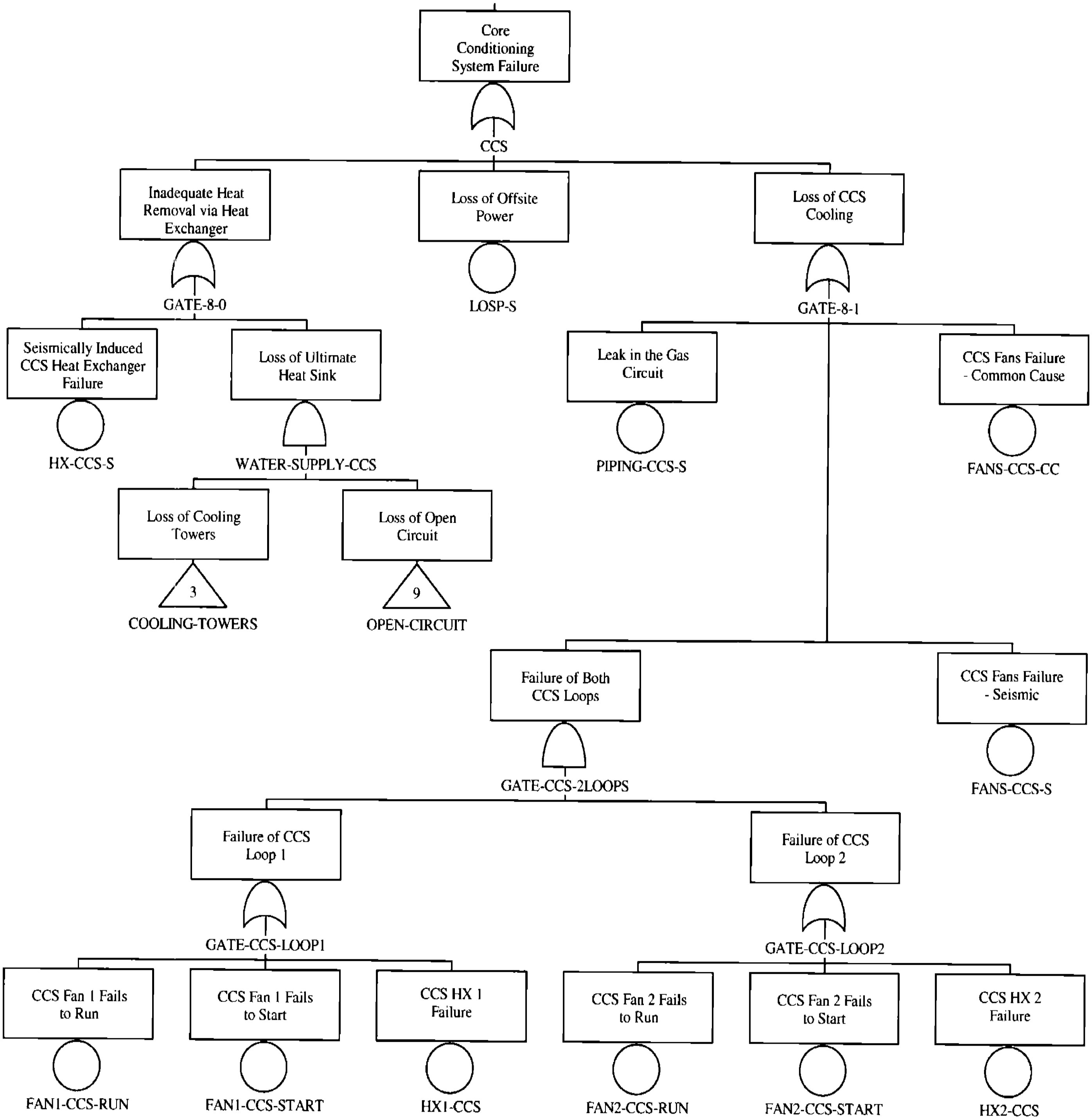


Figure 9-4 Core Conditioning System Performance Fault Tree (CCS)

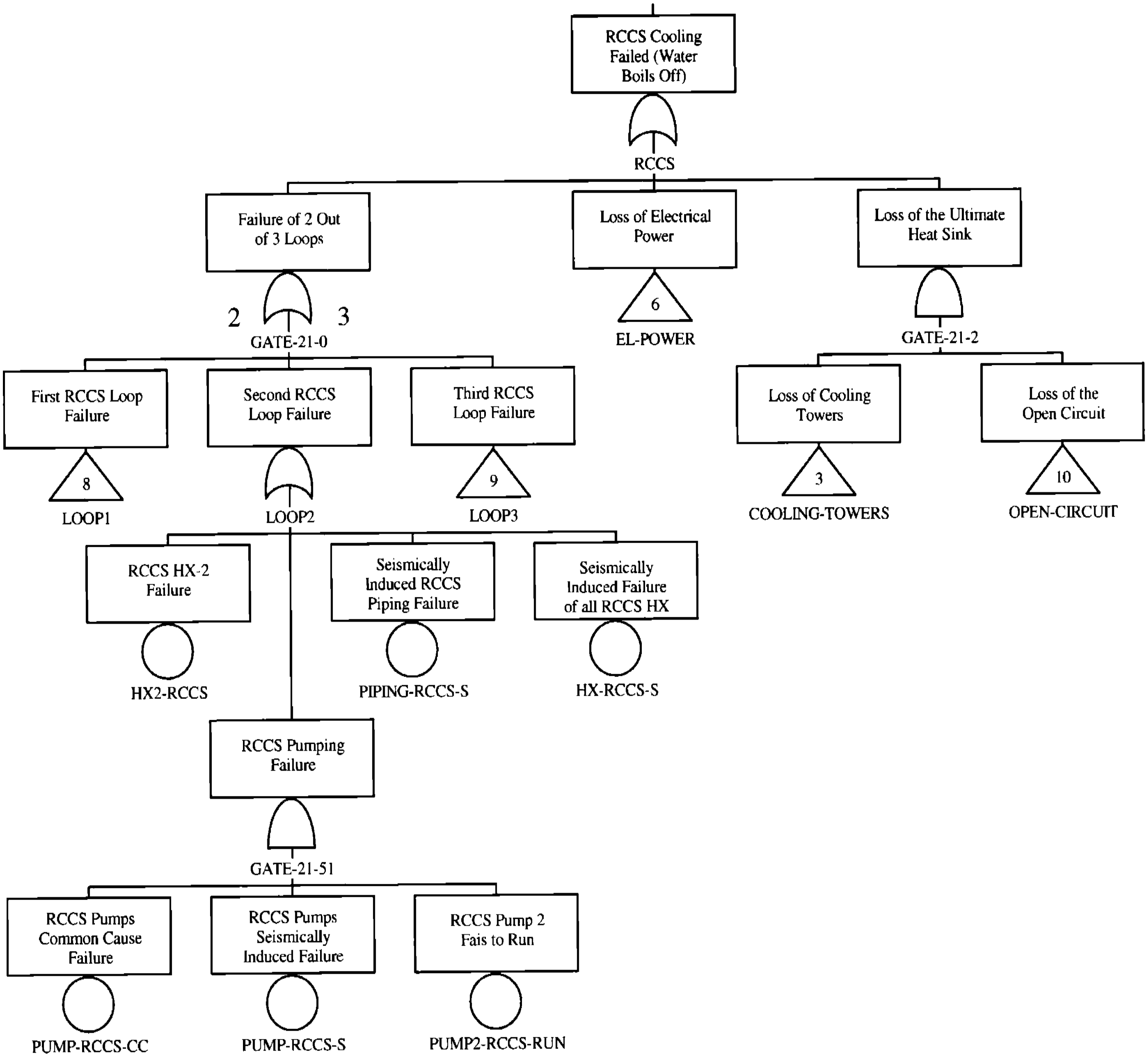


Figure 9-5 RCCS Failed (Water Boil Off) Fault Tree (RCCS)

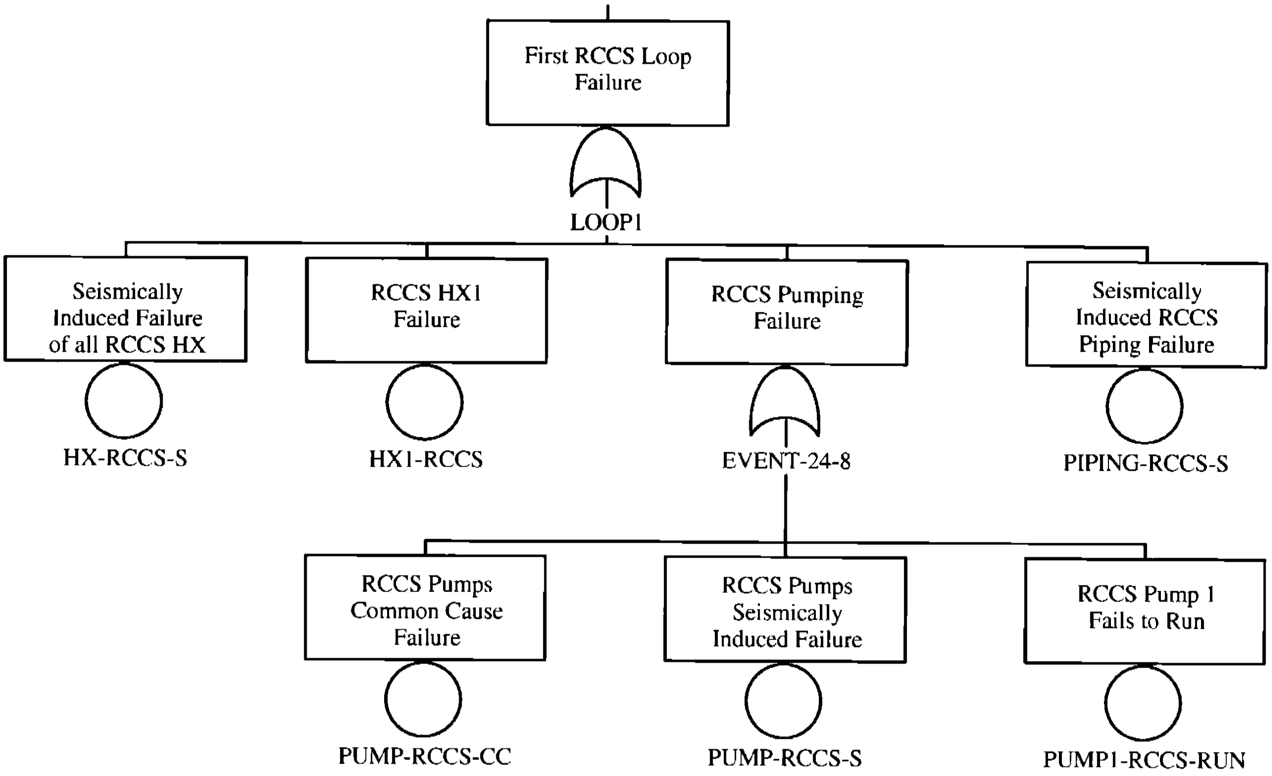


Figure 9-6 RCCS Loop 1 Failure Fault Tree (LOOP1)

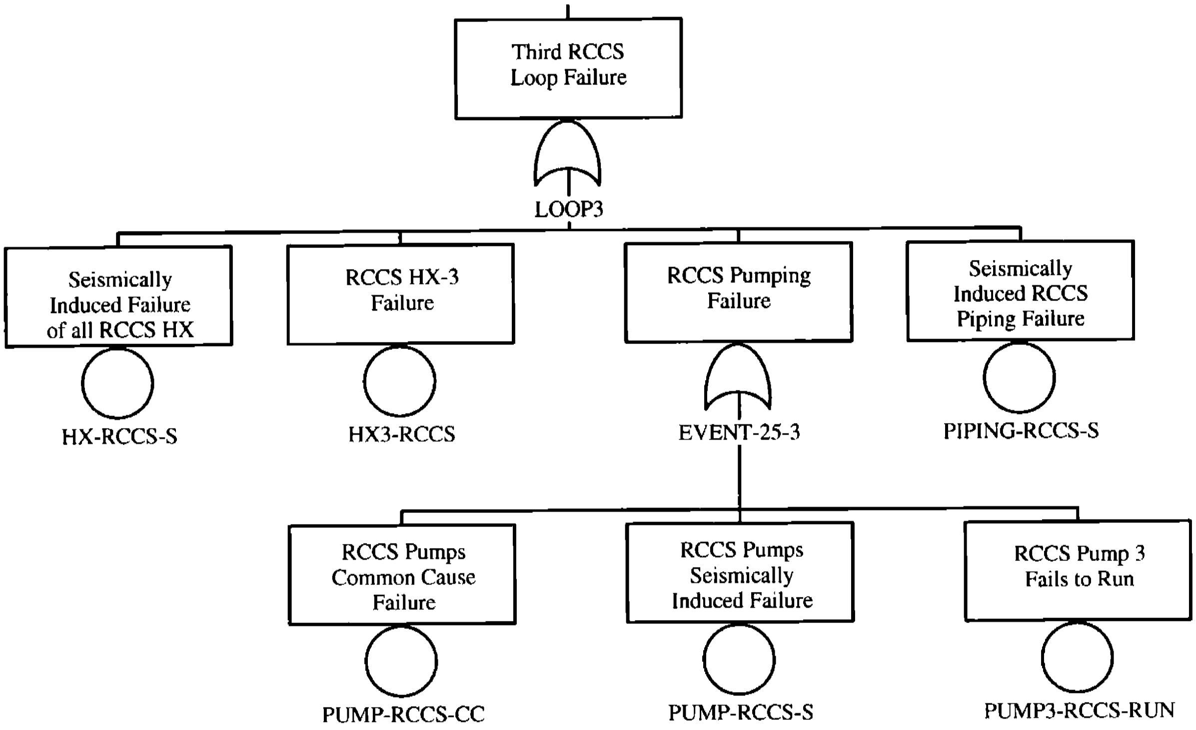


Figure 9-7 RCCS Loop 3 Failure Fault Tree (LOOP3)

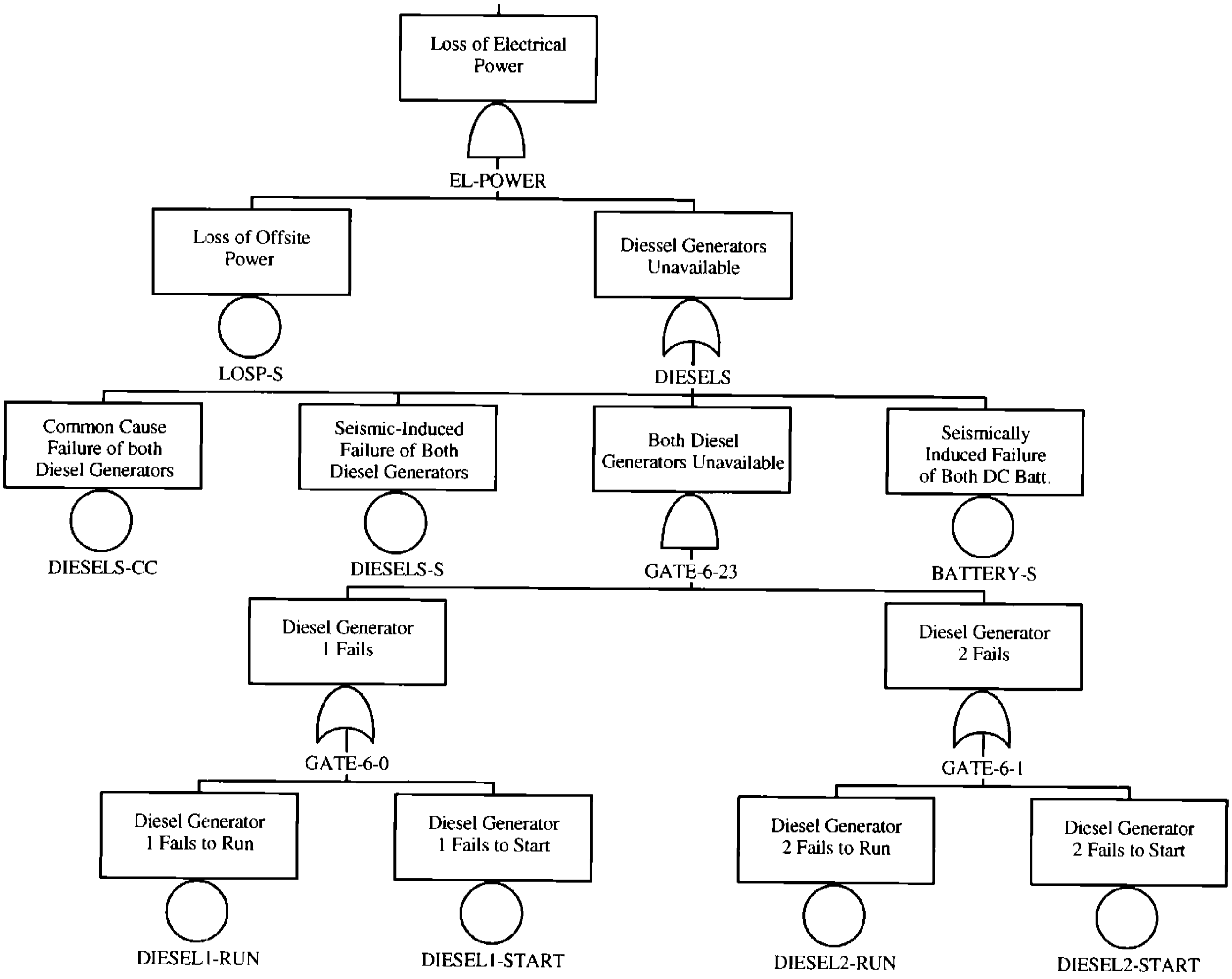


Figure 9-8 Loss of Electrical Power Fault Tree (EL-POWER)

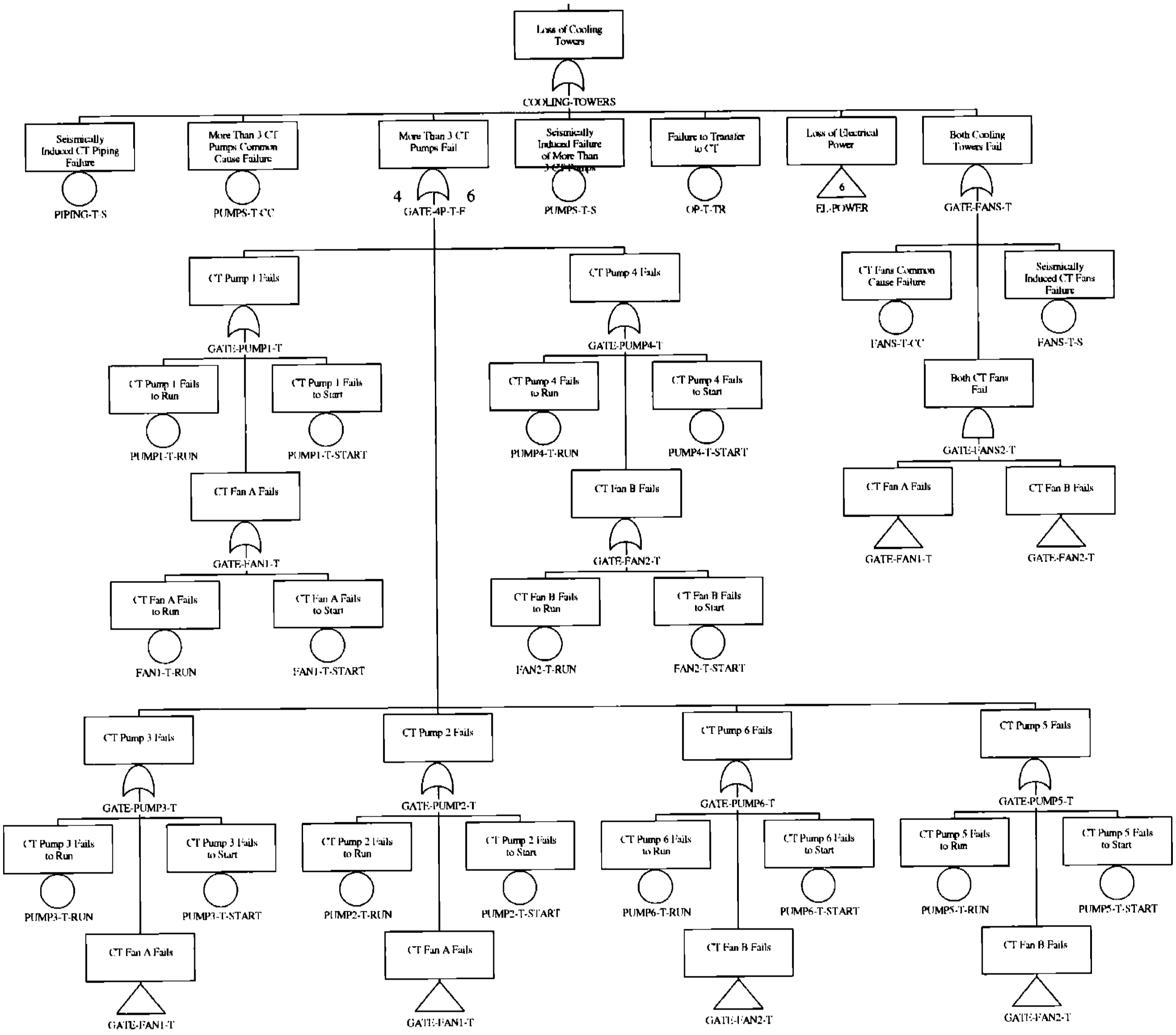


Figure 9-9 Loss of Cooling Towers Fault Tree (COOLING-TOWERS)

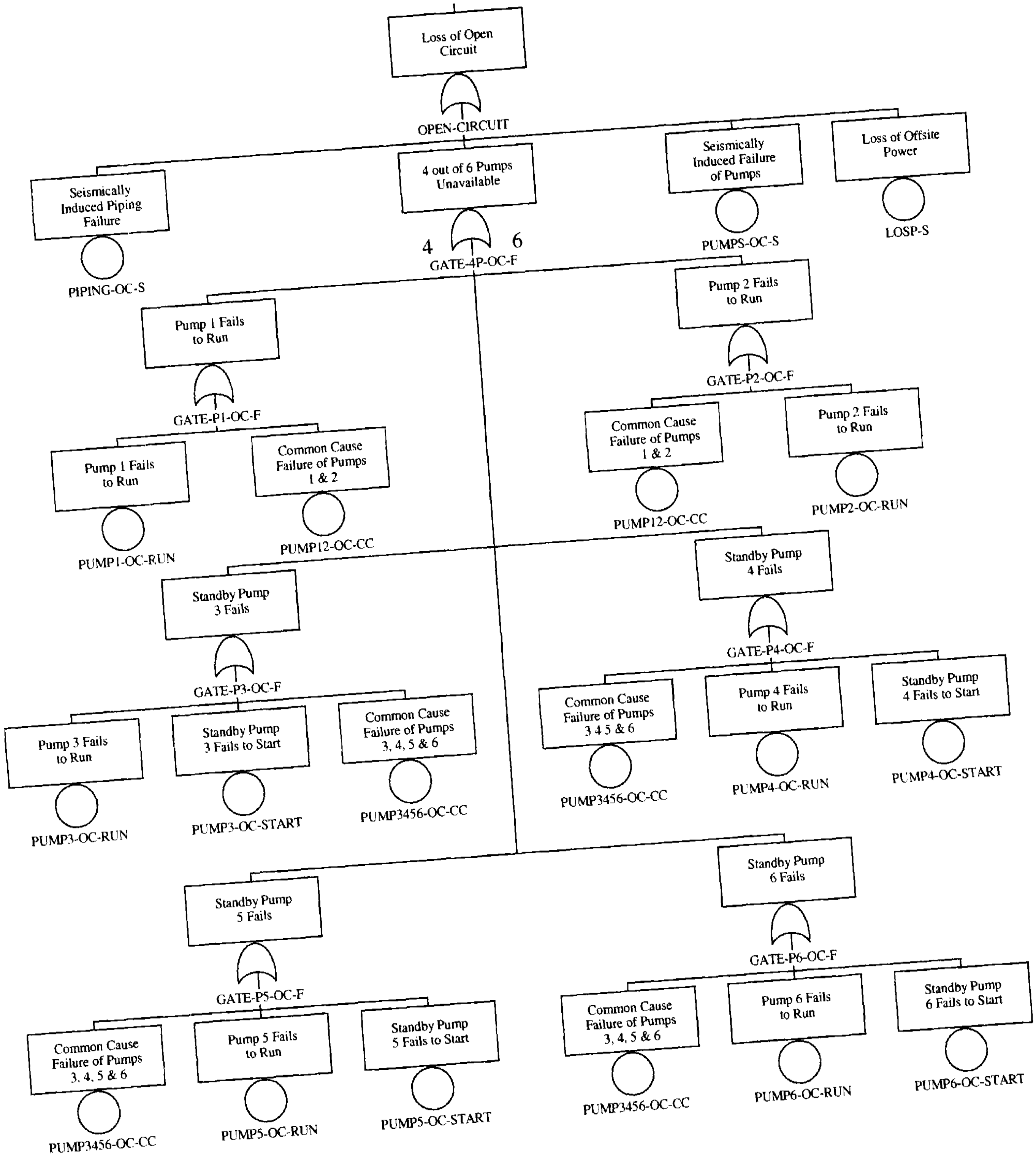


Figure 9-10 Loss of Open Circuit Fault Tree (OPEN-CIRCUIT)

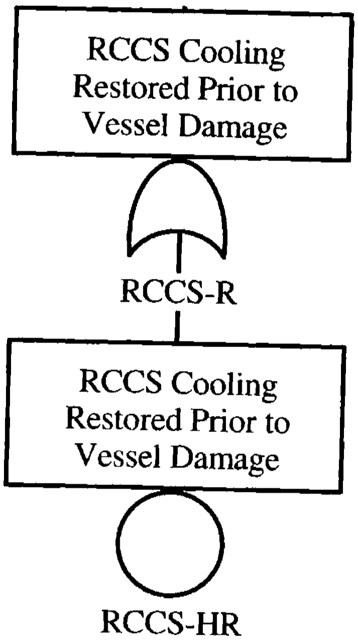


Figure 9-11 RCCS Cooling Restored Prior to Vessel Damage Fault Tree (RCCS-R)

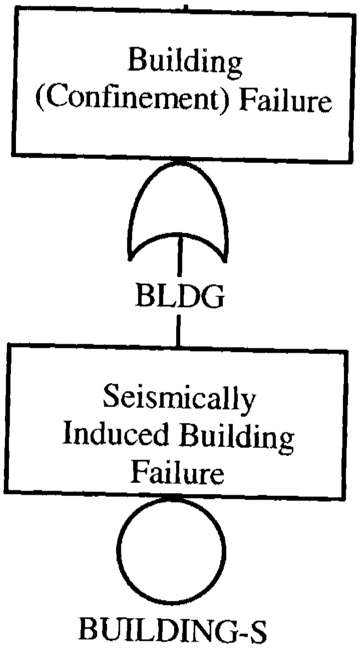


Figure 9-12 Building (Confinement) Failure (BLDG)

10.0 Data Used In The Analysis

10.1 Non-Seismic Events

Non-seismic event parameters are determined using the best available generic data sources. There are two separate groups of non-seismic event data:

1. Basic events shown in Table 10-1.
2. Undeveloped events shown in Table 10-2.

For all events which depend on mission time to be defined, 24 hours mission time is assumed. This mission time is judged to be reasonably conservative based on previous PRA analyses. Operator recovery action is included in the undeveloped events table. It is based on the diagnosis within time T, the upper bound values [10]. The upper bound is selected to reflect a high level of stress, created by a seismic event. The two values presented in Table 7.2 correspond to the T values of 5 days for the base case and 10 days for an alternate case with improved RCCS system (discussed in the following section). Note that the base case value is used for all release categories, independent of the timing estimated in Table 8-1. This is a conservative assumption.

10.2 Seismic Events

10.2.1 Seismic Initiating Event

Seismic initiating event frequency is a function of the location of the plant. Since the future PBMR location seismicity is not known, the available references are used.

Important steps in the seismic initiating frequency determination are related to the determination of an exceedence frequency for each seismic peak ground acceleration (PGA) level. Seabrook Station data are used as a reference for the seismic hazard curve, PGA levels, and the frequency determination.

Figure 10-1 presents the median hazard curve created with data from Table 4.3-1 in Seabrook Station Seismic PRA model [11].

Number of seismic intervals varies in the literature and the seismic PRA studies. The Seabrook model has 9 seismic acceleration levels. For this study, it is judged that 6 seismic acceleration levels (SAL's) would be sufficient. They are selected to cover the same acceleration range as the Seabrook study.

Maximum PGA level is determined by the seismicity of plant location. For this study the maximum PGA level is accepted from the Seabrook seismic study.

With data from Figure 10-1 and defined SAL ranges, the median SAL occurrence frequency is quantified and presented in the Table 10-3. The frequency of occurrence for each SAL is used as an initiating event frequency for the quantification of the PBMR seismic PRA model.

10.2.2 Seismic Basic Event

Seismic basic event failure probabilities are quantified separately for each seismic acceleration level (SAL).

A basic event failure probability is determined based on a component median failure acceleration level (α_m), a component random (variability) parameter (β_R), and the seismic acceleration level (SAL). The Probability of the failure for each basic event (***n***) and SAL (*i*) is determined with the following formula:

$$p_n = \Phi[\ln(SAL_i/\alpha_{mn})/\beta_{Rn}]$$

where :

p_n - basic event ***n*** probability of failure

Φ -standard normal cumulative distribution function

SAL_i -i_{th} seismic acceleration level

α_{mn} ***n*** -median failure acceleration for basic event ***n***

β_{Rn} - component variability (random) parameter for basic event ***n***

Table 7.4 presents seismically induced basic events fragility data. These data are taken from the generic database presented in Reference 12. For comparison, data are also shown from the two different plant seismic PRAs.

Two additional parameters are presented in Table 2-4:

β_U - modeling uncertainty parameter,

HCLPF - High Confidence of Low Probability of Failure acceleration level $\{=\alpha_m \exp[-1.645(\beta_R + \beta_U)]\}$

Table 10-5 presents basic events probabilities for all 6 SAL's (for seismically induced failures).

10.2.3 Input Data

Table 10-6 presents the input data to the SAPHIRE PRA model. These basic event inputs are based on the data presented in this section. The columns in Table 10-6 are described below.

`FdT` Basic event probability calculation type:

`1` The value specified in the probability field is directly used as the basic event failure probability.

`3` This calculation type is the full equation for the failure probability of an operating component without repair in mission time (t_m) with specified failure rate (λ) [$p=1-\mathrm{Exp}(-\lambda * t_m)$].

`G` This calculation type indicates that the basic event is to be treated as a seismic event. The probability value for screening will be calculated using the seismic acceleration level (SAL), median failure acceleration (α_m), and variability parameter (β_R). [$p = \Phi[\ln(SAL/\alpha_m)/\beta_R]$]

`Lambda` Probability parameter (i.e., failure rate λ for the probability calculation type 1 and seismic acceleration level SAL for probability calculation type G)

Mission Mission time for the probability calculation of type 3.

Prob Basic event probability for the basic event probability calculation types 1 and 3. Median failure acceleration level for the basic event probability calculation of type G.

Cat Event category:

Default general category appropriate for the most basic events

- **H** Hazard events: calculation type assigned for the histogram bins for hazard analysis.
- **I** Initiating events.

UdC Correlation class designator. Used to account for the data dependencies in uncertainty quantification. (Full correlation for the basic events with exactly the same uncertainty distributions is modeled in SAPHIRE.)

UdT Uncertainty distribution type:

- **L** LogNormal distribution (defined by mean and 95% error factor).
- **S** Seismic LogNormal distribution (defined by variability factor β_R and uncertainty factor β_U).

UdValue Uncertainty distribution parameter (i.e., 95% error factor for the LogNormal distribution, and variability random parameter β_R for the Seismic LogNormal distribution)

UdValue2 Second uncertainty distribution parameter if required (i.e., modeling uncertainty parameter β_U for the Seismic LogNormal distribution)

Table 10-1 Non-Seismic Basic Events

Basic Event ID	Description	Failure Likelihood						LN	Uncertainty			Source
		Demand	Rate [1 hr]	Prob. [for 24 hrs]	β Factor	γ Factor	Common Cause Failure Probability	EF(1)	Median	5%	95%	
DIESEL-START	Diesel Generator Fails to Start	5.8E-03	-	-			-	2.6	4.2E-3	1.8^{E}-3	1.2E-2	PLG database [11].
DIESEL-RUN	Diesel Generator Fails to Run	-	1.9E-03	4.6E-02				3.2	1.5E-3	3.6E-4	3.6E-3	PLG database [11].
DIESELS-CC	Common Cause DGs Failure (2 DGs to Start & Run)	-	-	-	0.1	N/A	4.6E-3	2.6	*1.0E-3*	4.0E-4	2.7E-3	PLG database [11]. INEL-95/0035 [13].
FAN-START	Fan Fails to Start	2.9E-03	-	-	-	-	-	4.7	1.7E-3	3.3^{E}-4	7.2E-3	PLG database [11].
FAN-RUN	Fan Fails to Run	-	7.9E-06	1.9E-04				3.2	1.5E-3	3.6E-4	3.6E-3	PLG database [11].
FANS-CC	Common Cause Fans Failure (2 Fans to Start & Run)	-			0.7	N/A	2.1E-4	3.0	-	-	-	PLG database [11].
HX-FAILS	Heat Exchanger Failure	-	2.0E-06	4.7E-05				4.0	1.3E-6	3.2E-7	5.2E-6	PLG database [11].
PUMP-RUN	Pump Fails to Run	-	2.6E-05	6.1E-04				4.5	1.6E-5	2.8E-6	5.6E-5	PLG database [11].
PUMP-START	Pump Fails to Start	2.2E-03	-	-			-	3.6	1.6E-3	3.4^{E}-4	4.5E-3	PLG database [11].
PUMP-CC	Common Cause Pump Failure (2 Pumps to Start & Run) (3 Pumps to Start & Run) (3 Pumps to Start)				0.01 0.01 0.01	 0.14 0.14	2.8E-5 3.9E-6 3.1E-6	3.0	-	-	-	PLG database [11].

(1) Estimated error factor (EF) from available uncertainty data and with assumption of LogNormal uncertainty distribution.

Table 10-2 Non Seismic Undeveloped Events

ID	Description	Probability	LN EF(1)	Source
RODS-NON-S	Rods Non-Seismic Failures	1.0E-04	3.0	Expert Judgment.
TRIP-RSS	Failure to Trip with Reserve Shutdown System	5.0E-03	3.0	Based on the MOV Failure to Open on Demand.
OP-TR-CT/ HA-T-R	Operator Failure to Transfer to Cooling Tower	1.0E-01	3.0	Expert Judgement.
RCCS-HR	RCCS Cooling Recovery Prior to Vessel Damage	1.0E-04(3) 1.0E-06(2)	10	Based on Human Analysis Procedure by Swain & Gutman (Reference 10)

(1) Estimated error factor (EF) from the available uncertainty data and with assumption of lognormal uncertainty distribution.

(2) Base Case.

(3) Case with an alternate Air RCCS System – discussed in Section 8

Table 10-3 Seismic Acceleration Levels and Frequencies

PBMR SPSA			Frequency of Exceedance [1/yr]		Median Seismic Acceleration	Frequency of Occurrence$^{(1)}$	SAPHIRE Approximation for the Frequency$^{(2)}$
	Range [g]						
SAL	Low	High	Low	High	[g]	[1/yr]	[1/yr]
1	0.05	0.25	5.26E-03	1.89^{E}-04	**0.15**	**5.08E-03**	**2.05E-3**
2	0.25	0.55	1.89E-04	2.34^{E}-05	**0.40**	**1.66E-04**	**1.28E-4**
3	0.55	0.85	2.34E-05	4.56^{E}-06	**0.70**	**1.88E-05**	**1.65E-5**
4	0.85	1.15	4.56E-06	8.12^{E}-07	**1.00**	**3.75E-06**	**3.75E-6**
5	1.15	1.65	8.12E-07	1.48^{E}-07	**1.40**	**6.64E-07**	**8.15E-7**
6	1.65		1.48E-07	~0	**2.00**	**1.48E-07**	**1.41E-7**

(1) Frequency of occurrence for each SAL is quantified in the following way:
[Frequency of Occurrence]$_i$ = [Frequency of Exceedence]$_{Low\ i}$ – [Frequency of Exceedence]$_{High\ i}$
where frequency of exceedence is taken from Figure 7-1.

(2) Due to the software limitations, the frequency of occurrence could not be entered directly into the model. Instead, this frequency was approximated by an addition to the existing top event (Reference 14).

Table 10-4 Seismically Induced Basic Events Fragility Data[1]

		GENERIC(1)				PLANT 1				PLANT 2			
Basic Event(s)	**Failure Mode**	α_m [g]	β_R	β_U	HCLPF [g]	α_m [g]	β_R	β_U	HCLPF [g]	α_m [g]	β_R	β_U	HCLPF [g]
RODS-S	Functional failure of control rod drive and hydraulic drive units	2.5	0.30	0.40	0.79	>2	-	-	-	11.71	0.41	0.34	3.4
CONTROL-BLOCKS-S	Panelboards and instrumentation panel (or SWGR/MCC)	3.1	0.3	0.35	1.06	1.78	0.30	0.20		10.76	0.34	0.36	3.38
LOSP-S	Failure of offsite power	0.3	0.30	0.45	0.10	0.30	0.25	0.50	-	1.69	0.24	0.20	0.82
HX-CCS-S HX-RCCS-S	Rapture of heat exchangers	1.9	0.30	0.35	0.65	>2	-	-	-	6.31	0.27	0.28	2.55
PIPING-CCS-S PIPING-RCCS-S PIPING-T-S PIPING-OSP-S	Loss of support for piping	3.8	0.35	0.50	0.93	>2	-	-	-	>10	-	-	-
FANS-CCS-S FANS-T-S	Support failure for motor driven pumps – used	2.0	0.30	0.35	0.68	1.71	0.41	0.39	-	9.79	0.33	0.24	3.82
PUMP-RCCS-S PUMP-T-S PUMP-OSP-S	Support failure for recirculation pumps	1.9	0.30	0.35	0.65	>2	-	-	-	8.53	0.29	0.21	3.74
PPB-S	Primary pressure boundary integrity (Support failure of	2.0	0.30	0.35	0.68	>2	-	-	-	11.03	0.40	0.39	3.0

---

[1] All data except where is otherwise noticed are taken from the NUREG/CR-6544, Reference (12) Table 6-1 Generic Component Seismic Fragilities.

		GENERIC$^{(1)}$				PLANT 1				PLANT 2			
Basic Event(s)	Failure Mode	α_m [g]	β_R	β_U	HCLPF [g]	α_m [g]	β_R	β_U	HCLPF [g]	α_m [g]	β_R	β_U	HCLPF [g]
	reactor pressure vessel)												
BUILDING-S$^{(2)}$	Auxiliary building wall flexure failure[2]	-	-	-	-	2.6	0.30	0.33	0.9	-	-	-	-
CONTAINMENT$^{(2)}$	Containment building wall flexure failure	-	-	-	-	7.6	0.31	0.32	2.7				
BATTERY-S	Structure failure of supports for batteries and battery racks	3.8	0.30	0.30	1.42	>2	-	-	-	6.04	0.30	0.18	2.74
DIESELS-S	Functional failure Diesel Generators and support systems	3.1	0.30	0.35	1.06	1.51	0.36	0.35	-	7.78	0.26	0.20	3.64
RCCS-AIR-S	Air Handling Unit Structural Failure / HVAC Ducts Support Failure	2.5	0.33	0.45	0.69	-	-	-	-	9.78	0.35	0.48	2.49

---

[2] The data for the PBMR building and containment failure were taken from the Seabrook Station SPSA Reference (11) Table 4.3-2.

Table 10-5 Seismically Induced Basic Events Probabilities for Different SAL's

Basic Event(s)	Probability of Failure for the Seismic Acceleration Level *i*					
	SAL1	SAL2	SAL3	SAL4	SAL5	SAL6
	0.15 g	0.40 g	0.70 g	1.00 g	1.40 g	2.00 g
RODS-S	0.00E+00	5.04E-10	1.10E-05	1.13E-03	2.66E-02	2.28E-01
CONTROL-BLOCKS-S	0.00E+00	4.40E-12	3.53E-07	8.12E-05	4.03E-03	7.20E-02
LOSP –S	1.04E-02	8.31E-01	9.98E-01	1.00E+00	1.00E+00	1.00E+00
HX-CCS-S HX-RCCS-S	0.00E+00	1.03E-07	4.37E-04	1.62E-02	1.54E-01	5.68E-01
PIPING-CCS-S PIPING-RCCS-S PIPING-T-S PIPING-OSP-S	0.00E+00	6.32E-11	6.72E-07	6.83E-05	2.17E-03	3.33E-02
FANS-CCS-S FANS-T-S	0.00E+00	4.06E-08	2.33E-04	1.04E-02	1.17E-01	5.00E-01
PUMP-RCCS-S PUMP-T-S PUMP-OSP-S	0.00E+00	1.03E-07	4.37E-04	1.62E-02	1.54E-01	5.68E-01
PPB –S	0.00E+00	4.06E-08	2.33E-04	1.04E-02	1.17E-01	5.00E-01
BUILDING-S	0.00E+00	2.21E-10	6.11E-06	7.24E-04	1.95E-02	1.91E-01
CONTAINMENT	*0.00E+00*	*0.00E+00*	*7.22E-15*	*3.04E-11*	*2.43E-08*	*8.30E-06*
BATTERY-S	0.00E+00	3.11E-14	8.58E-09	4.30E-06	4.37E-04	1.62E-02
DIESELS-S	0.00E+00	4.40E-12	3.53E-07	8.12E-05	4.03E-03	7.20E-02
RCCS-AIR-S	*0.00E+00*	*1.41E-08*	*5.73E-05*	*2.75E-03*	*3.95E-02*	*2.49E-01*

SAL*i* Seismic Acceleration Level *i*

Table 10-6 PBMR SPSA Basic Event Input Data

Basic Events	FdT	Lambda	Mission	Prob	at	UdC	dT	UdValue1	dValue2
BATTERY-S	G	2.0	-E-	3.8		1	S	3.00E-1	3.00E-01
BUILDING-S*	G	2.0	-E-	2.6		2	S	3.00E-1	3.30E-01
CONTROL-BLOCKS-S	G	2.0	-E-	3.1		3	S	3.00E-1	3.50E-01
DIESEL1-RUN	3	1.90E-3	24	4.60E-02		DGFR	L	3.2	-E-
DIESEL1-START	1	0	0	5.80E-03		DGFS	L	2.6	-E-
DIESEL2-RUN	3	1.90E-3	24	4.60E-02		DGFR	L	3.2	-E-
DIESEL2-START	1	0	0	5.80E-03		DGFS	L	2.6	-E-
DIESELS-CC	1	-E-	-E-	4.60E-03		5	L	2.6	-E-
DIESELS-S	G	2.0	-E-	3.1		6	S	3.00E-1	3.50E-01
E-IE	1	0	0	5.0E-02	I			-E-	-E-
FAN1-CCS-RUN	3	7.90E-6	24	1.90E-04		FANR	L	3.2	-E-
FAN1-CCS-START	1	0	0	2.90E-03		FANS	L	4.7	-E-
FAN1-T-RUN	3	7.90E-6	24	1.90E-04		FANR	L	3.2	-E-
FAN1-T-START	1	0	0	2.90E-03		FANS	L	4.7	-E-
FAN2-CCS-RUN	3	7.90E-6	24	1.90E-04		FANR	L	3.2	-E-
FAN2-CCS-START	1	0	0	2.90E-03		FANS	L	4.7	-E-
FAN2-T-RUN	3	7.90E-6	24	1.90E-04		FANR	L	3.2	-E-
FAN2-T-START	1	0	0	2.90E-03		FANS	L	4.7	-E-
FANS-CCS-CC	1	0	0	2.10E-04		FANC	L	3.0	-E-
FANS-CCS-S	G	2.0	-E-	2.0		61	S	3.00E-1	3.50E-01
FANS-T-CC	1	0	0	2.10E-04		FANC	L	3.0	-E-
FANS-T-S	G	2.0	-E-	2.0		7	S	3.00E-1	3.50E-01
HA-T-R	1	0	0	1.00E-01		8	L	3.0	-E-
HX1-CCS	3	2.00E-6	24	4.70E-05		HXPL	L	4.0	-E-
HX1-RCCS	3	2.00E-6	24	4.70E-05		HXPL	L	4.0	-E-
HX2-CCS	3	2.00E-6	24	4.70E-05		HXPL	L	4.0	-E-
HX2-RCCS	3	2.00E-6	24	4.70E-05		HXPL	L	4.0	-E-
HX3-RCCS	3	2.00E-6	24	4.70E-05		HXPL	L	4.0	-E-
HX-CCS-S	G	2.0	-E-	1.9		9	S	3.00E-1	3.50E-01
HX-RCCS-S	G	2.0	-E-	1.9		A	S	3.00E-1	3.50E-01
LOSP-S	G	2.0	-E-	3.00E-01		B	S	3.00E-1	4.50E-01
PIPING-CCS-S	G	2.0	-E-	3.8		C	S	3.50E-1	5.00E-01
PIPING-OC-S	G	2.0	-E-	3.8		D	S	3.50E-1	5.00E-01
PIPING-RCCS-S	G	2.0	-E-	3.8		E	S	3.50E-1	5.00E-01
PIPING-T-S	G	2.0	-E-	3.8		F	S	3.50E-1	5.00E-01
PPB-S	G	2.0	-E-	2.0		G	S	3.00E-1	3.50E-01
PUMP12-OC-CC	1	0	0	2.80E-5		PMCC	L	3.0	-E-
PUMP1-RCCS-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP1-OC-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-

Basic Events	FdT	Lambda	Mission	Prob	at	UdC	dT	UdValue1	dValue2
PUMP1-T-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP1-T-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP2-RCCS-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP2-OC-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP2-OC-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP2-T-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP2-T-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP3456-ST-CC	1	0	0	3.10E-6		PMCC	L	3.0	-E-
PUMP3-RCCS-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP3-OC-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP3-OC-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP3-T-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP3-T-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP4-OC-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP4-OC-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP4-T-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP4-T-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP5-OC-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP5-OC-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP5-T-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP5-T-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP6-OC-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP6-OC-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP6-T-RUN	3	2.60E-5	24	6.10E-04		PMFR	L	4.5	-E-
PUMP6-T-START	1	0	0	2.20E-03		PMFS	L	3.6	-E-
PUMP-RCCS-CC	1	0	0	2.80E-5		PMCC	L	3.0	-E-
PUMP-RCCS-S	G	2.0	-E-	1.9		H	S	3.00E-1	3.50E-01
PUMPS-OC-S	G	2.0	-E-	1.9		I	S	3.00E-1	3.50E-01
PUMPS-T-CC	1	0	0	3.90E-6		PMCC	L	3.0	-E-
PUMPS-T-S	G	2.0	-E-	1.9		J	S	3.00E-1	3.50E-01
RCCS-AIR-S	G	2.0	-E-	2.5		J	S	3.30E-1	4.50E-1
RCCS-HR	1	0	0	1.00E-06		K	L	3.0	-E-
RODS-NON-S	1	0	0	1.00E-04		L	L	3.0	-E-
RODS-S	G	2.0	-E-	2.5		M	S	3.00E-1	4.00E-01
TRIP-SAS	1	0	0	1.00E-02		N	L	3.0	-E-

*Those events have double values used in the different alternatives

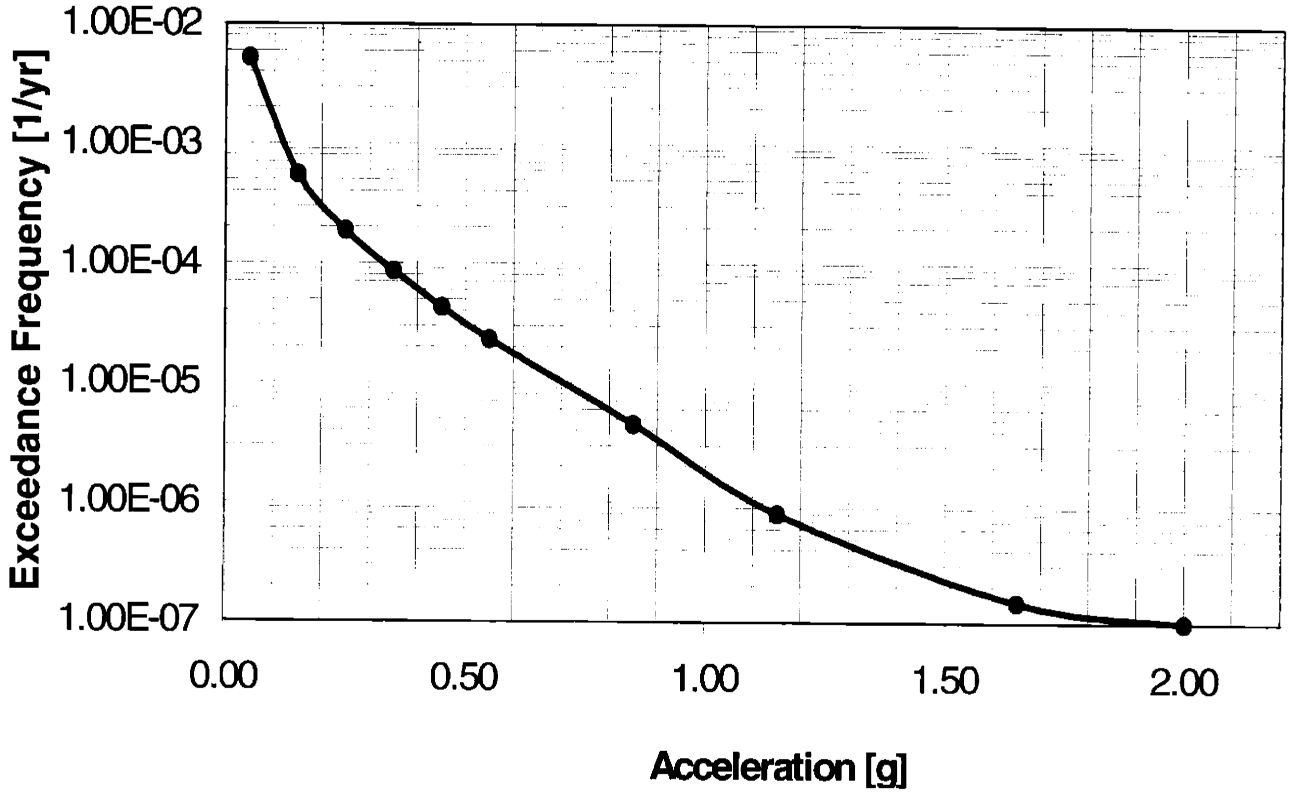


Figure 10-1 Seabrook Station Median Hazard Curve (Reference 11)

11.0 Evaluated Alternatives

Two alternative additions to the plant design were evaluated in this analysis:

***Alternative 1*:** An additional air cooling system is added to the RCCS. The new RCCS is based on two mixed subsystems – water-based and air-based. The air system is a passive system driven by a natural circulation. It is described in detail in Appendix A. Both systems are designed to work in parallel.

In this case, both the reliability of the RCCS systems and time to recovery (human recovery action probability) are improved. The new values are described in Section 7.0, and given in the table below.

***Alternative 2*:** Instead of the building in which PBMR releases are "confined", the pressure-tight containment enclosure is added. The reliability of the containment function improves significantly. The new values are described in Section 7.0, and given in the table below:

	Base Case	**Alternative 1 (Improved RCCS)**	**Alternative 2 (Containment)**
RCCS (for SAL 3)	1.1E-1	6.2E-6	1.1E-1
RCCS (for SAL 6)	9.9E-1	5.7E-1	9.9E-1
RCCS-HR (Operator Recovery)	1E-4	1E-6	1E-4
Confinement (for SAL 6)	1.9E-1	1.9E-1	8.3E-6

Table 11-1 Reliability Values for Evaluated Alternatives

The results for both alternatives, as well as the base case, are given in the following section.

12.0 Results and Conclusions

12.1 Qualifiers and Assumptions

The following qualifiers and assumptions are used in the evaluation/quantification of the PBMR seismic event tree:

1. Failure of the helium pressure boundary (PPB) as a result of the seismic event is not evaluated. Rather, only failure of the Reactor Vessel as a result of the elevated temperatures is considered.
2. Failure of the CCS piping is not considered to lead to a pressure boundary failure.
3. Release categories defined in Table 5.1 and corresponding "times before release" are based on an expert judgment. An additional supporting analysis is needed to confirm these assumptions. (Five days for recovery are used for each release category.)
4. Differences in the time available for the recovery between "2 of the 3 RCCS pumps" failed (6 to 10 days, [9]) and "3 of 3 RCCS pumps" failed (3 to 6 days,[9]) is not considered in the analysis. Instead, "2 out of 3" pumps are assumed to fail the RCCS system and 5 days are assumed to be available for the recovery.
5. Mechanical failure of the RCCS cylinders due to the high temperature is not considered in the analysis.
6. All RCCS pumps are assumed to be running during normal operation.
7. For the Open Circuit System and the Cooling Tower System, it is assumed that "3 out of 6" pumps are needed for the success. It is assumed that two pumps in the Open Circuit System are running during normal operation.

8. The Cooling Tower System and the RCCS Systems are modeled as being supported by an emergency power system (diesel generators). The Open Circuit system and Core Conditioning System are not supported by diesel generators and would fail if a loss of offsite power were to occur.

9. Mission time used in the analysis is 24 hours based on other analyses. No new data or information were available for support of a different assumption.
10. Failure of piping DC batteries, offsite power and a common cause failure of heat exchangers are not considered in the evaluation. The seismic failure probability is assumed to dominate over random independent failures.

11. SAPHIRE Version 7.16 is used for the model development and quantification. Because of difficulties in utilizing certain SAPHIRE capabilities, two other versions were also used (Version 6.47 and 7.18). The final SAPHIRE model is named "PBMR SPSA" and used with SAPHIRE Version 7.16.

12. Because of the software limitations, approximate frequencies are used for the difference seismic acceleration levels. They are defined in Table 7.3. There are also limitations discovered in the software ability to evaluate uncertainties [14]. Those limitations are not corrected in this evaluation.

12.2 Results

Quantified results, including the uncertainties and cut sets from the evaluation, are presented as follows:

Base Case:	Summary in Table 9.1, Details in Appendix A (cut sets)
Alternative 1:	Summary in Table 9.2, Details in Appendix B (cut sets)
Alternative 2:	Summary in Table 9.3, Details in Appendix C (cut sets)

The results from Tables 12-1, 12-2 and 12-3 demonstrate that the probability of the release is very low even in the base case, and even lower for the suggested design alternatives. Release probability results, for the seismic acceleration level 6 (2g), are compared in Table 12-4 (the frequency of occurrence is equal to 1.41 E-7/yr for that acceleration level).

12.3 Conclusions

The work reported herein demonstrates that the new highly risk-informed design and regulatory process can be used to assess design alternatives and compliance with safety criteria for a new reactor design such as a gas-cooled PBMR.

Although "reasonably conservative" assumptions had to be made for the PBMR design and for the corresponding PRA, the technical results are consistent with the use of inherent safety features and expectations for this design. As can be seen from the results presented in Table 12-4, the reduction in mean release frequency from either design alternative 1 (diverse reactor cavity cooling system) or design alternative 2 (leak-tight containment) could make any significant release very unlikely, independent of the initiator (the worst case seismic event assumed). The release probabilities for Alternative 1 and Alternative 2 satisfy the current safety goal policy and guidance for a large early release (<1E-7/yr) independent of the initiation frequency (assumed to be 1/year).

While additional design work remains for the PBMR and while regulatory review still needs to be accomplished, the results of this work indicate that a leak-tight containment – while improving safety – may not be required since other less-costly alternatives, well performing alternatives are available.

Table 12-1 Quantification Results for the Base Case

		SAL 6	Total	Uncertainty									
FT Seq.	MCS	Upper Bound	Min/Max(3)	Point estimate	Mean	5^{th}	Median	95th	Minimum	Maximum	Std. Dev	Skewness	Kurtosis
4	19	4.26E-12	**4.98E-12**	**5.37E-12**	6.73E-11	1.57E-14	2.75E-12	2.78E-10	0.00E+00	5.32E-09	2.99E-10	10.9	157.0
8	75	5.98E-12	**1.56E-11**	**7.21E-12**	7.14E-11	1.65E-14	4.63E-12	2.78E-10	0.00E+00	6.84E-09	3.30E-10	13.1	226.5
12	40	1.83E-14	**5.34E-14**	**1.92E-14**	1.88E-13	0.00E+00	5.44E-15	6.91E-13	0.00E+00	1.72E-11	1.05E-12	11.0	148.0
16	58	2.57E-14	**1.80E-13**	**2.65E-14**	2.12E-13	0.00E+00	6.22E-15	8.88E-13	0.00E+00	2.43E-11	1.10E-12	13.8	255.6

Table 12-2 Quantification Results for Alternative 1

Alternative 1 : Air RCCS				Uncertainty									
		SAL 6	Total										
FT Seq.	MCS	Upper Bound	Min/Max(3)	Point estimate	Mean	5^{th}	Median	95th	Minimum	Maximum	Std. Dev	Skewness	Kurtosis
4	69	1.08E-14	**1.07E-14**	**1.12E-14**	2.33E-13	0.00E+00	3.44E-15	8.50E-13	0.00E+00	2.41E-11	1.26E-12	11.7	176.7
8	90	1.54E-14	**3.70E-14**	**1.59E-14**	2.88E-13	0.00E+00	3.89E-15	9.24E-13	0.00E+00	4.42E-11	2.14E-12	16.5	312.5
12	42	*4.60E-17*	**1.31E-16**	***4.65E-17***	3.26E-16	0.00E+00	0.00E+00	1.55E-15	0.00E+00	2.22E-14	1.76E-15	8.3	81.4
16	62	6.46E-17	**4.48E-16**	***6.52E-17***	7.14E-16	0.00E+00	0.00E+00	1.67E-15	0.00E+00	9.83E-14	5.08E-15	12.3	188.5

NOTE

Point estimate and SAL 6 upper bound for FT Seq.#12 & #16 is Rare Event Approximation.

Table 12-3 Quantification Results for Alternative 2

Alternative 2: Containment				Uncertainty									
		SAL 6	Total										
FT Seq.	MCS	Upper Bound	Min/Max(3)	Point estimate	Mean	5th	Median	95th	Minimum	Maximum	Std. Dev	Skewness	Kurtosis
4	26	*1.85E-16*	**1.83E-16**	*1.87^{E}-16*	9.68E-14	0.00E+00	0.00E+00	1.33E-13	0.00E+00	2.68E-11	9.78E-13	21.9	569.5
8	37	*2.60E-16*	**6.40E-16**	*2.62^{E}-16*	4.48E-13	0.00E+00	0.00E+00	2.41E-13	0.00E+00	3.11E-10	9.95E-12	30.6	954.7
12	30	*7.99E-19*	**2.24E-18**	*8.00^{E}-19*	4.65E-16	0.00E+00	0.00E+00	2.22E-16	0.00E+00	1.13E-13	4.67E-15	17.2	365.5
16		*1.12E-18*	**7.70E-18**	*1.12^{E}-18*	3.92E-16	0.00E+00	0.00E+00	1.11E-16	0.00E+00	1.09E-13	4.33E-15	18.9	421.7

NOTE

Point estimate and SAL 6 upper bound are Rare Event Approximation.

Table 12-4 Release Probabilities for the Base Case and Two Alternatives (SAL 6 – 2g)

Release Category/Sequence	Base Case	Alternative 1	Alternative 2
A – Sequence 4	3.0 E-5	7.7 E-8	1.3 E-9
B – Sequence 8	4.2 E-5	1.1 E-7	1.8 E-9
C – Sequence 12	1.3 E-7	3.3 E-10	5.7 E-12
D – Sequence 16	1.8 E-7	4.6 E-10	7.9 E-12

13.0 References

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4. Fleming, Karl; George, Adrian; Magugumela, Maurice, "*The Role of PRA in the Design and Licensing of the Pebble Bed Modular Reactor.*"

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APPENDIX A

CONCEPTUAL DESIGN OF A MIXED REACTOR CAVITY COOLING SYSTEM FOR THE PEBBLE BED MODULAR REACTOR

Version July 10, 2002 Francesc Reventos

Summary

1. Overview

One of the proposed design alternatives (Alternative 1) involves modifications in the RCCS (Reactor Cavity Cooling System) configuration.

This report summarizes the conceptual design of a mixed RCCS for the Pebble Bed Modular Reactor (PBMR). The system is based on two different sub-systems, one of water and another of air. The former is an active system where water is re-circulated by means of motor-pumps and has the same bases as the original RCCS design <1>. The latter is a passive system driven by natural circulation and quite similar to the RCCS of the Standard Modular High Temperature Gas-cooled Reactor (HTGR) <2>. This mixed RCCS is proposed here as one of the possible alternative design options that can enhance PBMR safety features.

2. Background

2.1 Original Design for the Pebble Bed Modular Reactor

The original RCCS for PBMR has the function of dissipating to the ultimate heat sink the reactor cavity heat during all modes of reactor operation. The design relies on thermal radiation and convection to transport the heat from the vessel walls to the system cooling chambers located in the cavity (see figure 2.1.1).

The power rate dissipation is about 330 kW in normal operation and becomes 1300 kW under accidental or shutdown conditions. The RCCS is design to provide the adequate protection of concrete structure in both scenarios. These dissipation values are consistent with a reactor nominal power of 268 MW.

The system consists of three independent cooling trains designed to extract each one, 50% of the maximum heat produced in a Depressurized Loss Of Forced Cooling transient. Each train provides the supply and return of water to 1/3 of the chambers. Each chamber is a cylinder of 750 mm in diameter and 20 m long (see figure 2.1.2).

It is a low-pressure, closed-loop and pump-driven system. The flow rate of each train under normal conditions is 13 liters/second. In the event of the long failure of heat exchangers or pumps, the water in the chambers is converted to steam which is released into the atmosphere. The boil-off of all the water (with no restoration) lasts about seven days.

More detail on the system function or its design bases as well as operation and safety evaluation, can be found in Chapter 8.2 of reference [1].

2.2 Original Design for the Standard Modular High Temperature Gas-Cooled Reactor

During normal power operation the RCCS is required to remove heat from the reactor cavity and protect the concrete structures. In the event of failure of steam generators or main condenser, RCCS is also designed to remove decay heat by conduction and radiation. In this case, decay heat is radiated to air panels located all around the cavity and transported to the atmosphere by natural circulation (see Fig. 2.2.1 to 2.2.3). The system is completely passive and provides suitable protection to both the vessel and concrete.

Although the description given in Section 4.8 of Reference [2] has no more detail on design bases, some information can be derived from the contents of Appendix-F "Reactor Cavity Cooling System Reliability". Appendix-F has different schematics and isometric views devoted to clarify the response of the system to potential blockage and to permit the understanding of the usefulness of the interconnections and other layout aspects. Fig.F-5 of Appendix-F establishes a value of 1.2e5lbm/hr as the air mass flow for a non-blockage situation producing an exit air temperature of 300F.

Estimating an inlet temperature of 20C and using an air specific heat of 1005 J/kgC:

1.2e5 lbm/hr = 15.1 kg/s

300F = 150C,

Power = 1005 * (150 - 20) * 15.1 = 1,972,815 W.

This means that under these conditions, the system extracts about 2 MW. This dissipation value is consistent with a decay heat corresponding to reactor nominal power of 350 MW.

3. Mixed Reactor Cavity Cooling System for Pebble Bed Modular Reactor

3.1 System Function

The Mixed RCCS for PBMR is based on two different sub-systems, one of water and another of air. In all the considered options the water system is an active system where water is re-circulated by means of motor-pumps and has the same bases as the original RCCS design, as explained in Section 2.1. The air system, as explained in Section 2.2, is a passive system driven by natural circulation and is quite similar to the RCCS of the HTGR. Both sub-systems are designed to work in parallel.

3.2 Design Principle of the Base Option

As shown in Fig. 3.2.1, the layout of the base option allows each sub-system to extract roughly half of the heat radiated from the vessel. Under these conditions the water sub-system will work following the basic results of the performance of the original design, and the air sub-system will work at a slightly lower than designed power rate (recall that the HTGR nominal power is somewhat greater than that of the PBMR).

3.3 Safety Evaluation

When both sub-systems are available, the total amount of heat they are able to extract will be about:

$$(1.3 / 2)\ \text{MW} + (2.0 / 2)\ \text{MW} = 1.65\ \text{MW}$$

This adds some margin to the needed 1.3 MW.

In the event that the water sub-system becomes unavailable due to boil-off (or any other reason), the amount of energy transported would be as much as:

(2.0 / 2) MW = 1.0 MW.

This extraction availability can give an advantage when decay heat decreases to suitable values.

3.4 Improved Option

The base option is important because it fulfills the energy balance requirements and mainly because it is supported by the results of both of the original designs.

The performance of the basic option can be improved if some specific engineering tasks of optimization are carried out.

If heat conduction between the chambers and the panels is improved, then in the event of water sub-system unavailability the energy extracted by air sub-system will increase. If the number of chambers is increased, this will improve heat transfer in the early phases of transients (see Fig. 3.4.1).

In any case the base option is a bounding conceptual design valid for the purpose of this report. System optimization is not part of the current scope of work.

4. References

1. PBMR Safety Analysis Report Doc. No 001929

2. Probabilistic Risk Assessment for the Standard Modular High Temperature Gas-Cooled Reactor. DOE-HTGR-86011 Revision 5 / GA-C18718-Rev 5

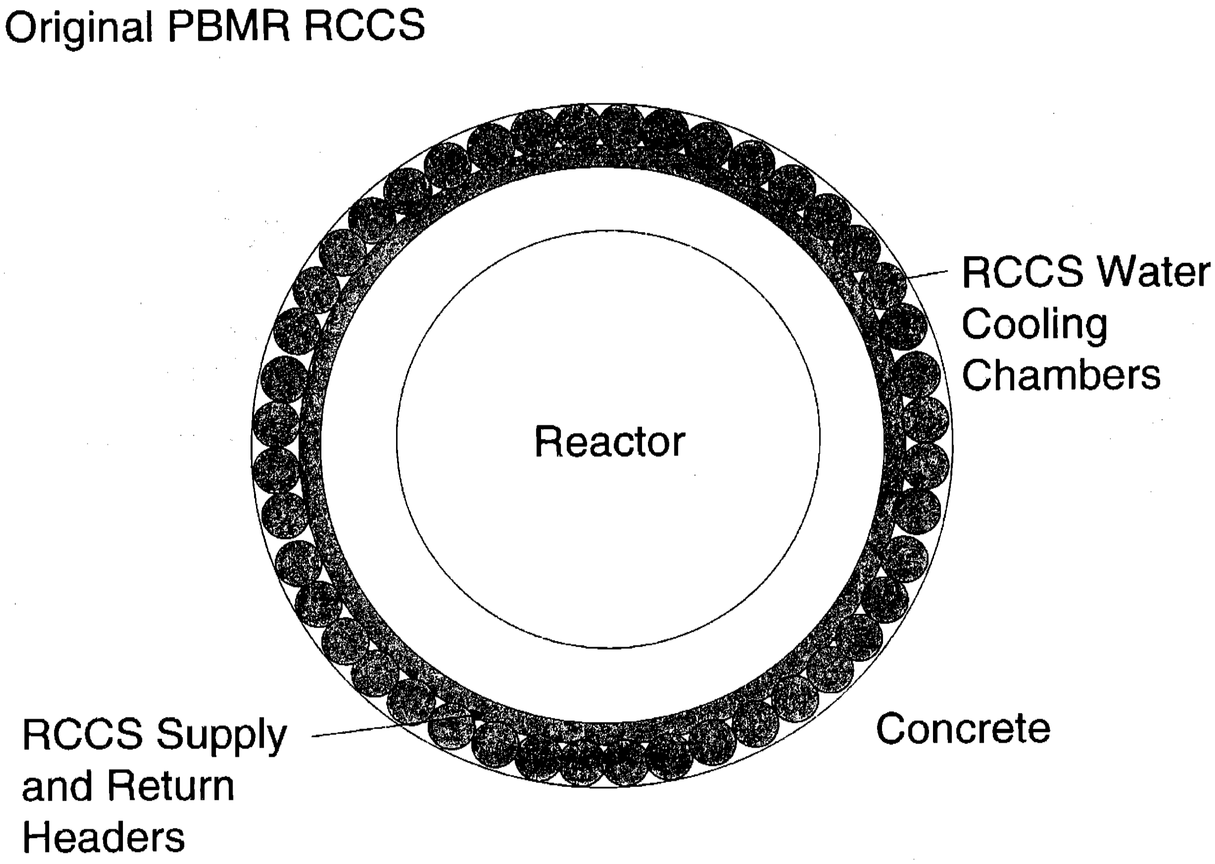

Figure 2.1.1 Outline of the Original RCCS for the PBMR

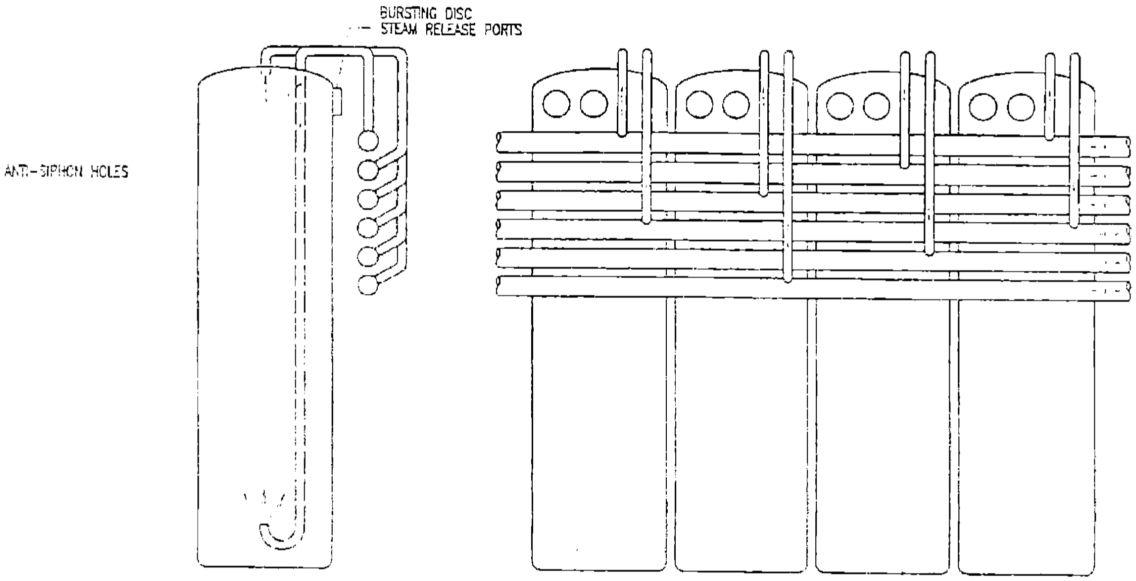

Figure 2.1.2 Arrangement of RCCS Water Chambers and Headers
(See Section 6.4.1 for the Full Description)

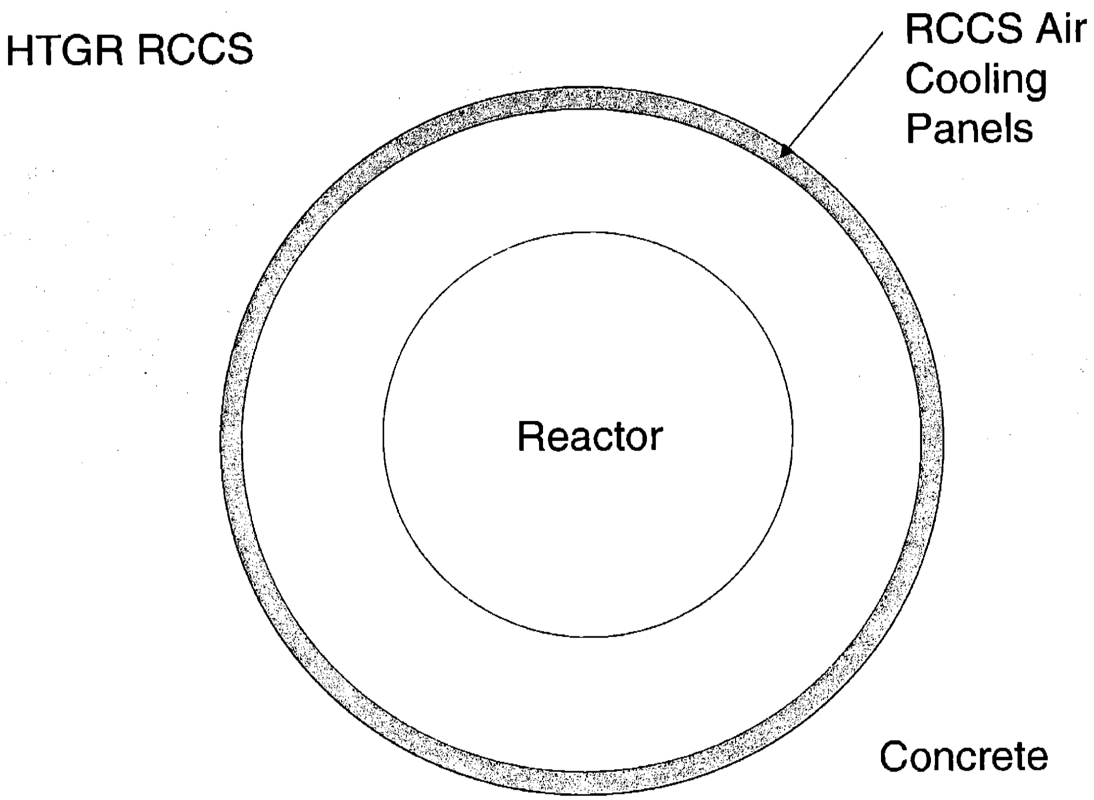

Figure 2.2.1 Outline of the RCCS for HTGR

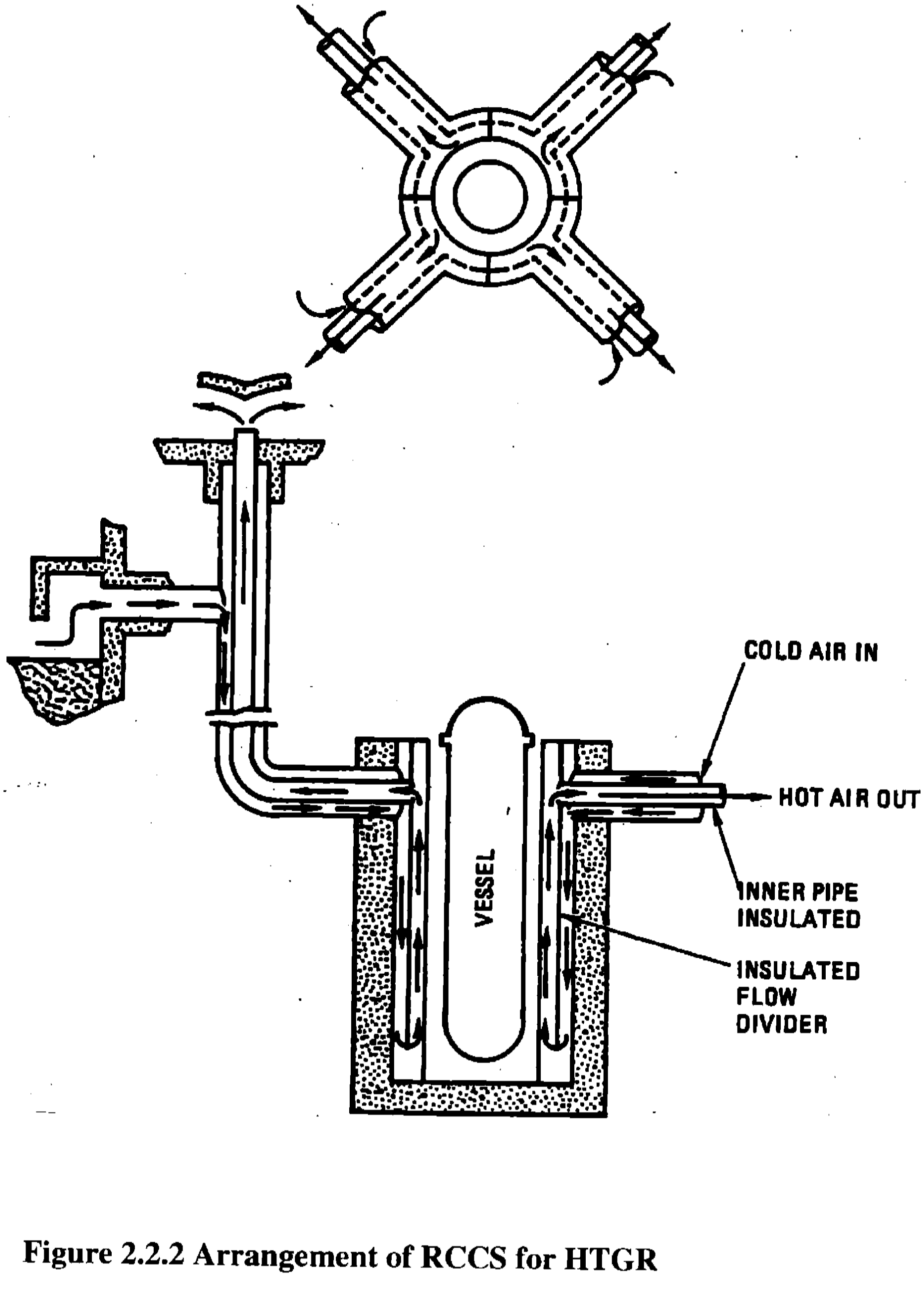

Figure 2.2.2 Arrangement of RCCS for HTGR

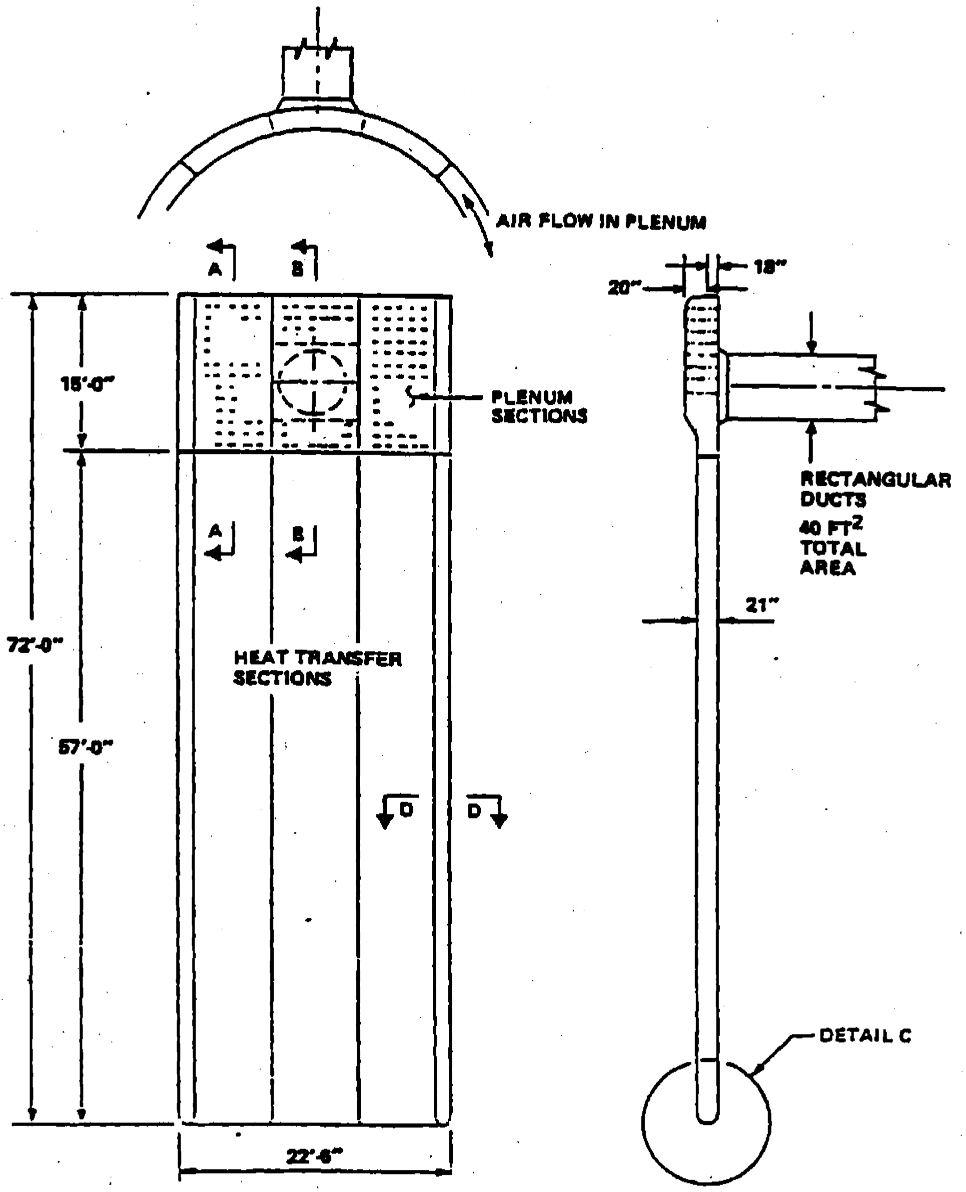

Figure 2.2.3 Air Cooling Panel Conceptual Design - Plan and Sections

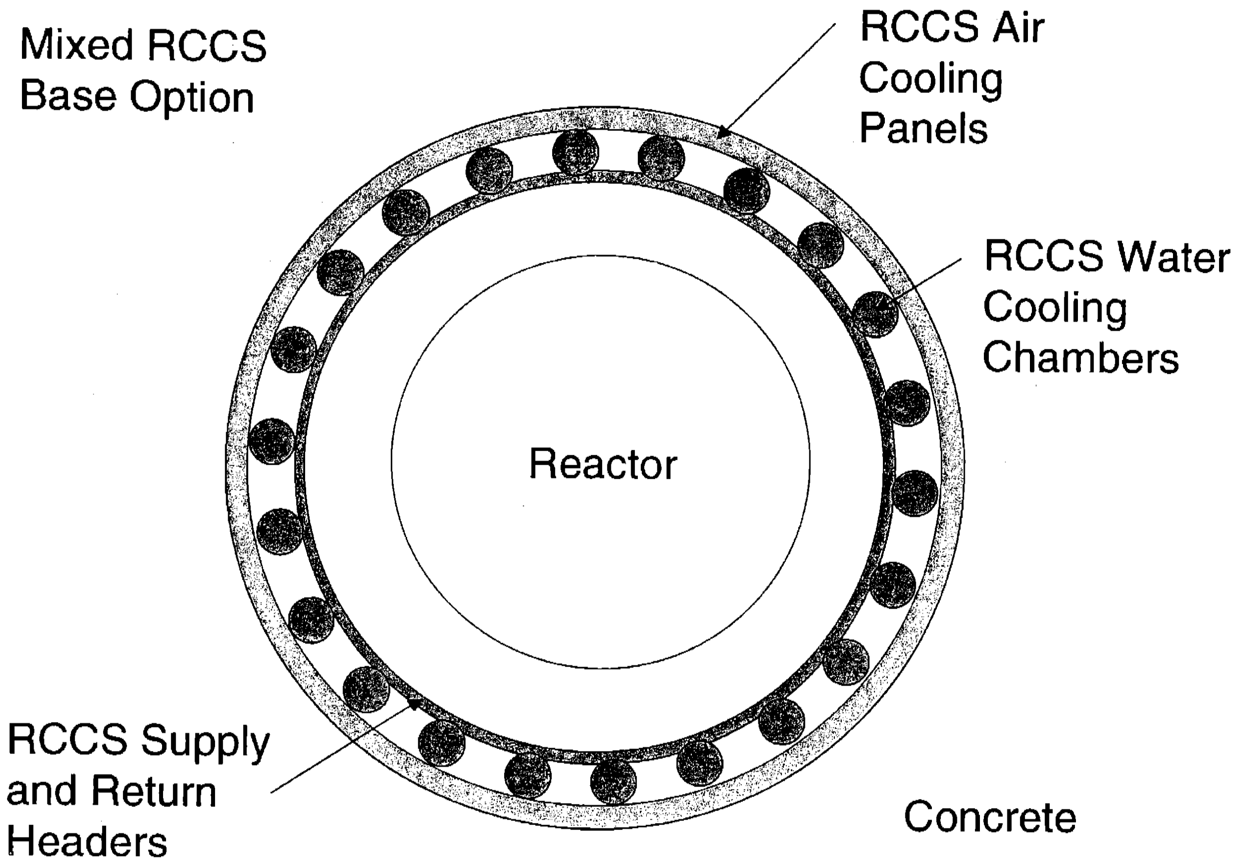

Figure 3.2.1 Outline of the Mixed RCCS for PBMR - Base Option

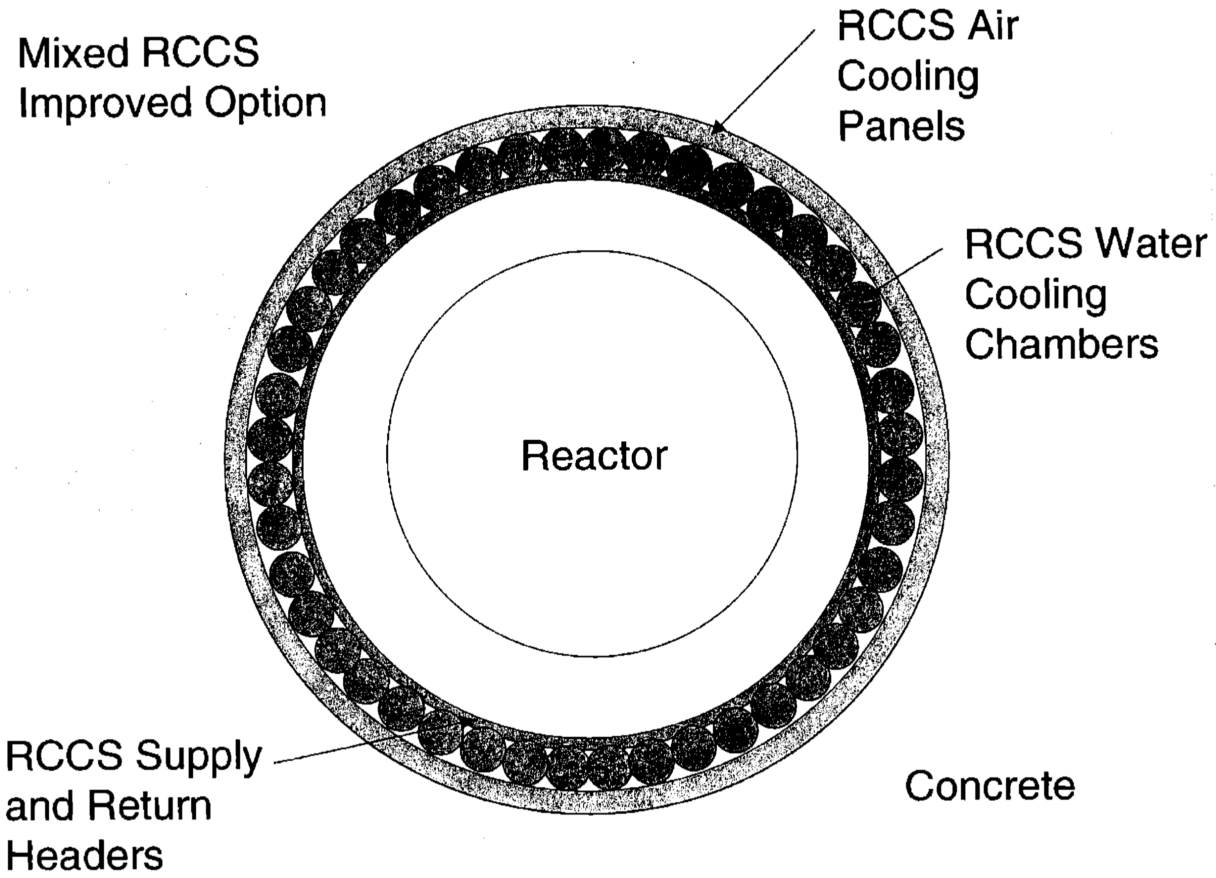

Figure 3.4.1 Outline of the Mixed RCCS for PBMR - Improved Option

APPENDIX B

PRA CUTSETS FOR THE BASE CASE AND THE SEISMIC ACCELERATION LEVEL 6 (2g)

Sequence 04 Uncertainty Cutsets

```
                          Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                    Fault Tree-> SEQ-04
  Mincut Upper Bound -> 4.261E-012      This Partition -> 4.261E-012

   Cut      %    % Cut
   No.    Total   Set    Frequency                     Cut Sets
-------- ----- ----- -----------  ---------------------------------------------
      1  17.8   17.8  7.593E-013  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                  PUMPS-T-S, RCCS-HR
      2  35.6   17.8  7.593E-013  BUILDING-S, E-IE, /EX-S, /PPB-S
                                  PUMPS-RCCS-S, RCCS-HR
      3  53.5   17.8  7.593E-013  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, /PPB-S
                                  RCCS-HR
      4  69.2   15.7  6.685E-013  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                  /PPB-S, RCCS-HR
      5  79.3   10.1  4.312E-013  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                  PUMPS-T-S, RCCS-HR
      6  88.2    8.9  3.796E-013  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                  PUMPS-OC-S, RCCS-HR
      7  91.3    3.1  1.337E-013  BUILDING-S, E-IE, /EX-S, LOSP-S, OP-T-TR
                                  /PPB-S, RCCS-HR
      8  93.6    2.3  9.631E-014  BUILDING-S, DIESELS-S, E-IE, /EX-S, LOSP-S
                                  /PPB-S, RCCS-HR
      9  95.4    1.8  7.593E-014  BUILDING-S, E-IE, /EX-S, OP-T-TR, /PPB-S
                                  PUMPS-OC-S, RCCS-HR
     10  96.4    1.1  4.457E-014  BUILDING-S, E-IE, /EX-S, LOSP-S, PIPING-T-S
                                  /PPB-S, RCCS-HR
     11  97.5    1.1  4.457E-014  BUILDING-S, E-IE, /EX-S, PIPING-RCCS-S
                                  /PPB-S, RCCS-HR
     12  98.1    0.6  2.531E-014  BUILDING-S, E-IE, /EX-S, PIPING-T-S, /PPB-S
                                  PUMPS-OC-S, RCCS-HR
     13  98.7    0.6  2.531E-014  BUILDING-S, E-IE, /EX-S, PIPING-OC-S
                                  /PPB-S, PUMPS-T-S, RCCS-HR
     14  99.2    0.5  2.229E-014  BUILDING-S, E-IE, /EX-S, FANS-T-S
                                  PIPING-OC-S, /PPB-S, RCCS-HR
     15  99.7    0.5  2.166E-014  BATTERY-S, BUILDING-S, E-IE, /EX-S, LOSP-S
                                  /PPB-S, RCCS-HR
     16  99.9    0.2  6.150E-015  BUILDING-S, DIESELS-CC, E-IE, /EX-S, LOSP-S
                                  /PPB-S, RCCS-HR
     17 100.0    0.1  4.457E-015  BUILDING-S, E-IE, /EX-S, OP-T-TR
                                  PIPING-OC-S, /PPB-S, RCCS-HR
     18 100.0    0.1  2.657E-015  BUILDING-S, DIESEL1-RUN, DIESEL2-RUN, E-IE
                                  /EX-S, LOSP-S, /PPB-S, RCCS-HR
     19 100.0    0.0  1.486E-015  BUILDING-S, E-IE, /EX-S, PIPING-OC-S
```

```
                              PIPING-T-S, /PPB-S, RCCS-HR

                         Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                     Fault Tree-> SEQ-04
 Mincut Upper Bound -> 4.261E-012       This Partition -> 4.261E-012

 Cut    Total  CutSet Prob/                                                                                           Event
 No.      %      %    Freq.       Basic Event              Description                                                 Prob.
-------- -----  ----- ----------  ------------------------ ------------------------------------------------------------ ----------
       1  17.8   17.8  7.593E-013  BUILDING-S               Seismically Induced Building Failure                         1.909E-001
                                   E-IE                     Earthquake Initiating Event                                  5.000E-002
                                   /EX-S                    Earthquake Initiating Event Correction                       2.801E-006
                                   LOSP-S                   Loss of Offsite Power                                        1.000E+000
                                   /PPB-S                   Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                   PUMPS-T-S                Seismically Induced Failure of More Than 3 CT Pumps          5.679E-001
                                   RCCS-HR                  RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       2  35.6   17.8  7.593E-013  BUILDING-S               Seismically Induced Building Failure                         1.909E-001
                                   E-IE                     Earthquake Initiating Event                                  5.000E-002
                                   /EX-S                    Earthquake Initiating Event Correction                       2.801E-006
                                   /PPB-S                   Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                   PUMPS-RCCS-S             RCCS Pumps Seismically Induced Failure                       5.679E-001
                                   RCCS-HR                  RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       3  53.5   17.8  7.593E-013  BUILDING-S               Seismically Induced Building Failure                         1.909E-001
                                   E-IE                     Earthquake Initiating Event                                  5.000E-002
                                   /EX-S                    Earthquake Initiating Event Correction                       2.801E-006
                                   HX-RCCS-S                Seismically Induced Failure of all RCCS HX                   5.679E-001
                                   /PPB-S                   Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                   RCCS-HR                  RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       4  69.2   15.7  6.685E-013  BUILDING-S               Seismically Induced Building Failure                         1.909E-001
                                   E-IE                     Earthquake Initiating Event                                  5.000E-002
                                   /EX-S                    Earthquake Initiating Event Correction                       2.801E-006
                                   FANS-T-S                 Seismically Induced CT Fans Failure                          5.000E-001
                                   LOSP-S                   Loss of Offsite Power                                        1.000E+000
                                   /PPB-S                   Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                   RCCS-HR                  RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       5  79.3   10.1  4.312E-013  BUILDING-S               Seismically Induced Building Failure                         1.909E-001
                                   E-IE                     Earthquake Initiating Event                                  5.000E-002
                                   /EX-S                    Earthquake Initiating Event Correction                       2.801E-006
                                   /PPB-S                   Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                   PUMPS-OC-S               Seismically Induced Failure of Pumps                         5.679E-001
                                   PUMPS-T-S                Seismically Induced Failure of More Than 3 CT Pumps          5.679E-001
                                   RCCS-HR                  RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       6  88.2    8.9  3.796E-013  BUILDING-S               Seismically Induced Building Failure                         1.909E-001
                                   E-IE                     Earthquake Initiating Event                                  5.000E-002
                                   /EX-S                    Earthquake Initiating Event Correction                       2.801E-006
                                   FANS-T-S                 Seismically Induced CT Fans Failure                          5.000E-001
                                   /PPB-S                   Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                   PUMPS-OC-S               Seismically Induced Failure of Pumps                         5.679E-001
                                   RCCS-HR                  RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       7  91.3    3.1  1.337E-013  BUILDING-S               Seismically Induced Building Failure                         1.909E-001
```

```
                          E-IE              Earthquake Initiating Event                                5.000E-002
                          /EX-S             Earthquake Initiating Event Correction                     2.801E-006
                          LOSP-S            Loss of Offsite Power                                      1.000E+000
                          OP-T-TR           Failure to Transfer to CT                                  1.000E-001
                          /PPB-S            Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                          RCCS-HR           RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
 8  93.6   2.3  9.631E-014 BUILDING-S       Seismically Induced Building Failure                       1.909E-001
                          DIESELS-S         Seismic-Induced Failure of Both Diesel Generators          7.203E-002
                          E-IE              Earthquake Initiating Event                                5.000E-002
                          /EX-S             Earthquake Initiating Event Correction                     2.801E-006
                          LOSP-S            Loss of Offsite Power                                      1.000E+000
                          /PPB-S            Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                          RCCS-HR           RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
 9  95.4   1.8  7.593E-014 BUILDING-S       Seismically Induced Building Failure                       1.909E-001
                          E-IE              Earthquake Initiating Event                                5.000E-002
                          /EX-S             Earthquake Initiating Event Correction                     2.801E-006
                          OP-T-TR           Failure to Transfer to CT                                  1.000E-001
                          /PPB-S            Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                          PUMPS-OC-S        Seismically Induced Failure of Pumps                       5.679E-001
                          RCCS-HR           RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
10  96.4   1.1  4.457E-014 BUILDING-S       Seismically Induced Building Failure                       1.909E-001
                          E-IE              Earthquake Initiating Event                                5.000E-002
                          /EX-S             Earthquake Initiating Event Correction                     2.801E-006
                          LOSP-S            Loss of Offsite Power                                      1.000E+000
                          PIPING-T-S        Seismically Induced CT Piping Failure                      3.334E-002
                          /PPB-S            Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                          RCCS-HR           RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
11  97.5   1.1  4.457E-014 BUILDING-S       Seismically Induced Building Failure                       1.909E-001
                          E-IE              Earthquake Initiating Event                                5.000E-002
                          /EX-S             Earthquake Initiating Event Correction                     2.801E-006
                          PIPING-RCCS-S     Seismically Induced RCCS Piping Failure                    3.334E-002
                          /PPB-S            Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                          RCCS-HR           RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
12  98.1   0.6  2.531E-014 BUILDING-S       Seismically Induced Building Failure                       1.909E-001
                          E-IE              Earthquake Initiating Event                                5.000E-002
                          /EX-S             Earthquake Initiating Event Correction                     2.801E-006
                          PIPING-T-S        Seismically Induced CT Piping Failure                      3.334E-002
                          /PPB-S            Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                          PUMPS-OC-S        Seismically Induced Failure of Pumps                       5.679E-001
                          RCCS-HR           RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
13  98.7   0.6  2.531E-014 BUILDING-S       Seismically Induced Building Failure                       1.909E-001
                          E-IE              Earthquake Initiating Event                                5.000E-002
                          /EX-S             Earthquake Initiating Event Correction                     2.801E-006
                          PIPING-OC-S       Seismically Induced Piping Failure                         3.334E-002
                          /PPB-S            Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                          PUMPS-T-S         Seismically Induced Failure of More Than 3 CT Pumps        5.679E-001
                          RCCS-HR           RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
14  99.2   0.5  2.229E-014 BUILDING-S       Seismically Induced Building Failure                       1.909E-001
                          E-IE              Earthquake Initiating Event                                5.000E-002
                          /EX-S             Earthquake Initiating Event Correction                     2.801E-006
                          FANS-T-S          Seismically Induced CT Fans Failure                        5.000E-001
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PIPING-OC-S	Seismically Induced Piping Failure	3.334E-002
/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-004

Sequence 08
Uncertainty
Cutsets

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                         Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                   Fault Tree-> SEQ-08
 Mincut Upper Bound -> 5.984E-012     This Partition -> 5.984E-012

  Cut     %    % Cut
  No.   Total   Set    Frequency                     Cut Sets
-------- -----  -----  -----------  ----------------------------------------------
       1  12.7   12.7   7.593E-013  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, LOSP-S
                                    /PPB-S, RCCS-HR
       2  25.4   12.7   7.593E-013  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                    PUMPS-T-S, RCCS-HR
       3  38.1   12.7   7.593E-013  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                    PUMPS-RCCS-S, RCCS-HR
       4  49.3   11.2   6.685E-013  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                    /PPB-S, RCCS-HR
       5  56.5    7.2   4.312E-013  BUILDING-S, E-IE, /EX-S, HX-CCS-S
                                    HX-RCCS-S, /PPB-S, RCCS-HR
       6  63.7    7.2   4.312E-013  BUILDING-S, E-IE, /EX-S, HX-CCS-S, /PPB-S
                                    PUMPS-RCCS-S, RCCS-HR
       7  70.9    7.2   4.312E-013  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                    PUMPS-T-S, RCCS-HR
       8  77.2    6.4   3.796E-013  BUILDING-S, E-IE, /EX-S, FANS-CCS-S
                                    HX-RCCS-S, /PPB-S, RCCS-HR
       9  83.6    6.4   3.796E-013  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                    PUMPS-OC-S, RCCS-HR
      10  89.9    6.4   3.796E-013  BUILDING-S, E-IE, /EX-S, FANS-CCS-S, /PPB-S
                                    PUMPS-RCCS-S, RCCS-HR
      11  92.2    2.2   1.337E-013  BUILDING-S, E-IE, /EX-S, LOSP-S, OP-T-TR
                                    /PPB-S, RCCS-HR
      12  93.8    1.6   9.631E-014  BUILDING-S, DIESELS-S, E-IE, /EX-S, LOSP-S
                                    /PPB-S, RCCS-HR
      13  95.1    1.3   7.593E-014  BUILDING-S, E-IE, /EX-S, OP-T-TR, /PPB-S
                                    PUMPS-OC-S, RCCS-HR
      14  95.8    0.8   4.457E-014  BUILDING-S, E-IE, /EX-S, LOSP-S, PIPING-T-S
                                    /PPB-S, RCCS-HR
      15  96.6    0.8   4.457E-014  BUILDING-S, E-IE, /EX-S, LOSP-S
                                    PIPING-RCCS-S, /PPB-S, RCCS-HR
      16  97.0    0.4   2.531E-014  BUILDING-S, E-IE, /EX-S, HX-RCCS-S
                                    PIPING-CCS-S, /PPB-S, RCCS-HR
      17  97.4    0.4   2.531E-014  BUILDING-S, E-IE, /EX-S, HX-CCS-S
                                    PIPING-RCCS-S, /PPB-S, RCCS-HR
      18  97.8    0.4   2.531E-014  BUILDING-S, E-IE, /EX-S, PIPING-T-S, /PPB-S
                                    PUMPS-OC-S, RCCS-HR
      19  98.3    0.4   2.531E-014  BUILDING-S, E-IE, /EX-S, PIPING-OC-S
                                    /PPB-S, PUMPS-T-S, RCCS-HR
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      20  98.7    0.4   2.531E-014  BUILDING-S, E-IE, /EX-S, PIPING-CCS-S
                                    /PPB-S, PUMPS-RCCS-S, RCCS-HR


                        Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                      Fault Tree-> SEQ-08
 Mincut Upper Bound -> 5.984E-012        This Partition -> 5.984E-012

 Cut     Total  CutSet  Prob/                                                                                           Event
 No.       %      %     Freq.       Basic Event               Description                                                Prob.
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       1  12.7   12.7   7.593E-013  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    HX-RCCS-S                 Seismically Induced Failure of all RCCS HX                   5.679E-001
                                    LOSP-S                    Loss of Offsite Power                                        1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       2  25.4   12.7   7.593E-013  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    LOSP-S                    Loss of Offsite Power                                        1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    PUMPS-T-S                 Seismically Induced Failure of More Than 3 CT Pumps          5.679E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       3  38.1   12.7   7.593E-013  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    LOSP-S                    Loss of Offsite Power                                        1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    PUMPS-RCCS-S              RCCS Pumps Seismically Induced Failure                       5.679E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       4  49.3   11.2   6.685E-013  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    FANS-T-S                  Seismically Induced CT Fans Failure                          5.000E-001
                                    LOSP-S                    Loss of Offsite Power                                        1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       5  56.5    7.2   4.312E-013  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    HX-CCS-S                  Seismically Induced CCS Heat Exchanger Failure               5.679E-001
                                    HX-RCCS-S                 Seismically Induced Failure of all RCCS HX                   5.679E-001
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-004
       6  63.7    7.2   4.312E-013  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
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                                   HX-CCS-S                   Seismically Induced CCS Heat Exchanger Failure              5.679E-001
                                   /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic       5.000E-001
                                   PUMPS-RCCS-S               RCCS Pumps Seismically Induced Failure                      5.679E-001
                                   RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                1.000E-004
       7  70.9    7.2  4.312E-013  BUILDING-S                 Seismically Induced Building Failure                        1.909E-001
                                   E-IE                       Earthquake Initiating Event                                 5.000E-002
                                   /EX-S                      Earthquake Initiating Event Correction                      2.801E-006
                                   /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic       5.000E-001
                                   PUMPS-OC-S                 Seismically Induced Failure of Pumps                        5.679E-001
                                   PUMPS-T-S                  Seismically Induced Failure of More Than 3 CT Pumps         5.679E-001
                                   RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                1.000E-004
       8  77.2    6.4  3.796E-013  BUILDING-S                 Seismically Induced Building Failure                        1.909E-001
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                                   E-IE                       Earthquake Initiating Event                                 5.000E-002
                                   /EX-S                      Earthquake Initiating Event Correction                      2.801E-006
                                   FANS-CCS-S                 CCS Fans Failure - Seismic                                  5.000E-001
                                   HX-RCCS-S                  Seismically Induced Failure of all RCCS HX                  5.679E-001
                                   /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic       5.000E-001
                                   RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                1.000E-004
       9  83.6    6.4  3.796E-013  BUILDING-S                 Seismically Induced Building Failure                        1.909E-001
                                   E-IE                       Earthquake Initiating Event                                 5.000E-002
                                   /EX-S                      Earthquake Initiating Event Correction                      2.801E-006
                                   FANS-T-S                   Seismically Induced CT Fans Failure                         5.000E-001
                                   /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic       5.000E-001
                                   PUMPS-OC-S                 Seismically Induced Failure of Pumps                        5.679E-001
                                   RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                1.000E-004
      10  89.9    6.4  3.796E-013  BUILDING-S                 Seismically Induced Building Failure                        1.909E-001
                                   E-IE                       Earthquake Initiating Event                                 5.000E-002
                                   /EX-S                      Earthquake Initiating Event Correction                      2.801E-006
                                   FANS-CCS-S                 CCS Fans Failure - Seismic                                  5.000E-001
                                   /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic       5.000E-001
                                   PUMPS-RCCS-S               RCCS Pumps Seismically Induced Failure                      5.679E-001
                                   RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                1.000E-004
      11  92.2    2.2  1.337E-013  BUILDING-S                 Seismically Induced Building Failure                        1.909E-001
                                   E-IE                       Earthquake Initiating Event                                 5.000E-002
                                   /EX-S                      Earthquake Initiating Event Correction                      2.801E-006
                                   LOSP-S                     Loss of Offsite Power                                       1.000E+000
                                   OP-T-TR                    Failure to Transfer to CT                                   1.000E-001
                                   /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic       5.000E-001
                                   RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                1.000E-004
      12  93.8    1.6  9.631E-014  BUILDING-S                 Seismically Induced Building Failure                        1.909E-001
                                   DIESELS-S                  Seismic-Induced Failure of Both Diesel Generators           7.203E-002
                                   E-IE                       Earthquake Initiating Event                                 5.000E-002
                                   /EX-S                      Earthquake Initiating Event Correction                      2.801E-006
                                   LOSP-S                     Loss of Offsite Power                                       1.000E+000
                                   /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic       5.000E-001
                                   RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                1.000E-004
      13  95.1    1.3  7.593E-014  BUILDING-S                 Seismically Induced Building Failure                        1.909E-001
                                   E-IE                       Earthquake Initiating Event                                 5.000E-002
                                   /EX-S                      Earthquake Initiating Event Correction                      2.801E-006
                                   OP-T-TR                    Failure to Transfer to CT                                   1.000E-001
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                        /PPB-S              Primary Pressure Boundary Integrity Failure - Seismic     5.000E-001
                        PUMPS-OC-S          Seismically Induced Failure of Pumps                      5.679E-001
                        RCCS-HR             RCCS Cooling Restored Prior to Vessel Damage              1.000E-004
14  95.8   0.8  4.457E-014  BUILDING-S      Seismically Induced Building Failure                      1.909E-001
                        E-IE                Earthquake Initiating Event                               5.000E-002
                        /EX-S               Earthquake Initiating Event Correction                    2.801E-006
                        LOSP-S              Loss of Offsite Power                                     1.000E+000
                        PIPING-T-S          Seismically Induced CT Piping Failure                     3.334E-002
                        /PPB-S              Primary Pressure Boundary Integrity Failure - Seismic     5.000E-001
                        RCCS-HR             RCCS Cooling Restored Prior to Vessel Damage              1.000E-004
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Sequence 12
Uncertainty
Cutsets

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                      Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                    Fault Tree-> SEQ-12
 Mincut Upper Bound -> 1.832E-014      This Partition -> 1.832E-014

  Cut     %    % Cut
  No.   Total   Set    Frequency                   Cut Sets
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       1  13.2  13.2  2.419E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                  HX-RCCS-S, /PPB-S, RCCS-HR, TRIP-RSS
       2  26.4  13.2  2.419E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                  LOSP-S, /PPB-S, PUMPS-T-S, RCCS-HR
                                  TRIP-RSS
       3  39.6  13.2  2.419E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                  /PPB-S, PUMPS-RCCS-S, RCCS-HR, TRIP-RSS
       4  51.3  11.6  2.130E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                  FANS-T-S, LOSP-S, /PPB-S, RCCS-HR, TRIP-RSS
       5  58.8   7.5  1.374E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                  /PPB-S, PUMPS-OC-S, PUMPS-T-S, RCCS-HR
                                  TRIP-RSS
       6  65.4   6.6  1.210E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                  FANS-T-S, /PPB-S, PUMPS-OC-S, RCCS-HR
                                  TRIP-RSS
       7  70.1   4.7  8.675E-016  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                  PUMPS-T-S, RCCS-HR, RODS-S, TRIP-RSS
       8  74.9   4.7  8.675E-016  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, /PPB-S
                                  RCCS-HR, RODS-S, TRIP-RSS
       9  79.6   4.7  8.675E-016  BUILDING-S, E-IE, /EX-S, /PPB-S
                                  PUMPS-RCCS-S, RCCS-HR, RODS-S, TRIP-RSS
      10  83.8   4.2  7.638E-016  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                  /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
      11  86.5   2.7  4.926E-016  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                  PUMPS-T-S, RCCS-HR, RODS-S, TRIP-RSS
      12  88.9   2.4  4.337E-016  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                  PUMPS-OC-S, RCCS-HR, RODS-S, TRIP-RSS
      13  91.2   2.3  4.260E-016  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                  LOSP-S, OP-T-TR, /PPB-S, RCCS-HR, TRIP-RSS
      14  92.9   1.7  3.069E-016  BUILDING-S, CONTROL-BLOCKS-S, DIESELS-S
                                  E-IE, /EX-S, LOSP-S, /PPB-S, RCCS-HR
                                  TRIP-RSS
      15  94.2   1.3  2.419E-016  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                  OP-T-TR, /PPB-S, PUMPS-OC-S, RCCS-HR
                                  TRIP-RSS
      16  95.0   0.8  1.528E-016  BUILDING-S, E-IE, /EX-S, LOSP-S, OP-T-TR
                                  /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
      17  95.8   0.8  1.420E-016  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
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                                    PIPING-RCCS-S, /PPB-S, RCCS-HR, TRIP-RSS
      18  96.6    0.8  1.420E-016  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    LOSP-S, PIPING-T-S, /PPB-S, RCCS-HR
                                    TRIP-RSS
      19  97.2    0.6  1.100E-016  BUILDING-S, DIESELS-S, E-IE, /EX-S, LOSP-S
                                    /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
      20  97.7    0.5  8.675E-017  BUILDING-S, E-IE, /EX-S, OP-T-TR, /PPB-S
                                    PUMPS-OC-S, RCCS-HR, RODS-S, TRIP-RSS


                           Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                    Fault Tree-> SEQ-12
  Mincut Upper Bound -> 1.832E-014      This Partition -> 1.832E-014

  Cut    Total  CutSet  Prob/                                                                                                 Event
  No.      %      %     Freq.       Basic Event               Description                                                     Prob.
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       1  13.2   13.2  2.419E-015  BUILDING-S                Seismically Induced Building Failure                          1.909E-001
                                    CONTROL-BLOCKS-S          Damage to Control Blocks                                      6.373E-001
                                    E-IE                      Earthquake Initiating Event                                   5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                        2.801E-006
                                    HX-RCCS-S                 Seismically Induced Failure of all RCCS HX                    5.679E-001
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic         5.000E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                  1.000E-004
                                    TRIP-RSS                  Failure to TRIP with Reserve Shutdown System                  5.000E-003
       2  26.4   13.2  2.419E-015  BUILDING-S                Seismically Induced Building Failure                          1.909E-001
                                    CONTROL-BLOCKS-S          Damage to Control Blocks                                      6.373E-001
                                    E-IE                      Earthquake Initiating Event                                   5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                        2.801E-006
                                    LOSP-S                    Loss of Offsite Power                                         1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic         5.000E-001
                                    PUMPS-T-S                 Seismically Induced Failure of More Than 3 CT Pumps           5.679E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                  1.000E-004
                                    TRIP-RSS                  Failure to TRIP with Reserve Shutdown System                  5.000E-003
       3  39.6   13.2  2.419E-015  BUILDING-S                Seismically Induced Building Failure                          1.909E-001
                                    CONTROL-BLOCKS-S          Damage to Control Blocks                                      6.373E-001
                                    E-IE                      Earthquake Initiating Event                                   5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                        2.801E-006
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic         5.000E-001
                                    PUMPS-RCCS-S              RCCS Pumps Seismically Induced Failure                        5.679E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                  1.000E-004
                                    TRIP-RSS                  Failure to TRIP with Reserve Shutdown System                  5.000E-003
       4  51.3   11.6  2.130E-015  BUILDING-S                Seismically Induced Building Failure                          1.909E-001
                                    CONTROL-BLOCKS-S          Damage to Control Blocks                                      6.373E-001
                                    E-IE                      Earthquake Initiating Event                                   5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                        2.801E-006
                                    FANS-T-S                  Seismically Induced CT Fans Failure                           5.000E-001
                                    LOSP-S                    Loss of Offsite Power                                         1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic         5.000E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                  1.000E-004
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                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System               5.000E-003
   5  58.8     7.5   1.374E-015    BUILDING-S                Seismically Induced Building Failure                       1.909E-001
                                   CONTROL-BLOCKS-S          Damage to Control Blocks                                   6.373E-001
                                   E-IE                      Earthquake Initiating Event                                5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction                     2.801E-006
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                   PUMPS-OC-S                Seismically Induced Failure of Pumps                       5.679E-001
                                   PUMPS-T-S                 Seismically Induced Failure of More Than 3 CT Pumps        5.679E-001
                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System               5.000E-003
   6  65.4     6.6   1.210E-015    BUILDING-S                Seismically Induced Building Failure                       1.909E-001
                                   CONTROL-BLOCKS-S          Damage to Control Blocks                                   6.373E-001
                                   E-IE                      Earthquake Initiating Event                                5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction                     2.801E-006
                                   FANS-T-S                  Seismically Induced CT Fans Failure                        5.000E-001
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                   PUMPS-OC-S                Seismically Induced Failure of Pumps                       5.679E-001
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                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System               5.000E-003
   7  70.1     4.7   8.675E-016    BUILDING-S                Seismically Induced Building Failure                       1.909E-001
                                   E-IE                      Earthquake Initiating Event                                5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction                     2.801E-006
                                   LOSP-S                    Loss of Offsite Power                                      1.000E+000
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                   PUMPS-T-S                 Seismically Induced Failure of More Than 3 CT Pumps        5.679E-001
                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
                                   RODS-S                    Seismic Failure: Misalignment of Control Rods & Guide Tubes 2.285E-001
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System               5.000E-003
   8  74.9     4.7   8.675E-016    BUILDING-S                Seismically Induced Building Failure                       1.909E-001
                                   E-IE                      Earthquake Initiating Event                                5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction                     2.801E-006
                                   HX-RCCS-S                 Seismically Induced Failure of all RCCS HX                 5.679E-001
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
                                   RODS-S                    Seismic Failure: Misalignment of Control Rods & Guide Tubes 2.285E-001
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System               5.000E-003
   9  79.6     4.7   8.675E-016    BUILDING-S                Seismically Induced Building Failure                       1.909E-001
                                   E-IE                      Earthquake Initiating Event                                5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction                     2.801E-006
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                   PUMPS-RCCS-S              RCCS Pumps Seismically Induced Failure                     5.679E-001
                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage               1.000E-004
                                   RODS-S                    Seismic Failure: Misalignment of Control Rods & Guide Tubes 2.285E-001
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System               5.000E-003
  10  83.8     4.2   7.638E-016    BUILDING-S                Seismically Induced Building Failure                       1.909E-001
                                   E-IE                      Earthquake Initiating Event                                5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction                     2.801E-006
                                   FANS-T-S                  Seismically Induced CT Fans Failure                        5.000E-001
                                   LOSP-S                    Loss of Offsite Power                                      1.000E+000
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
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                          RCCS-HR            RCCS Cooling Restored Prior to Vessel Damage             1.000E-004
                          RODS-S             Seismic Failure: Misalignment of Control Rods & Guide Tubes  2.285E-001
                          TRIP-RSS           Failure to TRIP with Reserve Shutdown System             5.000E-003
11  86.5    2.7  4.926E-016  BUILDING-S         Seismically Induced Building Failure                     1.909E-001
                          E-IE               Earthquake Initiating Event                              5.000E-002
                          /EX-S              Earthquake Initiating Event Correction                   2.801E-006
                          /PPB-S             Primary Pressure Boundary Integrity Failure - Seismic    5.000E-001
                          PUMPS-OC-S         Seismically Induced Failure of Pumps                     5.679E-001
                          PUMPS-T-S          Seismically Induced Failure of More Than 3 CT Pumps      5.679E-001
                          RCCS-HR            RCCS Cooling Restored Prior to Vessel Damage             1.000E-004
                          RODS-S             Seismic Failure: Misalignment of Control Rods & Guide Tubes  2.285E-001
                          TRIP-RSS           Failure to TRIP with Reserve Shutdown System             5.000E-003
```

Sequence 16 Uncertainty Cutsets

```
                    Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                     Fault Tree-> SEQ-16
 Mincut Upper Bound -> 2.565E-014       This Partition -> 2.565E-014

  Cut     %    % Cut
  No.   Total   Set    Frequency                  Cut Sets
-------- -----  -----  -----------  ----------------------------------------------
      1   9.4    9.4   2.419E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   LOSP-S, /PPB-S, PUMPS-RCCS-S, RCCS-HR
                                   TRIP-RSS
      2  18.9    9.4   2.419E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   LOSP-S, /PPB-S, PUMPS-T-S, RCCS-HR
                                   TRIP-RSS
      3  28.3    9.4   2.419E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   HX-RCCS-S, LOSP-S, /PPB-S, RCCS-HR
                                   TRIP-RSS
      4  36.6    8.3   2.130E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-T-S, LOSP-S, /PPB-S, RCCS-HR, TRIP-RSS
      5  42.0    5.4   1.374E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   HX-CCS-S, /PPB-S, PUMPS-RCCS-S, RCCS-HR
                                   TRIP-RSS
      6  47.4    5.4   1.374E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   /PPB-S, PUMPS-OC-S, PUMPS-T-S, RCCS-HR
                                   TRIP-RSS
      7  52.7    5.4   1.374E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   HX-CCS-S, HX-RCCS-S, /PPB-S, RCCS-HR
                                   TRIP-RSS
      8  57.4    4.7   1.210E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-T-S, /PPB-S, PUMPS-OC-S, RCCS-HR
                                   TRIP-RSS
      9  62.2    4.7   1.210E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-CCS-S, /PPB-S, PUMPS-RCCS-S, RCCS-HR
                                   TRIP-RSS
     10  66.9    4.7   1.210E-015  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-CCS-S, HX-RCCS-S, /PPB-S, RCCS-HR
                                   TRIP-RSS
     11  70.3    3.4   8.675E-016  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                   PUMPS-T-S, RCCS-HR, RODS-S, TRIP-RSS
     12  73.7    3.4   8.675E-016  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                   PUMPS-RCCS-S, RCCS-HR, RODS-S, TRIP-RSS
     13  77.0    3.4   8.675E-016  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, LOSP-S
                                   /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
     14  80.0    3.0   7.638E-016  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                   /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
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     15  82.0    1.9   4.926E-016  BUILDING-S, E-IE, /EX-S, HX-CCS-S
                                   HX-RCCS-S, /PPB-S, RCCS-HR, RODS-S
                                   TRIP-RSS
     16  83.9    1.9   4.926E-016  BUILDING-S, E-IE, /EX-S, HX-CCS-S, /PPB-S
                                   PUMPS-RCCS-S, RCCS-HR, RODS-S, TRIP-RSS
     17  85.8    1.9   4.926E-016  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                   PUMPS-T-S, RCCS-HR, RODS-S, TRIP-RSS
     18  87.5    1.7   4.337E-016  BUILDING-S, E-IE, /EX-S, FANS-CCS-S
                                   HX-RCCS-S, /PPB-S, RCCS-HR, RODS-S
                                   TRIP-RSS
     19  89.2    1.7   4.337E-016  BUILDING-S, E-IE, /EX-S, FANS-CCS-S, /PPB-S
                                   PUMPS-RCCS-S, RCCS-HR, RODS-S, TRIP-RSS
     20  90.9    1.7   4.337E-016  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                   PUMPS-OC-S, RCCS-HR, RODS-S, TRIP-RSS

                          Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                    Fault Tree-> SEQ-16
 Mincut Upper Bound -> 2.565E-014      This Partition -> 2.565E-014

 Cut    Total  CutSet  Prob/                                                                                 Event
 No.      %      %     Freq.       Basic Event               Description                                      Prob.
-------- -----  -----  ----------  ------------------------- ------------------------------------------------------------ ----------
      1   9.4    9.4   2.419E-015  BUILDING-S                Seismically Induced Building Failure            1.909E-001
                                   CONTROL-BLOCKS-S          Damage to Control Blocks                        6.373E-001
                                   E-IE                      Earthquake Initiating Event                     5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction          2.801E-006
                                   LOSP-S                    Loss of Offsite Power                           1.000E+000
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic 5.000E-001
                                   PUMPS-RCCS-S              RCCS Pumps Seismically Induced Failure          5.679E-001
                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage    1.000E-004
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System    5.000E-003
      2  18.9    9.4   2.419E-015  BUILDING-S                Seismically Induced Building Failure            1.909E-001
                                   CONTROL-BLOCKS-S          Damage to Control Blocks                        6.373E-001
                                   E-IE                      Earthquake Initiating Event                     5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction          2.801E-006
                                   LOSP-S                    Loss of Offsite Power                           1.000E+000
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic 5.000E-001
                                   PUMPS-T-S                 Seismically Induced Failure of More Than 3 CT Pumps 5.679E-001
                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage    1.000E-004
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System    5.000E-003
      3  28.3    9.4   2.419E-015  BUILDING-S                Seismically Induced Building Failure            1.909E-001
                                   CONTROL-BLOCKS-S          Damage to Control Blocks                        6.373E-001
                                   E-IE                      Earthquake Initiating Event                     5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction          2.801E-006
                                   HX-RCCS-S                 Seismically Induced Failure of all RCCS HX      5.679E-001
                                   LOSP-S                    Loss of Offsite Power                           1.000E+000
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic 5.000E-001
                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage    1.000E-004
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System    5.000E-003
      4  36.6    8.3   2.130E-015  BUILDING-S                Seismically Induced Building Failure            1.909E-001
```

				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-T-S	Seismically Induced CT Fans Failure	5.000E-001
				LOSP-S	Loss of Offsite Power	1.000E+000
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-004
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
5	42.0	5.4	1.374E-015	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				HX-CCS-S	Seismically Induced CCS Heat Exchanger Failure	5.679E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-RCCS-S	RCCS Pumps Seismically Induced Failure	5.679E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-004
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
6	47.4	5.4	1.374E-015	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-OC-S	Seismically Induced Failure of Pumps	5.679E-001
				PUMPS-T-S	Seismically Induced Failure of More Than 3 CT Pumps	5.679E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-004
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
7	52.7	5.4	1.374E-015	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				HX-CCS-S	Seismically Induced CCS Heat Exchanger Failure	5.679E-001
				HX-RCCS-S	Seismically Induced Failure of all RCCS HX	5.679E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-004
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
8	57.4	4.7	1.210E-015	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-T-S	Seismically Induced CT Fans Failure	5.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-OC-S	Seismically Induced Failure of Pumps	5.679E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-004
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
9	62.2	4.7	1.210E-015	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-CCS-S	CCS Fans Failure - Seismic	5.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-RCCS-S	RCCS Pumps Seismically Induced Failure	5.679E-001

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                            RCCS-HR            RCCS Cooling Restored Prior to Vessel Damage             1.000E-004
                            TRIP-RSS           Failure to TRIP with Reserve Shutdown System             5.000E-003
10  66.9    4.7  1.210E-015 BUILDING-S         Seismically Induced Building Failure                     1.909E-001
                            CONTROL-BLOCKS-S   Damage to Control Blocks                                 6.373E-001
                            E-IE               Earthquake Initiating Event                              5.000E-002
                            /EX-S              Earthquake Initiating Event Correction                   2.801E-006
                            FANS-CCS-S         CCS Fans Failure - Seismic                               5.000E-001
                            HX-RCCS-S          Seismically Induced Failure of all RCCS HX               5.679E-001
                            /PPB-S             Primary Pressure Boundary Integrity Failure - Seismic    5.000E-001
                            RCCS-HR            RCCS Cooling Restored Prior to Vessel Damage             1.000E-004
                            TRIP-RSS           Failure to TRIP with Reserve Shutdown System             5.000E-003
11  70.3    3.4  8.675E-016 BUILDING-S         Seismically Induced Building Failure                     1.909E-001
                            E-IE               Earthquake Initiating Event                              5.000E-002
                            /EX-S              Earthquake Initiating Event Correction                   2.801E-006
                            LOSP-S             Loss of Offsite Power                                    1.000E+000
                            /PPB-S             Primary Pressure Boundary Integrity Failure - Seismic    5.000E-001
                            PUMPS-T-S          Seismically Induced Failure of More Than 3 CT Pumps      5.679E-001
                            RCCS-HR            RCCS Cooling Restored Prior to Vessel Damage             1.000E-004
                            RODS-S             Seismic Failure: Misalignment of Control Rods & Guide Tubes 2.285E-001
                            TRIP-RSS           Failure to TRIP with Reserve Shutdown System             5.000E-003
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APPENDIX C

PRA CUTSETS FOR ALTERNATIVE CASE 1 (RCCS IMPROVEMENT) AND THE SEISMIC ACCELERATION LEVEL 6 (2g)

Sequence 04 Uncertainty Cutsets

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                         Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                    Fault Tree-> SEQ-04
  Mincut Upper Bound -> 1.077E-014      This Partition -> 1.077E-014

   Cut     %    % Cut
   No.   Total   Set    Frequency                 Cut Sets
-------- -----  -----  -----------  ---------------------------------------------
       1  17.6   17.6   1.894E-015  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, /PPB-S
                                    RCCS-AIR-S, RCCS-HR
       2  35.2   17.6   1.894E-015  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                    PUMPS-T-S, RCCS-AIR-S, RCCS-HR
       3  52.8   17.6   1.894E-015  BUILDING-S, E-IE, /EX-S, /PPB-S
                                    PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR
       4  68.3   15.5   1.668E-015  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
       5  78.3   10.0   1.076E-015  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                    PUMPS-T-S, RCCS-AIR-S, RCCS-HR
       6  87.1    8.8   9.470E-016  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                    PUMPS-OC-S, RCCS-AIR-S, RCCS-HR
       7  90.2    3.1   3.335E-016  BUILDING-S, E-IE, /EX-S, LOSP-S, OP-T-TR
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
       8  92.4    2.2   2.402E-016  BUILDING-S, DIESELS-S, E-IE, /EX-S, LOSP-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
       9  94.2    1.8   1.894E-016  BUILDING-S, E-IE, /EX-S, OP-T-TR, /PPB-S
                                    PUMPS-OC-S, RCCS-AIR-S, RCCS-HR
      10  95.2    1.0   1.112E-016  BUILDING-S, E-IE, /EX-S, LOSP-S, PIPING-T-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
      11  96.2    1.0   1.112E-016  BUILDING-S, E-IE, /EX-S, PIPING-RCCS-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
      12  96.8    0.6   6.314E-017  BUILDING-S, E-IE, /EX-S, PIPING-OC-S
                                    /PPB-S, PUMPS-T-S, RCCS-AIR-S, RCCS-HR
      13  97.4    0.6   6.314E-017  BUILDING-S, E-IE, /EX-S, PIPING-T-S, /PPB-S
                                    PUMPS-OC-S, RCCS-AIR-S, RCCS-HR
      14  97.9    0.5   5.560E-017  BUILDING-S, E-IE, /EX-S, FANS-T-S
                                    PIPING-OC-S, /PPB-S, RCCS-AIR-S, RCCS-HR
      15  98.5    0.5   5.402E-017  BATTERY-S, BUILDING-S, E-IE, /EX-S, LOSP-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
      16  98.6    0.2   1.534E-017  BUILDING-S, DIESELS-CC, E-IE, /EX-S, LOSP-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
      17  98.7    0.1   1.112E-017  BUILDING-S, E-IE, /EX-S, OP-T-TR
                                    PIPING-OC-S, /PPB-S, RCCS-AIR-S, RCCS-HR
      18  98.8    0.1   6.627E-018  BUILDING-S, DIESEL1-RUN, DIESEL2-RUN, E-IE
                                    /EX-S, LOSP-S, /PPB-S, RCCS-AIR-S, RCCS-HR
      19  98.8    0.0   3.707E-018  BUILDING-S, E-IE, /EX-S, PIPING-OC-S
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                                    PIPING-T-S, /PPB-S, RCCS-AIR-S, RCCS-HR
      20  98.8     0.0   8.623E-019 BUILDING-S, DIESEL1-RUN, DIESEL2-START
                                    E-IE, /EX-S, LOSP-S, /PPB-S, RCCS-AIR-S
                                    RCCS-HR

                             Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                     Fault Tree-> SEQ-04
 Mincut Upper Bound -> 1.077E-014       This Partition -> 1.077E-014

 Cut      Total  CutSet  Prob/                                                                                                    Event
 No.        %      %     Freq.      Basic Event                Description                                                         Prob.
-------- -----  -----   ----------  -------------------------  -----------------------------------------------------------------  ----------
       1  17.6    17.6   1.894E-015 BUILDING-S                 Seismically Induced Building Failure                                1.909E-001
                                    E-IE                       Earthquake Initiating Event                                         5.000E-002
                                    /EX-S                      Earthquake Initiating Event Correction                              2.801E-006
                                    HX-RCCS-S                  Seismically Induced Failure of all RCCS HX                          5.679E-001
                                    /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic               5.000E-001
                                    RCCS-AIR-S                 RCCS Air System Failure - Seismic                                   2.495E-001
                                    RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                        1.000E-006
       2  35.2    17.6   1.894E-015 BUILDING-S                 Seismically Induced Building Failure                                1.909E-001
                                    E-IE                       Earthquake Initiating Event                                         5.000E-002
                                    /EX-S                      Earthquake Initiating Event Correction                              2.801E-006
                                    LOSP-S                     Loss of Offsite Power                                               1.000E+000
                                    /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic               5.000E-001
                                    PUMPS-T-S                  Seismically Induced Failure of More Than 3 CT Pumps                 5.679E-001
                                    RCCS-AIR-S                 RCCS Air System Failure - Seismic                                   2.495E-001
                                    RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                        1.000E-006
       3  52.8    17.6   1.894E-015 BUILDING-S                 Seismically Induced Building Failure                                1.909E-001
                                    E-IE                       Earthquake Initiating Event                                         5.000E-002
                                    /EX-S                      Earthquake Initiating Event Correction                              2.801E-006
                                    /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic               5.000E-001
                                    PUMPS-RCCS-S               RCCS Pumps Seismically Induced Failure                              5.679E-001
                                    RCCS-AIR-S                 RCCS Air System Failure - Seismic                                   2.495E-001
                                    RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                        1.000E-006
       4  68.3    15.5   1.668E-015 BUILDING-S                 Seismically Induced Building Failure                                1.909E-001
                                    E-IE                       Earthquake Initiating Event                                         5.000E-002
                                    /EX-S                      Earthquake Initiating Event Correction                              2.801E-006
                                    FANS-T-S                   Seismically Induced CT Fans Failure                                 5.000E-001
                                    LOSP-S                     Loss of Offsite Power                                               1.000E+000
                                    /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic               5.000E-001
                                    RCCS-AIR-S                 RCCS Air System Failure - Seismic                                   2.495E-001
                                    RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                        1.000E-006
       5  78.3    10.0   1.076E-015 BUILDING-S                 Seismically Induced Building Failure                                1.909E-001
                                    E-IE                       Earthquake Initiating Event                                         5.000E-002
                                    /EX-S                      Earthquake Initiating Event Correction                              2.801E-006
                                    /PPB-S                     Primary Pressure Boundary Integrity Failure - Seismic               5.000E-001
                                    PUMPS-OC-S                 Seismically Induced Failure of Pumps                                5.679E-001
                                    PUMPS-T-S                  Seismically Induced Failure of More Than 3 CT Pumps                 5.679E-001
                                    RCCS-AIR-S                 RCCS Air System Failure - Seismic                                   2.495E-001
                                    RCCS-HR                    RCCS Cooling Restored Prior to Vessel Damage                        1.000E-006
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6	87.1	8.8	9.470E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-T-S	Seismically Induced CT Fans Failure	5.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-OC-S	Seismically Induced Failure of Pumps	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
7	90.2	3.1	3.335E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				LOSP-S	Loss of Offsite Power	1.000E+000
				OP-T-TR	Failure to Transfer to CT	1.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
8	92.4	2.2	2.402E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				DIESELS-S	Seismic-Induced Failure of Both Diesel Generators	7.203E-002
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				LOSP-S	Loss of Offsite Power	1.000E+000
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
9	94.2	1.8	1.894E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				OP-T-TR	Failure to Transfer to CT	1.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-OC-S	Seismically Induced Failure of Pumps	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
10	95.2	1.0	1.112E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				LOSP-S	Loss of Offsite Power	1.000E+000
				PIPING-T-S	Seismically Induced CT Piping Failure	3.334E-002
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
11	96.2	1.0	1.112E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				PIPING-RCCS-S	Seismically Induced RCCS Piping Failure	3.334E-002
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006

Sequence 08
Uncertainty
Cutsets

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                         Sort/Slice Cut Set Report
  Family-> PBMR-SPSA                        Fault Tree-> SEQ-08
  Mincut Upper Bound -> 1.543E-014      This Partition -> 1.543E-014

   Cut      %    % Cut
   No.    Total   Set    Frequency                    Cut Sets
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       1  12.3   12.3   1.894E-015  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, LOSP-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
       2  24.6   12.3   1.894E-015  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                    PUMPS-T-S, RCCS-AIR-S, RCCS-HR
       3  36.8   12.3   1.894E-015  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                    PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR
       4  47.7   10.8   1.668E-015  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
       5  54.6    7.0   1.076E-015  BUILDING-S, E-IE, /EX-S, HX-CCS-S
                                    HX-RCCS-S, /PPB-S, RCCS-AIR-S, RCCS-HR
       6  61.6    7.0   1.076E-015  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                    PUMPS-T-S, RCCS-AIR-S, RCCS-HR
       7  68.6    7.0   1.076E-015  BUILDING-S, E-IE, /EX-S, HX-CCS-S, /PPB-S
                                    PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR
       8  74.7    6.1   9.470E-016  BUILDING-S, E-IE, /EX-S, FANS-CCS-S
                                    HX-RCCS-S, /PPB-S, RCCS-AIR-S, RCCS-HR
       9  80.9    6.1   9.470E-016  BUILDING-S, E-IE, /EX-S, FANS-CCS-S, /PPB-S
                                    PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR
      10  87.0    6.1   9.470E-016  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                    PUMPS-OC-S, RCCS-AIR-S, RCCS-HR
      11  89.2    2.2   3.335E-016  BUILDING-S, E-IE, /EX-S, LOSP-S, OP-T-TR
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
      12  90.7    1.6   2.402E-016  BUILDING-S, DIESELS-S, E-IE, /EX-S, LOSP-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
      13  92.0    1.2   1.894E-016  BUILDING-S, E-IE, /EX-S, OP-T-TR, /PPB-S
                                    PUMPS-OC-S, RCCS-AIR-S, RCCS-HR
      14  92.7    0.7   1.112E-016  BUILDING-S, E-IE, /EX-S, LOSP-S
                                    PIPING-RCCS-S, /PPB-S, RCCS-AIR-S, RCCS-HR
      15  93.4    0.7   1.112E-016  BUILDING-S, E-IE, /EX-S, LOSP-S, PIPING-T-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR
      16  93.8    0.4   6.314E-017  BUILDING-S, E-IE, /EX-S, HX-CCS-S
                                    PIPING-RCCS-S, /PPB-S, RCCS-AIR-S, RCCS-HR
      17  94.2    0.4   6.314E-017  BUILDING-S, E-IE, /EX-S, HX-RCCS-S
                                    PIPING-CCS-S, /PPB-S, RCCS-AIR-S, RCCS-HR
      18  94.7    0.4   6.314E-017  BUILDING-S, E-IE, /EX-S, PIPING-OC-S
                                    /PPB-S, PUMPS-T-S, RCCS-AIR-S, RCCS-HR
      19  95.1    0.4   6.314E-017  BUILDING-S, E-IE, /EX-S, PIPING-CCS-S
                                    /PPB-S, PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR
      20  95.5    0.4   6.314E-017  BUILDING-S, E-IE, /EX-S, PIPING-T-S, /PPB-S
                                    PUMPS-OC-S, RCCS-AIR-S, RCCS-HR
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                           Sort/Slice Cut Set Report
  Family-> PBMR-SPSA                    Fault Tree-> SEQ-08
  Mincut Upper Bound -> 1.543E-014      This Partition -> 1.543E-014

  Cut    Total  CutSet  Prob/                                                                                                    Event
  No.      %      %     Freq.       Basic Event               Description                                                  Prob.
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       1  12.3   12.3  1.894E-015  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    HX-RCCS-S                 Seismically Induced Failure of all RCCS HX                   5.679E-001
                                    LOSP-S                    Loss of Offsite Power                                        1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    RCCS-AIR-S                RCCS Air System Failure - Seismic                            2.495E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-006
       2  24.6   12.3  1.894E-015  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    LOSP-S                    Loss of Offsite Power                                        1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    PUMPS-T-S                 Seismically Induced Failure of More Than 3 CT Pumps          5.679E-001
                                    RCCS-AIR-S                RCCS Air System Failure - Seismic                            2.495E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-006
       3  36.8   12.3  1.894E-015  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    LOSP-S                    Loss of Offsite Power                                        1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    PUMPS-RCCS-S              RCCS Pumps Seismically Induced Failure                       5.679E-001
                                    RCCS-AIR-S                RCCS Air System Failure - Seismic                            2.495E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-006
       4  47.7   10.8  1.668E-015  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    FANS-T-S                  Seismically Induced CT Fans Failure                          5.000E-001
                                    LOSP-S                    Loss of Offsite Power                                        1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    RCCS-AIR-S                RCCS Air System Failure - Seismic                            2.495E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-006
       5  54.6    7.0  1.076E-015  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
                                    /EX-S                     Earthquake Initiating Event Correction                       2.801E-006
                                    HX-CCS-S                  Seismically Induced CCS Heat Exchanger Failure               5.679E-001
                                    HX-RCCS-S                 Seismically Induced Failure of all RCCS HX                   5.679E-001
                                    /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic        5.000E-001
                                    RCCS-AIR-S                RCCS Air System Failure - Seismic                            2.495E-001
                                    RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage                 1.000E-006
       6  61.6    7.0  1.076E-015  BUILDING-S                Seismically Induced Building Failure                         1.909E-001
                                    E-IE                      Earthquake Initiating Event                                  5.000E-002
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				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-OC-S	Seismically Induced Failure of Pumps	5.679E-001
				PUMPS-T-S	Seismically Induced Failure of More Than 3 CT Pumps	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
7	68.6	7.0	1.076E-015	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				HX-CCS-S	Seismically Induced CCS Heat Exchanger Failure	5.679E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-RCCS-S	RCCS Pumps Seismically Induced Failure	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
8	74.7	6.1	9.470E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-CCS-S	CCS Fans Failure - Seismic	5.000E-001
				HX-RCCS-S	Seismically Induced Failure of all RCCS HX	5.679E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
9	80.9	6.1	9.470E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-CCS-S	CCS Fans Failure - Seismic	5.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-RCCS-S	RCCS Pumps Seismically Induced Failure	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
10	87.0	6.1	9.470E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-T-S	Seismically Induced CT Fans Failure	5.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-OC-S	Seismically Induced Failure of Pumps	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
11	89.2	2.2	3.335E-016	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				LOSP-S	Loss of Offsite Power	1.000E+000
				OP-T-TR	Failure to Transfer to CT	1.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006

Sequence 12
Uncertainty
Cutsets

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                         Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                    Fault Tree-> SEQ-12
 Mincut Upper Bound -> 0.000E+000      This Partition -> 0.000E+000

  Cut     %    % Cut
  No.   Total   Set    Frequency                   Cut Sets
-------- ----- -----  -----------  ----------------------------------------------
       1   0.0    0.0  6.035E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   HX-RCCS-S, /PPB-S, RCCS-AIR-S, RCCS-HR
                                   TRIP-RSS
       2   0.0    0.0  6.035E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   /PPB-S, PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR
                                   TRIP-RSS
       3   0.0    0.0  6.035E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   LOSP-S, /PPB-S, PUMPS-T-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
       4   0.0    0.0  5.314E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-T-S, LOSP-S, /PPB-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
       5   0.0    0.0  3.427E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   /PPB-S, PUMPS-OC-S, PUMPS-T-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
       6   0.0    0.0  3.018E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-T-S, /PPB-S, PUMPS-OC-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
       7   0.0    0.0  2.164E-018  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, /PPB-S
                                   RCCS-AIR-S, RCCS-HR, RODS-S, TRIP-RSS
       8   0.0    0.0  2.164E-018  BUILDING-S, E-IE, /EX-S, /PPB-S
                                   PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                   TRIP-RSS
       9   0.0    0.0  2.164E-018  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                   PUMPS-T-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                   TRIP-RSS
      10   0.0    0.0  1.905E-018  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                   /PPB-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                   TRIP-RSS
      11   0.0    0.0  1.229E-018  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                   PUMPS-T-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                   TRIP-RSS
      12   0.0    0.0  1.082E-018  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                   PUMPS-OC-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                   TRIP-RSS
      13   0.0    0.0  1.063E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   LOSP-S, OP-T-TR, /PPB-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
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     14   0.0     0.0   7.655E-019  BUILDING-S, CONTROL-BLOCKS-S, DIESELS-S
                                    E-IE, /EX-S, LOSP-S, /PPB-S, RCCS-AIR-S
                                    RCCS-HR, TRIP-RSS
     15   0.0     0.0   6.035E-019  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    OP-T-TR, /PPB-S, PUMPS-OC-S, RCCS-AIR-S
                                    RCCS-HR, TRIP-RSS
     16   0.0     0.0   3.811E-019  BUILDING-S, E-IE, /EX-S, LOSP-S, OP-T-TR
                                    /PPB-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                    TRIP-RSS
     17   0.0     0.0   3.543E-019  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    PIPING-RCCS-S, /PPB-S, RCCS-AIR-S, RCCS-HR
                                    TRIP-RSS
     18   0.0     0.0   3.543E-019  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    LOSP-S, PIPING-T-S, /PPB-S, RCCS-AIR-S
                                    RCCS-HR, TRIP-RSS
     19   0.0     0.0   2.745E-019  BUILDING-S, DIESELS-S, E-IE, /EX-S, LOSP-S
                                    /PPB-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                    TRIP-RSS
     20   0.0     0.0   2.164E-019  BUILDING-S, E-IE, /EX-S, OP-T-TR, /PPB-S
                                    PUMPS-OC-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                    TRIP-RSS


                         Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                     Fault Tree-> SEQ-12
  Mincut Upper Bound -> 0.000E+000       This Partition -> 0.000E+000

  Cut     Total  CutSet  Prob/                                                                                    Event
  No.       %      %     Freq.      Basic Event               Description                                          Prob.
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       1   0.0    0.0  6.035E-018  BUILDING-S                Seismically Induced Building Failure                  1.909E-001
                                   CONTROL-BLOCKS-S          Damage to Control Blocks                              6.373E-001
                                   E-IE                      Earthquake Initiating Event                           5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction                2.801E-006
                                   HX-RCCS-S                 Seismically Induced Failure of all RCCS HX            5.679E-001
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic 5.000E-001
                                   RCCS-AIR-S                RCCS Air System Failure - Seismic                     2.495E-001
                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage          1.000E-006
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System          5.000E-003
       2   0.0    0.0  6.035E-018  BUILDING-S                Seismically Induced Building Failure                  1.909E-001
                                   CONTROL-BLOCKS-S          Damage to Control Blocks                              6.373E-001
                                   E-IE                      Earthquake Initiating Event                           5.000E-002
                                   /EX-S                     Earthquake Initiating Event Correction                2.801E-006
                                   /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic 5.000E-001
                                   PUMPS-RCCS-S              RCCS Pumps Seismically Induced Failure                5.679E-001
                                   RCCS-AIR-S                RCCS Air System Failure - Seismic                     2.495E-001
                                   RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage          1.000E-006
                                   TRIP-RSS                  Failure to TRIP with Reserve Shutdown System          5.000E-003
       3   0.0    0.0  6.035E-018  BUILDING-S                Seismically Induced Building Failure                  1.909E-001
                                   CONTROL-BLOCKS-S          Damage to Control Blocks                              6.373E-001
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                                E-IE                   Earthquake Initiating Event                                5.000E-002
                                /EX-S                  Earthquake Initiating Event Correction                     2.801E-006
                                LOSP-S                 Loss of Offsite Power                                      1.000E+000
                                /PPB-S                 Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                PUMPS-T-S              Seismically Induced Failure of More Than 3 CT Pumps        5.679E-001
                                RCCS-AIR-S             RCCS Air System Failure - Seismic                          2.495E-001
                                RCCS-HR                RCCS Cooling Restored Prior to Vessel Damage               1.000E-006
                                TRIP-RSS               Failure to TRIP with Reserve Shutdown System               5.000E-003
4   0.0   0.0   5.314E-018      BUILDING-S             Seismically Induced Building Failure                       1.909E-001
                                CONTROL-BLOCKS-S       Damage to Control Blocks                                   6.373E-001
                                E-IE                   Earthquake Initiating Event                                5.000E-002
                                /EX-S                  Earthquake Initiating Event Correction                     2.801E-006
                                FANS-T-S               Seismically Induced CT Fans Failure                        5.000E-001
                                LOSP-S                 Loss of Offsite Power                                      1.000E+000
                                /PPB-S                 Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                RCCS-AIR-S             RCCS Air System Failure - Seismic                          2.495E-001
                                RCCS-HR                RCCS Cooling Restored Prior to Vessel Damage               1.000E-006
                                TRIP-RSS               Failure to TRIP with Reserve Shutdown System               5.000E-003
5   0.0   0.0   3.427E-018      BUILDING-S             Seismically Induced Building Failure                       1.909E-001
                                CONTROL-BLOCKS-S       Damage to Control Blocks                                   6.373E-001
                                E-IE                   Earthquake Initiating Event                                5.000E-002
                                /EX-S                  Earthquake Initiating Event Correction                     2.801E-006
                                /PPB-S                 Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                PUMPS-OC-S             Seismically Induced Failure of Pumps                       5.679E-001
                                PUMPS-T-S              Seismically Induced Failure of More Than 3 CT Pumps        5.679E-001
                                RCCS-AIR-S             RCCS Air System Failure - Seismic                          2.495E-001
                                RCCS-HR                RCCS Cooling Restored Prior to Vessel Damage               1.000E-006
                                TRIP-RSS               Failure to TRIP with Reserve Shutdown System               5.000E-003
6   0.0   0.0   3.018E-018      BUILDING-S             Seismically Induced Building Failure                       1.909E-001
                                CONTROL-BLOCKS-S       Damage to Control Blocks                                   6.373E-001
                                E-IE                   Earthquake Initiating Event                                5.000E-002
                                /EX-S                  Earthquake Initiating Event Correction                     2.801E-006
                                FANS-T-S               Seismically Induced CT Fans Failure                        5.000E-001
                                /PPB-S                 Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                PUMPS-OC-S             Seismically Induced Failure of Pumps                       5.679E-001
                                RCCS-AIR-S             RCCS Air System Failure - Seismic                          2.495E-001
                                RCCS-HR                RCCS Cooling Restored Prior to Vessel Damage               1.000E-006
                                TRIP-RSS               Failure to TRIP with Reserve Shutdown System               5.000E-003
7   0.0   0.0   2.164E-018      BUILDING-S             Seismically Induced Building Failure                       1.909E-001
                                E-IE                   Earthquake Initiating Event                                5.000E-002
                                /EX-S                  Earthquake Initiating Event Correction                     2.801E-006
                                HX-RCCS-S              Seismically Induced Failure of all RCCS HX                 5.679E-001
                                /PPB-S                 Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
                                RCCS-AIR-S             RCCS Air System Failure - Seismic                          2.495E-001
                                RCCS-HR                RCCS Cooling Restored Prior to Vessel Damage               1.000E-006
                                RODS-S                 Seismic Failure: Misalignment of Control Rods & Guide Tubes 2.285E-001
                                TRIP-RSS               Failure to TRIP with Reserve Shutdown System               5.000E-003
8   0.0   0.0   2.164E-018      BUILDING-S             Seismically Induced Building Failure                       1.909E-001
                                E-IE                   Earthquake Initiating Event                                5.000E-002
                                /EX-S                  Earthquake Initiating Event Correction                     2.801E-006
                                /PPB-S                 Primary Pressure Boundary Integrity Failure - Seismic      5.000E-001
```

				PUMPS-RCCS-S	RCCS Pumps Seismically Induced Failure	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				RODS-S	Seismic Failure: Misalignment of Control Rods & Guide Tubes	2.285E-001
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
9	0.0	0.0	2.164E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				LOSP-S	Loss of Offsite Power	1.000E+000
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-T-S	Seismically Induced Failure of More Than 3 CT Pumps	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				RODS-S	Seismic Failure: Misalignment of Control Rods & Guide Tubes	2.285E-001
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
10	0.0	0.0	1.905E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-T-S	Seismically Induced CT Fans Failure	5.000E-001
				LOSP-S	Loss of Offsite Power	1.000E+000
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				RODS-S	Seismic Failure: Misalignment of Control Rods & Guide Tubes	2.285E-001
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003

Sequence 16
Uncertainty
Cutsets

```
                         Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                       Fault Tree-> SEQ-16
 Mincut Upper Bound -> 0.000E+000      This Partition -> 0.000E+000

  Cut     %    % Cut
  No.   Total   Set    Frequency                    Cut Sets
-------- -----  -----  ----------- ---------------------------------------------
      1   0.0    0.0   6.035E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   HX-RCCS-S, LOSP-S, /PPB-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
      2   0.0    0.0   6.035E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   LOSP-S, /PPB-S, PUMPS-RCCS-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
      3   0.0    0.0   6.035E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   LOSP-S, /PPB-S, PUMPS-T-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
      4   0.0    0.0   5.314E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-T-S, LOSP-S, /PPB-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
      5   0.0    0.0   3.427E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   HX-CCS-S, /PPB-S, PUMPS-RCCS-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
      6   0.0    0.0   3.427E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   HX-CCS-S, HX-RCCS-S, /PPB-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
      7   0.0    0.0   3.427E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   /PPB-S, PUMPS-OC-S, PUMPS-T-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
      8   0.0    0.0   3.018E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-T-S, /PPB-S, PUMPS-OC-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
      9   0.0    0.0   3.018E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-CCS-S, /PPB-S, PUMPS-RCCS-S
                                   RCCS-AIR-S, RCCS-HR, TRIP-RSS
     10   0.0    0.0   3.018E-018  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                   FANS-CCS-S, HX-RCCS-S, /PPB-S, RCCS-AIR-S
                                   RCCS-HR, TRIP-RSS
     11   0.0    0.0   2.164E-018  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, LOSP-S
                                   /PPB-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                   TRIP-RSS
     12   0.0    0.0   2.164E-018  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                   PUMPS-T-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                   TRIP-RSS
     13   0.0    0.0   2.164E-018  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
```

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                                  PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                  TRIP-RSS
      14   0.0    0.0   1.905E-018  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                  /PPB-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                  TRIP-RSS
      15   0.0    0.0   1.229E-018  BUILDING-S, E-IE, /EX-S, HX-CCS-S, /PPB-S
                                  PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                  TRIP-RSS
      16   0.0    0.0   1.229E-018  BUILDING-S, E-IE, /EX-S, HX-CCS-S
                                  HX-RCCS-S, /PPB-S, RCCS-AIR-S, RCCS-HR
                                  RODS-S, TRIP-RSS
      17   0.0    0.0   1.229E-018  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                  PUMPS-T-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                  TRIP-RSS
      18   0.0    0.0   1.082E-018  BUILDING-S, E-IE, /EX-S, FANS-CCS-S, /PPB-S
                                  PUMPS-RCCS-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                  TRIP-RSS
      19   0.0    0.0   1.082E-018  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                  PUMPS-OC-S, RCCS-AIR-S, RCCS-HR, RODS-S
                                  TRIP-RSS
      20   0.0    0.0   1.082E-018  BUILDING-S, E-IE, /EX-S, FANS-CCS-S
                                  HX-RCCS-S, /PPB-S, RCCS-AIR-S, RCCS-HR
                                  RODS-S, TRIP-RSS


                         Sort/Slice Cut Set Report

 Family-> PBMR-SPSA                  Fault Tree-> SEQ-16
 Mincut Upper Bound -> 0.000E+000    This Partition -> 0.000E+000

 Cut     Total  CutSet  Prob/                                                                                       Event
 No.       %      %     Freq.       Basic Event               Description                                         Prob.
-------- -----  -----  ----------  ------------------------- ---------------------------------------------------- ----------
       1   0.0    0.0   6.035E-018  BUILDING-S                Seismically Induced Building Failure                 1.909E-001
                                  CONTROL-BLOCKS-S          Damage to Control Blocks                             6.373E-001
                                  E-IE                      Earthquake Initiating Event                          5.000E-002
                                  /EX-S                     Earthquake Initiating Event Correction               2.801E-006
                                  HX-RCCS-S                 Seismically Induced Failure of all RCCS HX           5.679E-001
                                  LOSP-S                    Loss of Offsite Power                                1.000E+000
                                  /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic 5.000E-001
                                  RCCS-AIR-S                RCCS Air System Failure - Seismic                    2.495E-001
                                  RCCS-HR                   RCCS Cooling Restored Prior to Vessel Damage         1.000E-006
                                  TRIP-RSS                  Failure to TRIP with Reserve Shutdown System         5.000E-003
       2   0.0    0.0   6.035E-018  BUILDING-S                Seismically Induced Building Failure                 1.909E-001
                                  CONTROL-BLOCKS-S          Damage to Control Blocks                             6.373E-001
                                  E-IE                      Earthquake Initiating Event                          5.000E-002
                                  /EX-S                     Earthquake Initiating Event Correction               2.801E-006
                                  LOSP-S                    Loss of Offsite Power                                1.000E+000
                                  /PPB-S                    Primary Pressure Boundary Integrity Failure - Seismic 5.000E-001
                                  PUMPS-RCCS-S              RCCS Pumps Seismically Induced Failure               5.679E-001
                                  RCCS-AIR-S                RCCS Air System Failure - Seismic                    2.495E-001
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				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
3	0.0	0.0	6.035E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				LOSP-S	Loss of Offsite Power	1.000E+000
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-T-S	Seismically Induced Failure of More Than 3 CT Pumps	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
4	0.0	0.0	5.314E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-T-S	Seismically Induced CT Fans Failure	5.000E-001
				LOSP-S	Loss of Offsite Power	1.000E+000
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
5	0.0	0.0	3.427E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				HX-CCS-S	Seismically Induced CCS Heat Exchanger Failure	5.679E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-RCCS-S	RCCS Pumps Seismically Induced Failure	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
6	0.0	0.0	3.427E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				HX-CCS-S	Seismically Induced CCS Heat Exchanger Failure	5.679E-001
				HX-RCCS-S	Seismically Induced Failure of all RCCS HX	5.679E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
7	0.0	0.0	3.427E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-OC-S	Seismically Induced Failure of Pumps	5.679E-001
				PUMPS-T-S	Seismically Induced Failure of More Than 3 CT Pumps	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006

				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
8	0.0	0.0	3.018E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-T-S	Seismically Induced CT Fans Failure	5.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-OC-S	Seismically Induced Failure of Pumps	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
9	0.0	0.0	3.018E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-CCS-S	CCS Fans Failure - Seismic	5.000E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				PUMPS-RCCS-S	RCCS Pumps Seismically Induced Failure	5.679E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003
10	0.0	0.0	3.018E-018	BUILDING-S	Seismically Induced Building Failure	1.909E-001
				CONTROL-BLOCKS-S	Damage to Control Blocks	6.373E-001
				E-IE	Earthquake Initiating Event	5.000E-002
				/EX-S	Earthquake Initiating Event Correction	2.801E-006
				FANS-CCS-S	CCS Fans Failure - Seismic	5.000E-001
				HX-RCCS-S	Seismically Induced Failure of all RCCS HX	5.679E-001
				/PPB-S	Primary Pressure Boundary Integrity Failure - Seismic	5.000E-001
				RCCS-AIR-S	RCCS Air System Failure - Seismic	2.495E-001
				RCCS-HR	RCCS Cooling Restored Prior to Vessel Damage	1.000E-006
				TRIP-RSS	Failure to TRIP with Reserve Shutdown System	5.000E-003

APPENDIX D

PRA CUTSETS FOR THE ALTERNATIVE CASE 2 (CONTAINMENT) AND THE SEISMIC ACCELERATION LEVEL 6 (2g)

Sequence 04 Uncertainty Cutsets

```
                         Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                     Fault Tree-> SEQ-04
  Mincut Upper Bound -> 0.000E+000       This Partition -> 0.000E+000

   Cut     %    % Cut
   No.   Total   Set    Frequency                  Cut Sets
-------- -----  -----  -----------  --------------------------------------------
       1   0.0    0.0  3.299E-017  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                   PUMPS-T-S, RCCS-HR
       2   0.0    0.0  3.299E-017  BUILDING-S, E-IE, /EX-S, /PPB-S
                                   PUMPS-RCCS-S, RCCS-HR
       3   0.0    0.0  3.299E-017  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, /PPB-S
                                   RCCS-HR
       4   0.0    0.0  2.905E-017  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                   /PPB-S, RCCS-HR
       5   0.0    0.0  1.873E-017  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                   PUMPS-T-S, RCCS-HR
       6   0.0    0.0  1.649E-017  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                   PUMPS-OC-S, RCCS-HR
       7   0.0    0.0  5.809E-018  BUILDING-S, E-IE, /EX-S, LOSP-S, OP-T-TR
                                   /PPB-S, RCCS-HR
       8   0.0    0.0  4.184E-018  BUILDING-S, DIESELS-S, E-IE, /EX-S, LOSP-S
                                   /PPB-S, RCCS-HR
       9   0.0    0.0  3.299E-018  BUILDING-S, E-IE, /EX-S, OP-T-TR, /PPB-S
                                   PUMPS-OC-S, RCCS-HR
      10   0.0    0.0  1.937E-018  BUILDING-S, E-IE, /EX-S, LOSP-S, PIPING-T-S
                                   /PPB-S, RCCS-HR
      11   0.0    0.0  1.937E-018  BUILDING-S, E-IE, /EX-S, PIPING-RCCS-S
                                   /PPB-S, RCCS-HR
      12   0.0    0.0  1.100E-018  BUILDING-S, E-IE, /EX-S, PIPING-T-S, /PPB-S
                                   PUMPS-OC-S, RCCS-HR
      13   0.0    0.0  1.100E-018  BUILDING-S, E-IE, /EX-S, PIPING-OC-S
                                   /PPB-S, PUMPS-T-S, RCCS-HR
      14   0.0    0.0  9.683E-019  BUILDING-S, E-IE, /EX-S, FANS-T-S
                                   PIPING-OC-S, /PPB-S, RCCS-HR
      15   0.0    0.0  9.409E-019  BATTERY-S, BUILDING-S, E-IE, /EX-S, LOSP-S
                                   /PPB-S, RCCS-HR
      16   0.0    0.0  2.672E-019  BUILDING-S, DIESELS-CC, E-IE, /EX-S, LOSP-S
                                   /PPB-S, RCCS-HR
      17   0.0    0.0  1.937E-019  BUILDING-S, E-IE, /EX-S, OP-T-TR
                                   PIPING-OC-S, /PPB-S, RCCS-HR
      18   0.0    0.0  1.154E-019  BUILDING-S, DIESEL1-RUN, DIESEL2-RUN, E-IE
                                   /EX-S, LOSP-S, /PPB-S, RCCS-HR
      19   0.0    0.0  6.456E-020  BUILDING-S, E-IE, /EX-S, PIPING-OC-S
                                   PIPING-T-S, /PPB-S, RCCS-HR
      20   0.0    0.0  1.502E-020  BUILDING-S, DIESEL1-RUN, DIESEL2-START
                                   E-IE, /EX-S, LOSP-S, /PPB-S, RCCS-HR


                         Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                     Fault Tree-> SEQ-04
  Mincut Upper Bound -> 0.000E+000       This Partition -> 0.000E+000

  Cut                         Total                CutSet                Prob/
Event
  No.        %          %         Freq.          Basic  Event                 Description
Prob.
-------- -----  -----  ----------  ------------------------ ----------------------------------
------------------------ ----------
       1    0.0      0.0    3.299E-017  BUILDING-S             Seismically Induced Building
Failure                   8.295E-006
                                E-IE                     Earthquake Initiating Event

5.000E-002
                                /EX-S                    Earthquake Initiating Event

Correction                 2.801E-006
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                                             LOSP-S                                 Loss  of  Offsite  Power
1.000E+000
                                             /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                             PUMPS-T-S                  Seismically Induced Failure of More
Than 3 CT Pumps            5.679E-001
                                             RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                   1.000E-004
      2    0.0      0.0    3.299E-017  BUILDING-S                         Seismically Induced Building
Failure                           8.295E-006
                                             E-IE                          Earthquake Initiating Event
5.000E-002
                                             /EX-S                          Earthquake Initiating Event
Correction                      2.801E-006
                                             /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                             PUMPS-RCCS-S                   RCCS Pumps Seismically Induced
Failure                         5.679E-001
                                             RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                   1.000E-004
      3    0.0      0.0    3.299E-017  BUILDING-S                         Seismically Induced Building
Failure                           8.295E-006
                                             E-IE                          Earthquake Initiating Event
5.000E-002
                                             /EX-S                          Earthquake Initiating Event
Correction                      2.801E-006
                                             HX-RCCS-S                   Seismically Induced Failure of all
RCCS HX                     5.679E-001
                                             /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                             RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                   1.000E-004
      4    0.0      0.0    2.905E-017  BUILDING-S                         Seismically Induced Building
Failure                           8.295E-006
                                             E-IE                          Earthquake Initiating Event
5.000E-002
                                             /EX-S                          Earthquake Initiating Event
Correction                      2.801E-006
                                             FANS-T-S                   Seismically Induced CT Fans Failure
5.000E-001
                                             LOSP-S                                 Loss  of  Offsite  Power
1.000E+000
                                             /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                             RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                   1.000E-004
      5    0.0      0.0    1.873E-017  BUILDING-S                         Seismically Induced Building
Failure                           8.295E-006
                                             E-IE                          Earthquake Initiating Event
5.000E-002
                                             /EX-S                          Earthquake Initiating Event
Correction                      2.801E-006
                                             /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                             PUMPS-OC-S                     Seismically Induced Failure of
Pumps                           5.679E-001
                                             PUMPS-T-S                  Seismically Induced Failure of More
Than 3 CT Pumps            5.679E-001
                                             RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                   1.000E-004
      6    0.0      0.0    1.649E-017  BUILDING-S                         Seismically Induced Building
Failure                           8.295E-006
                                             E-IE                          Earthquake Initiating Event
5.000E-002
                                             /EX-S                          Earthquake Initiating Event
Correction                      2.801E-006
                                             FANS-T-S                   Seismically Induced CT Fans Failure
5.000E-001
                                             /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                             PUMPS-OC-S                     Seismically Induced Failure of
Pumps                           5.679E-001
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                                           RCCS-HR                          RCCS Cooling Restored Prior to
Vessel Damage                          1.000E-004
       7    0.0      0.0    5.809E-018   BUILDING-S                          Seismically Induced Building
Failure                                 8.295E-006
                                           E-IE                              Earthquake Initiating Event
5.000E-002
                                           /EX-S                             Earthquake Initiating Event
Correction                              2.801E-006
                                           LOSP-S                                  Loss of Offsite Power
1.000E+000
                                           OP-T-TR                            Failure to Transfer to CT
1.000E-001
                                           /PPB-S                       Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                           RCCS-HR                          RCCS Cooling Restored Prior to
Vessel Damage                          1.000E-004
       8    0.0      0.0    4.184E-018   BUILDING-S                          Seismically Induced Building
Failure                                 8.295E-006
                                           DIESELS-S                     Seismic-Induced Failure of Both
Diesel Generators                    7.203E-002
                                           E-IE                              Earthquake Initiating Event
5.000E-002
                                           /EX-S                             Earthquake Initiating Event
Correction                              2.801E-006
                                           LOSP-S                                  Loss of Offsite Power
1.000E+000
                                           /PPB-S                       Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                           RCCS-HR                          RCCS Cooling Restored Prior to
Vessel Damage                          1.000E-004
       9    0.0      0.0    3.299E-018   BUILDING-S                          Seismically Induced Building
Failure                                 8.295E-006
                                           E-IE                              Earthquake Initiating Event
5.000E-002
                                           /EX-S                             Earthquake Initiating Event
Correction                              2.801E-006
                                           OP-T-TR                            Failure to Transfer to CT
1.000E-001
                                           /PPB-S                       Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                           PUMPS-OC-S                     Seismically Induced Failure of
Pumps                                   5.679E-001
                                           RCCS-HR                          RCCS Cooling Restored Prior to
Vessel Damage                          1.000E-004
      10    0.0      0.0    1.937E-018   BUILDING-S                          Seismically Induced Building
Failure                                 8.295E-006
                                           E-IE                              Earthquake Initiating Event
5.000E-002
                                           /EX-S                             Earthquake Initiating Event
Correction                              2.801E-006
                                           LOSP-S                                  Loss of Offsite Power
1.000E+000
                                           PIPING-T-S                      Seismically Induced CT Piping
Failure                                 3.334E-002
                                           /PPB-S                       Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                           RCCS-HR                          RCCS Cooling Restored Prior to
Vessel Damage                          1.000E-004
```

Sequence 08 Uncertainty Cutsets

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                              Sort/Slice Cut Set Report

   Family-> PBMR-SPSA                      Fault Tree-> SEQ-08
   Mincut Upper Bound -> 0.000E+000        This Partition -> 0.000E+000

    Cut      %    % Cut
    No.    Total   Set    Frequency                        Cut Sets
 -------- -----  -----  -----------  ---------------------------------------------
        1   0.0    0.0   3.299E-017  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, LOSP-S
```

```
                                   /PPB-S, RCCS-HR
    2    0.0     0.0    3.299E-017  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                   PUMPS-T-S, RCCS-HR
    3    0.0     0.0    3.299E-017  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                   PUMPS-RCCS-S, RCCS-HR
    4    0.0     0.0    2.905E-017  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                   /PPB-S, RCCS-HR
    5    0.0     0.0    1.873E-017  BUILDING-S, E-IE, /EX-S, HX-CCS-S
                                   HX-RCCS-S, /PPB-S, RCCS-HR
    6    0.0     0.0    1.873E-017  BUILDING-S, E-IE, /EX-S, HX-CCS-S, /PPB-S
                                   PUMPS-RCCS-S, RCCS-HR
    7    0.0     0.0    1.873E-017  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                   PUMPS-T-S, RCCS-HR
    8    0.0     0.0    1.649E-017  BUILDING-S, E-IE, /EX-S, FANS-CCS-S
                                   HX-RCCS-S, /PPB-S, RCCS-HR
    9    0.0     0.0    1.649E-017  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                   PUMPS-OC-S, RCCS-HR
   10    0.0     0.0    1.649E-017  BUILDING-S, E-IE, /EX-S, FANS-CCS-S, /PPB-S
                                   PUMPS-RCCS-S, RCCS-HR
   11    0.0     0.0    5.809E-018  BUILDING-S, E-IE, /EX-S, LOSP-S, OP-T-TR
                                   /PPB-S, RCCS-HR
   12    0.0     0.0    4.184E-018  BUILDING-S, DIESELS-S, E-IE, /EX-S, LOSP-S
                                   /PPB-S, RCCS-HR
   13    0.0     0.0    3.299E-018  BUILDING-S, E-IE, /EX-S, OP-T-TR, /PPB-S
                                   PUMPS-OC-S, RCCS-HR
   14    0.0     0.0    1.937E-018  BUILDING-S, E-IE, /EX-S, LOSP-S, PIPING-T-S
                                   /PPB-S, RCCS-HR
   15    0.0     0.0    1.937E-018  BUILDING-S, E-IE, /EX-S, LOSP-S
                                   PIPING-RCCS-S, /PPB-S, RCCS-HR
   16    0.0     0.0    1.100E-018  BUILDING-S, E-IE, /EX-S, HX-RCCS-S
                                   PIPING-CCS-S, /PPB-S, RCCS-HR
   17    0.0     0.0    1.100E-018  BUILDING-S, E-IE, /EX-S, HX-CCS-S
                                   PIPING-RCCS-S, /PPB-S, RCCS-HR
   18    0.0     0.0    1.100E-018  BUILDING-S, E-IE, /EX-S, PIPING-T-S, /PPB-S
                                   PUMPS-OC-S, RCCS-HR
   19    0.0     0.0    1.100E-018  BUILDING-S, E-IE, /EX-S, PIPING-OC-S
                                   /PPB-S, PUMPS-T-S, RCCS-HR
   20    0.0     0.0    1.100E-018  BUILDING-S, E-IE, /EX-S, PIPING-CCS-S
                                   /PPB-S, PUMPS-RCCS-S, RCCS-HR


                        Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                     Fault Tree-> SEQ-08
  Mincut Upper Bound -> 0.000E+000       This Partition -> 0.000E+000

  Cut                                  Total                    CutSet                   Prob/
Event
  No.         %          %          Freq.          Basic  Event                      Description
Prob.
-------- -----  -----   ----------  -------------------------  ------------------------------------
------------------------- ----------
      1    0.0       0.0    3.299E-017   BUILDING-S                     Seismically Induced Building
Failure                      8.295E-006
                                    E-IE                           Earthquake Initiating Event
5.000E-002

                                    /EX-S                          Earthquake Initiating Event
Correction                     2.801E-006
                                    HX-RCCS-S               Seismically Induced Failure of all
RCCS HX                 5.679E-001
                                    LOSP-S                               Loss  of  Offsite  Power
1.000E+000

                                    /PPB-S                  Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                    RCCS-HR                    RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
      2    0.0       0.0    3.299E-017   BUILDING-S                     Seismically Induced Building
Failure                      8.295E-006
                                    E-IE                           Earthquake Initiating Event
5.000E-002

                                    /EX-S                          Earthquake Initiating Event
Correction                     2.801E-006
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                                        LOSP-S                              Loss  of  Offsite  Power
1.000E+000
                                        /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                        PUMPS-T-S              Seismically Induced Failure of More
Than 3 CT Pumps           5.679E-001
                                        RCCS-HR                    RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
      3    0.0     0.0     3.299E-017   BUILDING-S                   Seismically Induced Building
Failure                          8.295E-006
                                        E-IE                          Earthquake Initiating Event
5.000E-002
                                        /EX-S                         Earthquake Initiating Event
Correction                      2.801E-006
                                        LOSP-S                              Loss  of  Offsite  Power
1.000E+000
                                        /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                        PUMPS-RCCS-S                   RCCS  Pumps  Seismically  Induced
Failure                       5.679E-001
                                        RCCS-HR                    RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
      4    0.0     0.0     2.905E-017   BUILDING-S                   Seismically Induced Building
Failure                          8.295E-006
                                        E-IE                          Earthquake Initiating Event
5.000E-002
                                        /EX-S                         Earthquake Initiating Event
Correction                      2.801E-006
                                        FANS-T-S               Seismically Induced CT Fans Failure
5.000E-001
                                        LOSP-S                              Loss  of  Offsite  Power
1.000E+000
                                        /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                        RCCS-HR                    RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
      5    0.0     0.0     1.873E-017   BUILDING-S                   Seismically Induced Building
Failure                          8.295E-006
                                        E-IE                          Earthquake Initiating Event
5.000E-002
                                        /EX-S                         Earthquake Initiating Event
Correction                      2.801E-006
                                        HX-CCS-S                      Seismically Induced CCS Heat
Exchanger Failure                5.679E-001
                                        HX-RCCS-S               Seismically Induced Failure of all
RCCS HX                   5.679E-001
                                        /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                        RCCS-HR                    RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
      6    0.0     0.0     1.873E-017   BUILDING-S                   Seismically Induced Building
Failure                          8.295E-006
                                        E-IE                          Earthquake Initiating Event
5.000E-002
                                        /EX-S                         Earthquake Initiating Event
Correction                      2.801E-006
                                        HX-CCS-S                      Seismically Induced CCS Heat
Exchanger Failure                5.679E-001
                                        /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                        PUMPS-RCCS-S                   RCCS  Pumps  Seismically  Induced
Failure                       5.679E-001
                                        RCCS-HR                    RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
      7    0.0     0.0     1.873E-017   BUILDING-S                   Seismically Induced Building
Failure                          8.295E-006
                                        E-IE                          Earthquake Initiating Event
5.000E-002
                                        /EX-S                         Earthquake Initiating Event
Correction                      2.801E-006
                                        /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
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                                     PUMPS-OC-S                    Seismically Induced Failure of
Pumps                          5.679E-001
                                     PUMPS-T-S                Seismically Induced Failure of More
Than 3 CT Pumps           5.679E-001
                                     RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                  1.000E-004
       8    0.0     0.0    1.649E-017  BUILDING-S                 Seismically Induced Building
Failure                          8.295E-006
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                                     E-IE                              Earthquake Initiating Event
5.000E-002
                                     /EX-S                             Earthquake Initiating Event
Correction                        2.801E-006
                                     FANS-CCS-S                        CCS Fans Failure - Seismic
5.000E-001
                                     HX-RCCS-S                Seismically Induced Failure of all
RCCS HX                    5.679E-001
                                     /PPB-S                  Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                     RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                  1.000E-004
       9    0.0     0.0    1.649E-017  BUILDING-S                 Seismically Induced Building
Failure                          8.295E-006
                                     E-IE                              Earthquake Initiating Event
5.000E-002
                                     /EX-S                             Earthquake Initiating Event
Correction                        2.801E-006
                                     FANS-T-S                Seismically Induced CT Fans Failure
5.000E-001
                                     /PPB-S                  Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                     PUMPS-OC-S                    Seismically Induced Failure of
Pumps                          5.679E-001
                                     RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                  1.000E-004
      10    0.0     0.0    1.649E-017  BUILDING-S                 Seismically Induced Building
Failure                          8.295E-006
                                     E-IE                              Earthquake Initiating Event
5.000E-002
                                     /EX-S                             Earthquake Initiating Event
Correction                        2.801E-006
                                     FANS-CCS-S                        CCS Fans Failure - Seismic
5.000E-001
                                     /PPB-S                  Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                     PUMPS-RCCS-S                  RCCS Pumps Seismically Induced
Failure                        5.679E-001
                                     RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                  1.000E-004
      11    0.0     0.0    5.809E-018  BUILDING-S                 Seismically Induced Building
Failure                          8.295E-006
                                     E-IE                              Earthquake Initiating Event
5.000E-002
                                     /EX-S                             Earthquake Initiating Event
Correction                        2.801E-006
                                     LOSP-S                                 Loss of Offsite Power
1.000E+000
                                     OP-T-TR                            Failure to Transfer to CT
1.000E-001
                                     /PPB-S                  Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                     RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                  1.000E-004
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Sequence 12 Uncertainty Cutsets

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                              Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                          Fault Tree-> SEQ-12
  Mincut Upper Bound -> 0.000E+000            This Partition -> 0.000E+000

   Cut     %    % Cut
   No.   Total   Set    Frequency                    Cut Sets
-------- -----  -----  -----------  ----------------------------------------------
       1   0.0    0.0  1.051E-019  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    HX-RCCS-S, /PPB-S, RCCS-HR, TRIP-RSS
       2   0.0    0.0  1.051E-019  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    LOSP-S, /PPB-S, PUMPS-T-S, RCCS-HR
                                    TRIP-RSS
       3   0.0    0.0  1.051E-019  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    /PPB-S, PUMPS-RCCS-S, RCCS-HR, TRIP-RSS
       4   0.0    0.0  9.255E-020  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    FANS-T-S, LOSP-S, /PPB-S, RCCS-HR, TRIP-RSS
       5   0.0    0.0  5.969E-020  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    /PPB-S, PUMPS-OC-S, PUMPS-T-S, RCCS-HR
                                    TRIP-RSS
       6   0.0    0.0  5.256E-020  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    FANS-T-S, /PPB-S, PUMPS-OC-S, RCCS-HR
                                    TRIP-RSS
       7   0.0    0.0  3.769E-020  BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                    PUMPS-T-S, RCCS-HR, RODS-S, TRIP-RSS
       8   0.0    0.0  3.769E-020  BUILDING-S, E-IE, /EX-S, HX-RCCS-S, /PPB-S
                                    RCCS-HR, RODS-S, TRIP-RSS
       9   0.0    0.0  3.769E-020  BUILDING-S, E-IE, /EX-S, /PPB-S
                                    PUMPS-RCCS-S, RCCS-HR, RODS-S, TRIP-RSS
      10   0.0    0.0  3.318E-020  BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                    /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
      11   0.0    0.0  2.140E-020  BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                    PUMPS-T-S, RCCS-HR, RODS-S, TRIP-RSS
      12   0.0    0.0  1.884E-020  BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                    PUMPS-OC-S, RCCS-HR, RODS-S, TRIP-RSS
      13   0.0    0.0  1.851E-020  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    LOSP-S, OP-T-TR, /PPB-S, RCCS-HR, TRIP-RSS
      14   0.0    0.0  1.333E-020  BUILDING-S, CONTROL-BLOCKS-S, DIESELS-S
                                    E-IE, /EX-S, LOSP-S, /PPB-S, RCCS-HR
                                    TRIP-RSS
      15   0.0    0.0  1.051E-020  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    OP-T-TR, /PPB-S, PUMPS-OC-S, RCCS-HR
                                    TRIP-RSS
      16   0.0    0.0  6.637E-021  BUILDING-S, E-IE, /EX-S, LOSP-S, OP-T-TR
                                    /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
      17   0.0    0.0  6.171E-021  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    PIPING-RCCS-S, /PPB-S, RCCS-HR, TRIP-RSS
      18   0.0    0.0  6.171E-021  BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                    LOSP-S, PIPING-T-S, /PPB-S, RCCS-HR
                                    TRIP-RSS
      19   0.0    0.0  4.780E-021  BUILDING-S, DIESELS-S, E-IE, /EX-S, LOSP-S
                                    /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
      20   0.0    0.0  3.769E-021  BUILDING-S, E-IE, /EX-S, OP-T-TR, /PPB-S
                                    PUMPS-OC-S, RCCS-HR, RODS-S, TRIP-RSS


                              Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                          Fault Tree-> SEQ-12
  Mincut Upper Bound -> 0.000E+000            This Partition -> 0.000E+000

  Cut                                 Total                  CutSet                 Prob/
Event
  No.          %          %        Freq.          Basic  Event                  Description
Prob.
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------------------------ ----------
       1   0.0      0.0    1.051E-019  BUILDING-S                 Seismically Induced Building
Failure                        8.295E-006
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                                    CONTROL-BLOCKS-S                  Damage to Control Blocks
6.373E-001
                                    E-IE                           Earthquake Initiating Event
5.000E-002
                                    /EX-S                          Earthquake Initiating Event
Correction                       2.801E-006
                                    HX-RCCS-S               Seismically Induced Failure of all
RCCS HX                   5.679E-001
                                    /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic        5.000E-001
                                    RCCS-HR                     RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                      Failure to TRIP with Reserve
Shutdown System                 5.000E-003
       2    0.0     0.0    1.051E-019  BUILDING-S                 Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                  Damage to Control Blocks
6.373E-001
                                    E-IE                           Earthquake Initiating Event
5.000E-002
                                    /EX-S                          Earthquake Initiating Event
Correction                       2.801E-006
                                    LOSP-S                               Loss of Offsite Power
1.000E+000
                                    /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic        5.000E-001
                                    PUMPS-T-S              Seismically Induced Failure of More
Than 3 CT Pumps          5.679E-001
                                    RCCS-HR                     RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                      Failure to TRIP with Reserve
Shutdown System                 5.000E-003
       3    0.0     0.0    1.051E-019  BUILDING-S                 Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                  Damage to Control Blocks
6.373E-001
                                    E-IE                           Earthquake Initiating Event
5.000E-002
                                    /EX-S                          Earthquake Initiating Event
Correction                       2.801E-006
                                    /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic        5.000E-001
                                    PUMPS-RCCS-S               RCCS Pumps Seismically Induced
Failure                       5.679E-001
                                    RCCS-HR                     RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                      Failure to TRIP with Reserve
Shutdown System                 5.000E-003
       4    0.0     0.0    9.255E-020  BUILDING-S                 Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                  Damage to Control Blocks
6.373E-001
                                    E-IE                           Earthquake Initiating Event
5.000E-002
                                    /EX-S                          Earthquake Initiating Event
Correction                       2.801E-006
                                    FANS-T-S              Seismically Induced CT Fans Failure
5.000E-001
                                    LOSP-S                               Loss of Offsite Power
1.000E+000
                                    /PPB-S                 Primary Pressure Boundary Integrity
Failure - Seismic        5.000E-001
                                    RCCS-HR                     RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                      Failure to TRIP with Reserve
Shutdown System                 5.000E-003
       5    0.0     0.0    5.969E-020  BUILDING-S                 Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                  Damage to Control Blocks
6.373E-001
                                    E-IE                           Earthquake Initiating Event
5.000E-002
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                                     /EX-S                          Earthquake Initiating Event
Correction                         2.801E-006
                                     /PPB-S                    Primary Pressure Boundary Integrity
Failure - Seismic            5.000E-001
                                     PUMPS-OC-S                    Seismically Induced Failure of
Pumps                           5.679E-001
                                     PUMPS-T-S                 Seismically Induced Failure of More
Than 3 CT Pumps              5.679E-001
                                     RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                   1.000E-004
                                     TRIP-RSS                          Failure to TRIP with Reserve
Shutdown System                   5.000E-003
      6    0.0      0.0     5.256E-020   BUILDING-S                    Seismically Induced Building
Failure                           8.295E-006
                                     CONTROL-BLOCKS-S                      Damage to Control Blocks
6.373E-001
                                     E-IE                           Earthquake Initiating Event
5.000E-002
                                     /EX-S                          Earthquake Initiating Event
Correction                         2.801E-006
                                     FANS-T-S                  Seismically Induced CT Fans Failure
5.000E-001
                                     /PPB-S                    Primary Pressure Boundary Integrity
Failure - Seismic            5.000E-001
                                     PUMPS-OC-S                    Seismically Induced Failure of
Pumps                           5.679E-001
                                     RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                   1.000E-004
                                     TRIP-RSS                          Failure to TRIP with Reserve
Shutdown System                   5.000E-003
      7    0.0      0.0     3.769E-020   BUILDING-S                    Seismically Induced Building
Failure                           8.295E-006
                                     E-IE                           Earthquake Initiating Event
5.000E-002
                                     /EX-S                          Earthquake Initiating Event
Correction                         2.801E-006
                                     LOSP-S                               Loss of Offsite Power
1.000E+000
                                     /PPB-S                    Primary Pressure Boundary Integrity
Failure - Seismic            5.000E-001
                                     PUMPS-T-S                 Seismically Induced Failure of More
Than 3 CT Pumps              5.679E-001
                                     RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                   1.000E-004
                                     RODS-S                       Seismic Failure: Misalignment of
Control Rods & Guide Tubes   2.285E-001
                                     TRIP-RSS                          Failure to TRIP with Reserve
Shutdown System                   5.000E-003
      8    0.0      0.0     3.769E-020   BUILDING-S                    Seismically Induced Building
Failure                           8.295E-006
                                     E-IE                           Earthquake Initiating Event
5.000E-002
                                     /EX-S                          Earthquake Initiating Event
Correction                         2.801E-006
                                     HX-RCCS-S                  Seismically Induced Failure of all
RCCS HX                        5.679E-001
                                     /PPB-S                    Primary Pressure Boundary Integrity
Failure - Seismic            5.000E-001
                                     RCCS-HR                        RCCS Cooling Restored Prior to
Vessel Damage                   1.000E-004
                                     RODS-S                       Seismic Failure: Misalignment of
Control Rods & Guide Tubes   2.285E-001
                                     TRIP-RSS                          Failure to TRIP with Reserve
Shutdown System                   5.000E-003
      9    0.0      0.0     3.769E-020   BUILDING-S                    Seismically Induced Building
Failure                           8.295E-006
                                     E-IE                           Earthquake Initiating Event
5.000E-002
                                     /EX-S                          Earthquake Initiating Event
Correction                         2.801E-006
                                     /PPB-S                    Primary Pressure Boundary Integrity
Failure - Seismic            5.000E-001
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                                    PUMPS-RCCS-S                 RCCS Pumps Seismically Induced
Failure                       5.679E-001
                                    RCCS-HR                      RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    RODS-S                    Seismic Failure: Misalignment of
Control Rods & Guide Tubes  2.285E-001
                                    TRIP-RSS                       Failure to TRIP with Reserve
Shutdown System                 5.000E-003
      10    0.0      0.0    3.318E-020  BUILDING-S                Seismically Induced Building
Failure                         8.295E-006
                                    E-IE                         Earthquake Initiating Event
5.000E-002
                                    /EX-S                        Earthquake Initiating Event
Correction                       2.801E-006
                                    FANS-T-S              Seismically Induced CT Fans Failure
5.000E-001
                                    LOSP-S                              Loss of Offsite Power
1.000E+000
                                    /PPB-S                Primary Pressure Boundary Integrity
Failure - Seismic           5.000E-001
                                    RCCS-HR                      RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    RODS-S                    Seismic Failure: Misalignment of
Control Rods & Guide Tubes  2.285E-001
                                    TRIP-RSS                       Failure to TRIP with Reserve
Shutdown System                 5.000E-003
      11    0.0      0.0    2.140E-020  BUILDING-S                Seismically Induced Building
Failure                         8.295E-006
                                    E-IE                         Earthquake Initiating Event
5.000E-002
                                    /EX-S                        Earthquake Initiating Event
Correction                       2.801E-006
                                    /PPB-S                Primary Pressure Boundary Integrity
Failure - Seismic           5.000E-001
                                    PUMPS-OC-S                   Seismically Induced Failure of
Pumps                         5.679E-001
                                    PUMPS-T-S             Seismically Induced Failure of More
Than 3 CT Pumps             5.679E-001
                                    RCCS-HR                      RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    RODS-S                    Seismic Failure: Misalignment of
Control Rods & Guide Tubes  2.285E-001
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Sequence 16 Uncertainty Cutsets

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                              Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                     Fault Tree-> SEQ-16
  Mincut Upper Bound -> 0.000E+000      This Partition -> 0.000E+000

   Cut      %     % Cut
   No.    Total    Set    Frequency                   Cut Sets
-------- -----   -----   -----------   ------------------------------------------
       1   0.0     0.0   1.051E-019   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      LOSP-S, /PPB-S, PUMPS-RCCS-S, RCCS-HR
                                      TRIP-RSS
       2   0.0     0.0   1.051E-019   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      LOSP-S, /PPB-S, PUMPS-T-S, RCCS-HR
                                      TRIP-RSS
       3   0.0     0.0   1.051E-019   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      HX-RCCS-S, LOSP-S, /PPB-S, RCCS-HR
                                      TRIP-RSS
       4   0.0     0.0   9.255E-020   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      FANS-T-S, LOSP-S, /PPB-S, RCCS-HR, TRIP-RSS
       5   0.0     0.0   5.969E-020   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      HX-CCS-S, /PPB-S, PUMPS-RCCS-S, RCCS-HR
                                      TRIP-RSS
       6   0.0     0.0   5.969E-020   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      /PPB-S, PUMPS-OC-S, PUMPS-T-S, RCCS-HR
                                      TRIP-RSS
       7   0.0     0.0   5.969E-020   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      HX-CCS-S, HX-RCCS-S, /PPB-S, RCCS-HR
                                      TRIP-RSS
       8   0.0     0.0   5.256E-020   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      FANS-T-S, /PPB-S, PUMPS-OC-S, RCCS-HR
                                      TRIP-RSS
       9   0.0     0.0   5.256E-020   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      FANS-CCS-S, /PPB-S, PUMPS-RCCS-S, RCCS-HR
                                      TRIP-RSS
      10   0.0     0.0   5.256E-020   BUILDING-S, CONTROL-BLOCKS-S, E-IE, /EX-S
                                      FANS-CCS-S, HX-RCCS-S, /PPB-S, RCCS-HR
                                      TRIP-RSS
      11   0.0     0.0   3.769E-020   BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                      PUMPS-T-S, RCCS-HR, RODS-S, TRIP-RSS
      12   0.0     0.0   3.769E-020   BUILDING-S, E-IE, /EX-S, LOSP-S, /PPB-S
                                      PUMPS-RCCS-S, RCCS-HR, RODS-S, TRIP-RSS
      13   0.0     0.0   3.769E-020   BUILDING-S, E-IE, /EX-S, HX-RCCS-S, LOSP-S
                                      /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
      14   0.0     0.0   3.318E-020   BUILDING-S, E-IE, /EX-S, FANS-T-S, LOSP-S
                                      /PPB-S, RCCS-HR, RODS-S, TRIP-RSS
      15   0.0     0.0   2.140E-020   BUILDING-S, E-IE, /EX-S, HX-CCS-S
                                      HX-RCCS-S, /PPB-S, RCCS-HR, RODS-S
                                      TRIP-RSS
      16   0.0     0.0   2.140E-020   BUILDING-S, E-IE, /EX-S, HX-CCS-S, /PPB-S
                                      PUMPS-RCCS-S, RCCS-HR, RODS-S, TRIP-RSS
      17   0.0     0.0   2.140E-020   BUILDING-S, E-IE, /EX-S, /PPB-S, PUMPS-OC-S
                                      PUMPS-T-S, RCCS-HR, RODS-S, TRIP-RSS
      18   0.0     0.0   1.884E-020   BUILDING-S, E-IE, /EX-S, FANS-CCS-S
                                      HX-RCCS-S, /PPB-S, RCCS-HR, RODS-S
                                      TRIP-RSS
      19   0.0     0.0   1.884E-020   BUILDING-S, E-IE, /EX-S, FANS-CCS-S, /PPB-S
                                      PUMPS-RCCS-S, RCCS-HR, RODS-S, TRIP-RSS
      20   0.0     0.0   1.884E-020   BUILDING-S, E-IE, /EX-S, FANS-T-S, /PPB-S
                                      PUMPS-OC-S, RCCS-HR, RODS-S, TRIP-RSS


                              Sort/Slice Cut Set Report

  Family-> PBMR-SPSA                     Fault Tree-> SEQ-16
  Mincut Upper Bound -> 0.000E+000      This Partition -> 0.000E+000

  Cut                                       Total                   CutSet                    Prob/
Event
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  No.          %          %         Freq.          Basic  Event                          Description
Prob.
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       1    0.0      0.0    1.051E-019   BUILDING-S                    Seismically Induced Building
Failure                          8.295E-006
                                    CONTROL-BLOCKS-S                  Damage  to  Control  Blocks

6.373E-001
                                    E-IE                            Earthquake  Initiating  Event

5.000E-002
                                    /EX-S                           Earthquake  Initiating  Event
Correction                        2.801E-006
                                    LOSP-S                              Loss  of  Offsite  Power

1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                    PUMPS-RCCS-S                  RCCS  Pumps  Seismically  Induced
Failure                        5.679E-001
                                    RCCS-HR                        RCCS  Cooling  Restored  Prior  to
Vessel Damage                  1.000E-004
                                    TRIP-RSS                        Failure  to  TRIP  with  Reserve
Shutdown System                  5.000E-003
       2    0.0      0.0    1.051E-019   BUILDING-S                    Seismically Induced Building
Failure                          8.295E-006
                                    CONTROL-BLOCKS-S                  Damage  to  Control  Blocks

6.373E-001
                                    E-IE                            Earthquake  Initiating  Event

5.000E-002
                                    /EX-S                           Earthquake  Initiating  Event
Correction                        2.801E-006
                                    LOSP-S                              Loss  of  Offsite  Power

1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                    PUMPS-T-S                 Seismically Induced Failure of More
Than 3 CT Pumps           5.679E-001
                                    RCCS-HR                        RCCS  Cooling  Restored  Prior  to
Vessel Damage                  1.000E-004
                                    TRIP-RSS                        Failure  to  TRIP  with  Reserve
Shutdown System                  5.000E-003
       3    0.0      0.0    1.051E-019   BUILDING-S                    Seismically Induced Building
Failure                          8.295E-006
                                    CONTROL-BLOCKS-S                  Damage  to  Control  Blocks

6.373E-001
                                    E-IE                            Earthquake  Initiating  Event

5.000E-002
                                    /EX-S                           Earthquake  Initiating  Event
Correction                        2.801E-006
                                    HX-RCCS-S                  Seismically Induced Failure of all
RCCS HX                    5.679E-001
                                    LOSP-S                              Loss  of  Offsite  Power

1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                    RCCS-HR                        RCCS  Cooling  Restored  Prior  to
Vessel Damage                  1.000E-004
                                    TRIP-RSS                        Failure  to  TRIP  with  Reserve
Shutdown System                  5.000E-003
       4    0.0      0.0    9.255E-020   BUILDING-S                    Seismically Induced Building
Failure                          8.295E-006
                                    CONTROL-BLOCKS-S                  Damage  to  Control  Blocks

6.373E-001
                                    E-IE                            Earthquake  Initiating  Event

5.000E-002
                                    /EX-S                           Earthquake  Initiating  Event
Correction                        2.801E-006
                                    FANS-T-S                  Seismically Induced CT Fans Failure

5.000E-001
                                    LOSP-S                              Loss  of  Offsite  Power

1.000E+000
                                    /PPB-S                    Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
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                                    RCCS-HR                         RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                          Failure to TRIP with Reserve
Shutdown System                 5.000E-003
       5    0.0     0.0    5.969E-020  BUILDING-S                     Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                      Damage to Control Blocks

6.373E-001
                                    E-IE                               Earthquake Initiating Event

5.000E-002
                                    /EX-S                              Earthquake Initiating Event
Correction                       2.801E-006
                                    HX-CCS-S                          Seismically Induced CCS Heat
Exchanger Failure               5.679E-001
                                    /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                    PUMPS-RCCS-S                    RCCS Pumps Seismically Induced
Failure                       5.679E-001
                                    RCCS-HR                         RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                          Failure to TRIP with Reserve
Shutdown System                 5.000E-003
       6    0.0     0.0    5.969E-020  BUILDING-S                     Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                      Damage to Control Blocks

6.373E-001
                                    E-IE                               Earthquake Initiating Event

5.000E-002
                                    /EX-S                              Earthquake Initiating Event
Correction                       2.801E-006
                                    /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                    PUMPS-OC-S                      Seismically Induced Failure of
Pumps                         5.679E-001
                                    PUMPS-T-S                  Seismically Induced Failure of More
Than 3 CT Pumps           5.679E-001
                                    RCCS-HR                         RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                          Failure to TRIP with Reserve
Shutdown System                 5.000E-003
       7    0.0     0.0    5.969E-020  BUILDING-S                     Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                      Damage to Control Blocks

6.373E-001
                                    E-IE                               Earthquake Initiating Event

5.000E-002
                                    /EX-S                              Earthquake Initiating Event
Correction                       2.801E-006
                                    HX-CCS-S                          Seismically Induced CCS Heat
Exchanger Failure               5.679E-001
                                    HX-RCCS-S                   Seismically Induced Failure of all
RCCS HX                    5.679E-001
                                    /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                    RCCS-HR                         RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                          Failure to TRIP with Reserve
Shutdown System                 5.000E-003
       8    0.0     0.0    5.256E-020  BUILDING-S                     Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                      Damage to Control Blocks

6.373E-001
                                    E-IE                               Earthquake Initiating Event

5.000E-002
                                    /EX-S                              Earthquake Initiating Event
Correction                       2.801E-006
                                    FANS-T-S                   Seismically Induced CT Fans Failure

5.000E-001
                                    /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic         5.000E-001
                                    PUMPS-OC-S                      Seismically Induced Failure of
Pumps                         5.679E-001
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                                    RCCS-HR                       RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                        Failure to TRIP with Reserve
Shutdown System                 5.000E-003
       9    0.0      0.0    5.256E-020   BUILDING-S                  Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                   Damage  to  Control  Blocks
6.373E-001
                                    E-IE                             Earthquake Initiating Event
5.000E-002
                                    /EX-S                            Earthquake Initiating Event
Correction                       2.801E-006
                                    FANS-CCS-S                       CCS  Fans  Failure  -  Seismic
5.000E-001
                                    /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                    PUMPS-RCCS-S                  RCCS Pumps Seismically Induced
Failure                       5.679E-001
                                    RCCS-HR                       RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                        Failure to TRIP with Reserve
Shutdown System                 5.000E-003
      10    0.0      0.0    5.256E-020   BUILDING-S                  Seismically Induced Building
Failure                         8.295E-006
                                    CONTROL-BLOCKS-S                   Damage  to  Control  Blocks
6.373E-001
                                    E-IE                             Earthquake Initiating Event
5.000E-002
                                    /EX-S                            Earthquake Initiating Event
Correction                       2.801E-006
                                    FANS-CCS-S                       CCS  Fans  Failure  -  Seismic
5.000E-001
                                    HX-RCCS-S                   Seismically Induced Failure of all
RCCS HX                    5.679E-001
                                    /PPB-S                     Primary Pressure Boundary Integrity
Failure - Seismic          5.000E-001
                                    RCCS-HR                       RCCS Cooling Restored Prior to
Vessel Damage                 1.000E-004
                                    TRIP-RSS                        Failure to TRIP with Reserve
Shutdown System                 5.000E-003
```