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Risk-Based Performance Indicators

Results of Phase-1 Development

January 2001

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EXECUTIVE SUMMARY

Purpose

The purpose of this report is to present the results of the Phase-1 development of risk-based performance indicators (RBPIs) to potentially enhance the Reactor Oversight Process (ROP). The White Paper entitled "Development of Risk-Based Performance Indicators: Program Overview" described the concepts for the RBPI development. The purpose of the RBPI development is to examine the technical feasibility of providing improved performance indicators for potential implementation in the ROP. Phase 1 of the RBPI development includes indicators that are related to the initiating events cornerstone, mitigating systems cornerstone, and the containment portion of the barrier integrity cornerstone. In addition, industry wide trending is provided to support the agency's Strategic Plan Performance Measures, provide input to assessing the ROP effectiveness, and feedback of insights to the inspection program.

This work is part of the development and evolution of performance indicators in the current ROP and is closely coordinated with existing ROP efforts. Changes to the existing ROP indicators are not imminent. There are several key implementation issues summarized in this executive summary and Section 6 of the report, including the verification of risk models and data. The potential integration of RBPIs into the ROP would follow the guidelines in IMC0608, "Performance Indicator Program." This would include a pilot program prior to the full implementation of RBPIs and interaction with stakeholders to resolve implementation issues raised in this report or from external stakeholders during the review of this report.

What Are RBPIs?

RBPIs reflect changes in licensee performance that are logically related to risk and associated models. That is, they provide performance measures whose impact on core damage frequency (CDF) and large, early release frequency (LERF) can be established through a risk model or risk logic. In developing RBPIs, "performance" refers to the conduct of activities in design, procurement, construction, operation, and maintenance that support achievement of the objectives of the cornerstones of safety in the ROP.

The RBPIs developed in this report collectively have the following characteristics:

- The RBPIs are compatible with, and complementary to, the risk-informed inspection activities of the oversight process.
- The RBPIs cover all modes of plant operation.
- Within each mode, the RBPIs cover risk-important SSCs to the extent practical.
- The RBPIs are capable of implementation without excessive burdens to licensees or NRC in the areas of data collection and quantification.
- To the extent practical, the RBPIs identify declining performance before performance becomes unacceptable, without incorrectly identifying normal variations as degradations (i.e., avoid false-positive indications and false-negative indications).
- The RBPIs are amenable to establishment of plant-specific thresholds consistent with the ROP.

In addition to plant-specific RBPIs, some risk-significant aspects of performance that cannot be effectively assessed on a plant-specific basis have been identified for industry-wide trending. This task provides an input for measuring the effectiveness of the overall ROP, as well as supporting the agency's Strategic Plan Performance Measures.

Potential Benefits of RBPIs

The ROP uses two methods for monitoring plant performance, cumulative indicators and individual findings from inspections. Both methods provide indications that are evaluated with respect to their risk significance, and are used to determine the level of NRC oversight. The current ROP utilizes performance indicators that measure plant performance and use generic performance thresholds as described in SECY-99-007, "Recommendations for Reactor Oversight Process Improvement." SECY-99-007 recognized that improved performance indicators may be developed as part of the evolution of the ROP.

RBPIs are intended to provide improved indicators to the ROP. However, the decision to use the candidate RBPIs, in whole or in part, in the ROP will be made as part of the established ROP change process.

In addition to RBPIs, selected performance areas will be trended on an industry-wide basis. The industry-wide trending effort under the RBPI development task is part of the overall industry-wide trending undertaken by the agency to support the Strategic Plan Performance Measures. Specifically, the industry-wide trending from this program along with trending from other programs, such as the Accident Sequence Precursor (ASP) Program, will be used to assess performance against the Nuclear Reactor Safety measure: "no statistically significant adverse industry trends in safety performance."

The RBPI development potentially provides the following benefits to the ROP:

- More comprehensive coverage of significant contributors to plant risk
  - Reliability indicators were developed at the component/train/system level.
  - Indicators for shutdown modes were developed. RBPIs for fire and the containment portion of the barrier integrity cornerstone were identified consistent with the state-of-the-art models, data, and methods currently available for these areas.
- More recognition of plant-specific attributes
  - The RBPI threshold values are more plant-specific and reflect risk-significant differences in plant designs.
  - An indicator will be developed (Phase 2) that could provide the capability to assess the integrated risk-significance of the performance indicators and the inspection findings on overall plant performance.

- Industry-wide trending of plant-specific RBPIs as well as risk-significant performance measures that are impractical to monitor on a plant-specific basis.
  - It provides measures of the ROP effectiveness.
  - It provides feedback to the ROP to adjust technical emphasis and overall inspection frequencies.
  - It provides input to the agency's Strategic Plan Performance Measures.

Risk Perspectives on RBPI Development

The thresholds in the ROP for Performance Indicators and Significance Determination Process (SDP) are based on changes in the CDF of approximately 1E-6, 1E-5, and 1E-4 per year. CDF changes associated with the lower thresholds are only a fraction of the total CDF at a plant. Changes in performance corresponding to the red performance band (delta CDF above 1E-4 per year) are on the same order of magnitude of our current estimates of total CDFs. Thus, the ROP thresholds represent a graded approach that responds to larger increases in risk with greater regulatory response. In addition, our understanding of public risk corresponding to these values for CDF indicates that a large margin exists between the risk associated with performance changes at the ROP thresholds and either the Quantitative Health Objectives (QHOs) of the Commission's Safety Goal Policy Statement or the existing individual risk of accidental death (approximately a factor of 25 and 2500 respectively).

An inherent implication of monitoring risk attributes is that there is a time delay between the onset of a change in performance and the ability of the indicator to detect that a change has occurred. In this sense, all indicators are "lagging," or at best concurrent with, the performance change being monitored. However, in the case of RBPIs, this is not significant, because each indicator represents one of many elements of risk, for which there is still a large margin to the agency-stated public health objectives.

In addition, operating experience does not indicate that the large changes in the reliability of equipment or the frequency of initiators necessary to cause an indicator to go from nominal to unacceptable performance occur often. However, even if this were to occur, the monitoring intervals and thresholds have been set so that the probability of failure to detect that performance has changed over the monitoring period is low and the incremental risk accumulation over that time is small compared to the QHOs and individual accidental death risk.

Summary of Results

The Phase-1 RBPI development identified performance indicators and areas for industry-wide trending for potential use in the ROP. The RBPIs were developed by disaggregation of risk elements in order to develop thresholds for the indicators that would consistently reflect the risk impact of performance changes. For the majority of RBPIs, this required train-level rather than system-level indicators. It also required treating unreliability and unavailability separately, rather

than as a combined failure probability. The differences in the risk implication of performance changes at these levels is inherent in the calculation of risk. While performance can be monitored at other levels, setting thresholds with consistent risk implications between and among indicators is problematic. A total of 21 indicators for pressurized water reactors (PWRs) and 16 indicators for boiling water reactors (BWRs) were identified (including proposed RBPIs with no current data reporting). These RBPIs are listed in Table ES-1and are briefly discussed below.

Initiating Events Cornerstone:

Three initiating event frequency indicators for internal events were identified under the initiating events cornerstone of safety; General Transients, Loss of Feedwater, and Loss of Heat Sink. Other risk-significant initiating events did not accumulate data in a timely manner for plant-specific assessment of performance due to their low frequencies, and were therefore included in the industry-wide trending. The risk-significant initiating events during the shutdown modes, and fire initiating events were also included in the industry-wide trending due to their low frequencies.

Mitigating Systems Cornerstone:

For power operation, thirteen RBPIs for BWRs and eighteen RBPIs for PWRs under the mitigating systems cornerstone of safety were identified. These involved unreliability and unavailability indicators at the train-level for risk-significant safety systems and cross-system performance of key components. RBPIs for key components were developed to help assess cross-cutting performance issues that might not be practical to detect by any individual system or train performance indicator.

The thresholds for these indicators are currently based on plant-specific assessment of CDF changes. Some of these systems may also affect LERF, and it is possible for thresholds determined from changes in LERF to be more limiting than thresholds determined from changes in CDF. However, the LERF models and related data needed to determine these thresholds are not currently available.

For shutdown modes of operation, three RBPIs under the mitigating systems cornerstone of safety for PWRs and BWRs were proposed. They consist of monitoring time spent in risk-significant shutdown configurations. The risk-significant shutdown configurations are combinations of equipment unavailabilities and the reactor states associated with decay heat rates, reactor coolant system (RCS) integrity, and RCS level. The threshold values are generic and reflect CDF changes associated with spending excess time in the more risk-significant shutdown configurations. The generic baseline performance values were based on the past performance data for a number of plants. The generic threshold values were derived using two shutdown risk models (one for a PWR, and one for a BWR) that are representative of risk during shutdown operation.

Potential RBPIs for fire events under the mitigating systems cornerstone of safety were identified. These RBPIs were related to the unreliability and unavailability of fire detection/suppression systems. However, the current data reporting requirements for these systems are not sufficient for evaluating these RBPIs, or trending at the industry level.

Containment Portion of Barrier Integrity Cornerstone:

Potential RBPIs for the containment systems affecting LERF for selected containment types were identified. These involved the containment isolation function and drywell spray system. However, baseline performance values for these potential containment RBPIs could not be determined due to the unavailability of performance data. LERF models for setting thresholds are not available for all containment types. In addition, the available models are not compatible with the Standardized Plant Analysis Risk (SPAR) Revision 3 models for assessing CDF impacts which are the inputs to the LERF models. Therefore, no containment RBPIs are provided.

Industry-Wide Trending:

The industry-wide trending includes the plant-specific RBPIs as well as risk-significant performance areas that cannot be monitored at a plant-specific level. The RBPIs each have the characteristic that there is sufficient data for plant-specific trending so that plant-specific performance changes can be detected in a timely manner. Some performance features that are risk significant do not occur frequently enough to be trended on a plant-specific basis, but can be trended on an industry basis. For example, loss of offsite power events during power operations occur on average about once every 20 reactor years. Thus, approximately five events are expected to occur each year in the industry. These events can be trended at the industry level, but are not amenable to plant-specific monitoring. The industry trending will consist of trending of each of the RBPIs identified earlier as well as the performance elements noted in Table ES-2.

Risk Coverage:

As part of this RBPI development effort, an evaluation was done to assess the extent of risk coverage by RBPIs and industry-wide trending. Approximately 40% of the risk-significant elements in the SPAR models were covered by RBPIs.

In addition, the dominant accident sequences from the IPE database were reviewed. Most of the dominant accident sequences had one or more events covered by RBPIs or industry-wide trending. Tables (4-2a and 4-2b) are provided in the report to show which elements of the dominant accident sequences were covered and which ones were not.

Key Issues Affecting Feasibility of Potential Implementation of RBPIs

There are five key issues that affect the potential to implement the results of the RBPI development in the ROP. These issues evolved out of both the technical aspects of RBPI development as well as programmatic feedback regarding potential ROP implementation. Each issue is discussed briefly below.

Are any additional performance indicators needed in the ROP?

Interactions with stakeholders commenting on the White Paper indicated differing views on this subject. Industry representatives questioned whether NRC needed to have a broader coverage of risk measured in the ROP indicators, especially if it did not result in a corresponding reduction in

the inspection program. Other external stakeholder comments favored more indicators as well as additional inspections. The ROP is in its first year of full implementation. NRR will provide the Commission with its assessment of the process in June 2001. The RBPI development program is focused on demonstrating the technical feasibility of providing additional objective indicators that cover a broader spectrum of risk-significant plant performance.

Is the number of potential new indicators appropriate? / Which of the proposed indicators would be most beneficial?

The RBPI Phase-1 development identified 21 potential indicators for PWRs and 16 potential indicators for BWRs. If all of these performance indicators were implemented, they could potentially replace 8 (3 initiating event and 5 mitigating system) of 18 existing indicators in whole or in part bringing the total number of indicators per plant to about 30. In addition to the issue of the appropriate risk scope of ROP indicators (noted above), it will be necessary to assess whether potentially expanding the total number of indicators to approximately 30 per plant is reasonable from a logistics/process point of view. For example, the criteria that result in plants entering various columns of the Action Matrix would have to be reconsidered. If deemed appropriate, future RBPI development will examine the feasibility of developing indicators at a higher level (systems) by combining results of lower level data and models. The program will also examine means to use risk insights to develop a shorter list at the component/train level.

Do the data sources for RBPIs exist and have sufficient quality for use in the ROP?

A significant portion of the RBPIs require access to and use of data from the Equipment Performance and Information Exchange (EPIX) system. These data are voluntarily provided by industry in response to the Commission decision to forgo the Reliability Data Rule. Full industry participation, verification and validation of existing EPIX data, and development of guidelines for consistent reporting are important to the feasibility of many RBPIs as potential improvements to the ROP. In addition, certain data for shutdown and containment systems will need to be developed in order to have RBPIs in those areas. The issue of the regulatory mechanisms for certifying the accuracy of data used in RBPIs for the ROP will be dealt with through the ROP change process if a decision is made to proceed with potential implementation of some or all of the identified RBPIs.

Will SPAR Revision 3i models be available for setting plant-specific thresholds for all plants?

Approximately 30 Standardized Plant Accident Risk (SPAR) Revision 3i models are currently available. Completion of all 70 SPAR Revision 3i models is scheduled for the end of calendar year 2002. As more models are made available for use in the RBPI development program, it will be possible to determine if plants can be grouped so that a few models can be used to set thresholds for all plants or individual models will be needed for each. The RBPI development program will continue to use the SPAR Revision 3i models as they are developed. External stakeholder comments on the White Paper indicated that peer review by licensees should be included in the development of these models. An additional implementation issue relates to whether licensees or NRC will calculate the thresholds and indicators as well as whether licensee

models (meeting as yet to be developed NRC specifications) could be used instead of the SPAR models.

Will LERF models be available for setting thresholds for mitigating and containment systems?

There are a limited number of large, early release frequency (LERF) models available to set thresholds for performance of systems that impact the integrity of the containment barrier. In addition, currently available data are inadequate for establishing performance measures for the containment systems. Also, for some systems under the mitigating systems cornerstone, the thresholds associated with changes in core damage frequency (CDF) due to performance degradations may not be limiting compared to changes in LERF. To assess that condition, LERF models that reflect the impact of potential CDF changes are needed. The current plan for developing LERF models over the next several years will support only limited capability for identifying RBPIs or setting plant-specific LERF thresholds.

Table ES-1 Summary of Phase-1 Risk-Based Performance Indicators

Safety Cornerstone	Existing PIs	Proposed RBPIs			
Initiating Event	- Unplanned Scram - LONHR - Unplanned Reactor Power Changes	- General Transient - LOFW - LOHS			
		PWR at Power	**BWR at Power**	**Shutdown**	**Fire**
Mitigating System	- EPS (UA) - RHR (UA) - PWR AFW (UA) HPI (UA) - BWR HPCS/HPCI (UA) RCIC/IC (UA) - Safety system functional failures	- EPS (UR&UA) - AFW-MDP (UR&UA) - AFW-TDP (UR&UA) - HPI (UR&UA) - PORV (UR) - RHR (UR&UA) - SWS (UR&UA) - CCW (UR&UA) - AOV (UR) - MOV (UR) - MDP (UR)	- EPS (UR&UA) - HPCS/HPCI (UR&UA) - RCIC/IC (UR&UA) - RHR (UR&UA) - SWS (UR&UA) - AOV (UR) - MOV (UR) - MDP (UR)	- *Time in High/Medium/Low Risk-Significant Configurations	- *Fire Suppression System (UR&UA)
Barriers	- RCS Specific Activity - RCS Identified Leak Rate	- *CIV (UR&UA)	- *Drywell Spray (MarkI)(UR&UA) - *CIV (Mark III) (UR&UA)	None	None

* Requires data that are not currently reported.

Note: The emergency preparedness, occupational radiation safety, public radiation safety, and physical protection cornerstones of safety are not included in the Phase-1 RBPI scope.

Table ES-2 Summary of Phase-1 Performance Areas Proposed for Industry-Wide Trending

Safety Cornerstone	Industry-Wide Trend
Initiating Event	**Full Power:** - All proposed IE RBPIs listed in Table ES-1 - Internal flooding - Initiators evaluated as ASPs - Loss of instrument/control air (for BWRs and PWRs) - LOOP - Loss of vital AC bus - Loss of vital DC bus - Small LOCA (including very small LOCA) - SGTR - Stuck open safety/relief valves **Shutdown:** - LOOP during shutdown modes - Loss of RHR during shutdown modes - Loss or diversion of RCS inventory during shutdown modes leading to loss of RHR - Loss of RCS level control (during transition to mid-loop) leading to loss of RHR (for PWRs only) **Fire:** - Fire events in risk-significant fire areas
Mitigating System	- All proposed mitigating system RBPIs listed in Table ES-1 - CCF events for AFW pumps - CCF events for Diesel Generators - Total CCF events
Barriers	None

FOREWORD

The Reactor Oversight Process (ROP) was recently revised to improve the NRC's regulatory oversight of licensee operation of commercial nuclear power plants. It is intended to better risk-inform agency actions and bring more objectivity to the regulatory process. The revised ROP is consistent with the goals of the Commission's PRA Policy Statement and the NRC's Strategic Plan (NUREG-1614), which include increased use of the PRA technology in ". . . regulatory matters to the extent supported by the state-of-the-art in PRA methods and data and in a manner that complements the NRC's deterministic approach and supports the NRC's traditional defense-in-depth philosophy." The ROP is reflective of the NRC's efforts to better risk-inform its core processes. The development of the potential Risk-based Performance Indicators (RBPIs) described in this report is intended to represent a further improvement to the ROP that would be appropriate as part of this regulatory evolution.

SECY-99-007 and 99-007A described the revised Reactor Oversight Process. The ROP was implemented at all plants in April 2000 following a six-month pilot program conducted in 1999. The results of this pilot program were described in SECY-00-0049. A fundamental aspect of the ROP is the use of both performance indicators and inspection findings to determine whether the objectives of the ROP's cornerstones of safety are being met on a plant-specific basis.

In addition to these changes at the NRC, the industry is using more performance-based approaches to enhance its operations, including gathering and analyzing both plant-specific and industry-wide data. Furthermore, technological advances such as the Internet and microcomputer use have resulted in improved capabilities to gather and share such data. Through such technological developments, both the industry and the NRC have expanded their capabilities to model and assess the risk-significance of plant operations.

In light of these evolving capabilities and the movement toward more risk-informed and performance-based oversight, the Risk-based Performance Indicators were developed to (1) address specific areas in the current ROP that were identified in SECY-00-0049 as possible enhancements and (2) potentially support any future development of performance indicators using improved risk analysis tools. This report discusses the technical feasibility of using currently available risk models and data to enhance the NRC's ability to monitor plant-specific safety performance of reactors in a risk-informed and performance-based manner. This development activity is designed to fit into the ROP concept for indicators, thresholds, and performance monitoring while continuing to move the NRC's programs forward in accordance with the PRA Policy Statement and the goals of the Strategic Plan.

The Strategic Plan also articulates the NRC's efforts to increase public confidence. One of the strategies for achieving that goal is, "We will make public participation in the regulatory process more accessible. We will listen to the public's concerns and involve our stakeholders more fully in the regulatory process." In keeping with this philosophy, the NRC has sought, and continues to seek, input from internal and external stakeholders on the ROP as the program evolves. With respect to the development of potential RBPIs, the first key stakeholder interactions were held to obtain input to the RBPI White Paper (SECY-00-0146), which described the principles for the RBPI development. This report represents the second opportunity for external stakeholder

participation in the RBPI development process. There will be additional opportunities for internal and external stakeholder involvement as the process continues to evaluate the feasibility of potential implementation of these (or other) performance indicators in accordance with the ROP change process.

ABBREVIATIONS AND ACRONYMS

A	Large Loss of Coolant Accident
AC	Vital AC Buses
ACBU1	Other Onsite Backup 1
ACC	Accumulators
ADS	Automatic Depressurization System
AFW	Auxiliary Feedwater
AM1	Alternate Makeup 1
AM2	Alternate Makeup 2
AOV	Air-Operated Valve
ARI	Alternate Rod Insertion
ASP	Accident Sequence Precursor
ASPC	Alternate Suppression Pool Cooling
AUXC1	Auxiliary Cooling 1
AUXC2	Auxiliary Cooling 2
BI	Borated Injection
BWR	Boiling Water Reactor
CCDP	Conditional Core Damage Probability
CCDF	Conditional Core Damage Frequency
CCF	Common Cause Failure
CCW	Component Cooling Water
CD	Core Damage
CDF	Core Damage Frequency
CHPI	Normally Running Makeup (Injection)
CHPR	Normally Running Makeup (During Recirculation)
CIV	Containment Isolation Valve
CONDA	Condenser Available
CRDS	Control Rod Drive Pumps
CS	Core Spray
CSR	Containment Spray Recirculation

CTS	Condensate Pumps
DBI	Design Basis Issue
DWS	Drywell Spray
EAC	Emergency AC Power (usually EDGs)
EDC	Battery-backed DC Buses
EDG	Emergency Diesel Generator
EPIX	Equipment Performance and Information Exchange System
EPS	Emergency Power System
ESAS1	Engineered Safety Actuation System 1
ESW	Emergency Service Water
GT	General Transients
HP1	High-Pressure 1
HPCI	High-Pressure Coolant Injection
HPCS	High-Pressure Core Spray
HPI	High-Pressure Injection System
HPR	High Head Safety Injection (During Recirculation)
HUM	Operator Action
HVAC	Heating, Ventilation, Air Conditioning
HVAC1	Heating, Ventilation, Air Conditioning 1
HVAC2	Heating, Ventilation, Air Conditioning 2
HVAC3	Heating, Ventilation, Air Conditioning 3
IA	Instrument Air Compressors
IC	Isolation Condenser
INEEL	Idaho National Engineering and Environmental Laboratory
IPE	Individual Plant Examination
IPEEE	Individual Plant Examinations for External Events
ISLOCA	Interfacing Systems LOCA
LER	Licensee Event Report
LERF	Large Early Release Frequency
LLOCA	Large Loss of Coolant Accident
LOCA	Loss of Coolant Accident

LOFW	Loss of Feedwater
LOHS	Loss of Heat Sink
LONHR	Loss of Normal Heat Removal
LOOP	Loss of Offsite Power Event
LOSP	Loss of Offsite Power
LP1	Low-Pressure 1
LP2	Low-Pressure 2
LP3	Low-Pressure 3
LPCI	Low-Pressure Coolant Injection
LPCS	Low-Pressure Core Spray
LPI	Low Pressure Injection
LPR	Low Pressure Injection
MDAFW	Motor-Driven Auxiliary Feedwater Pumps
MDPs	Motor Driven Pumps
MFW	Main Feedwater Pumps
MLOCA	Medium Loss of Coolant Accident
MOR	Monthly Operating Report
MOV	Motor-Operated Valve
MSIV	Main Steam Isolation Valve
NISP	Non-1E Startup Pumps
NRC	U.S. Nuclear Regulatory Commission
NRR	Nuclear Reactor Regulation
OA3	Alternate Air System 3
PORV	Power Operated Relief Valve
PPORV	Pressurizer Power Operated Relief Valves
PRA	Probabilistic Risk Assessment
PSRV	Pressurizer Safety Relief Valves
PWR	Pressurized Water Reactor
QHO	Quantitative Health Objective
RADS	Reliability and Availability Database System
RAW	Risk Achievement Worth

RBCLCW	Reactor Building Closed Loop Cooling Water
RBPI	Risk-Based Performance Indicator
RCIC	Reactor Core Isolation Cooling
RCPS	Reactor Coolant Pump Seals
RCS	Reactor Coolant System
RECIRC	Recirculation Pumps
RHR	Residual Heat Removal
ROP	Reactor Oversight Process
RPS	Reactor Protection System
RWST	Refueling Water Storage Tank
SCSS	Sequence Coding and Search System
SDC	Shutdown Cooling
SDP	Significance Determination Process
SG	Steam Generator
SGTR	Steam Generator Tube Rupture
S1	Medium Loss of Coolant Accident
S2	Small Loss of Coolant Accident
S3	Small-small Loss of Coolant Accident
SDAWF	Steam-Driven Auxiliary Feedwater Pumps
SGA	Steam Generator Atmospheric Dump Valves
SGS	Steam Generator Safety Valves
SI	Safety Injection
SLC	Standby Liquid Control
SLOCA	Small Loss of Coolant Accident
SPAR	Standardized Plant Analysis Risk
SPC	Suppression Pool Cooling
SRV	Safety Relief Valve
SRVS	Safety Relief Valves Steam
SSCs	Systems, Structures, and Components
SSW	Standby Service Water
SW2	Alternate Service Water 2

SW3	Alternate Service Water 3
SWS	Service Water System
T-AC	Transient - Initiated by Loss of Vital AC Buses
T-ATWS	Transient - Anticipated Transient without Scram
T-AUXC2	Transient - Initiated by Loss of Auxiliary Cooling 2
T-CCW	Transient - Initiated by Loss of Component Cooling Water
T-DC	Transient - Initiated by Loss of DC Buses
T-ESW	Transient - Initiated by Loss of Essential Service Water Pumps
T-EXFW	Transient - Excessive Feedwater Addition
T-HVAC1	Transient - Initiated by Loss of Heating, Ventilation, and Air Conditioning 1
T-HVAC2	Transient - Initiated by Loss of Heating, Ventilation, and Air Conditioning 2
T-IA	Transient - Initiated by Loss of Instrument Air Compressors
T-IFL	Transient - Internal Flood
T-IORV	Transient - Intermittent Open Relief Valve
T-IORV/ SORV	Transient - Intermittent or Stuck Open Relief Valve
T-LMFW	Transient - Loss of Main Feedwater
T-LOOP	Transient - Loss of Offsite Power
T-MSIV	Transient - Initiated by Loss of Main Steam Isolation Valve
T-NSW	Transient - Initiated by Loss of Normal Service Water Pumps
T-RX	Transient - Reactor Trip
T-SGTR	Transient - Steam Generator Tube Rupture
T-SLBIC	Transient - Steam Line Break Inside Containment
T-SLBOC	Transient - Steam Line Break Outside Containment
T-SW2	Transient - Initiated by Loss of Alternate Service Water 2
T-TBCLCW	Transient - Initiated by Loss of Turbine Building Closed Loop Cooling Water
T-TT	Transient - Turbine Trip
T-UHS	Transient - Loss of Ultimate Heat Sink
T-VAC	Transient - Initiated by Loss of Vital Instrument AC
TB	Turbine Bypass Valves
UA	Unavailability

UR	Unreliability
V	Interfacing System Loss of Coolant Accident
V&V	Validation and Verification
V-AR1	Interfacing System Loss of Coolant Accident in Alternate Recirculation 1
V-CCW	Interfacing System Loss of Coolant Accident in Component Cooling Water
V-CHPI	Interfacing System Loss of Coolant Accident in Normally Running Makeup (Injection)
V-HPI	Interfacing System Loss of Coolant Accident in High Head Safety Injection
V-LPI	Interfacing System Loss of Coolant Accident in Low Pressure Injection
V-RHR	Interfacing System Loss of Coolant Accident in Residual Heat Removal
VAC	Vital Instrument AC
VENT	Venting System

1. INTRODUCTION

1.1 Purpose of Report

The purpose of this report is to present the results of the Phase-1 development of risk-based performance indicators (RBPIs) to potentially enhance the Reactor Oversight Process (ROP). The development process was previously described in the White Paper entitled "Development of Risk-Based Performance Indicators: Program Overview" (Ref. 1, provided here as Appendix G).

This work is part of the development and evolution of performance indicators in the current ROP and is closely coordinated with existing ROP efforts. Changes to the existing ROP indicators are not imminent. There are several key implementation issues summarized in the executive summary and Section 6 of the report, including the verification of risk models and data. The potential integration of RBPIs into the ROP would follow the guidelines in IMC0608, "Performance Indicator Program." This would include a pilot program prior to the full implementation of RBPIs and interaction with stakeholders to resolve implementation issues raised in this report or from external stakeholders during the review of this report.

The current results presented include:

- Formulations of plant-specific RBPIs and their thresholds for 23 plants;
- Potential candidates for industry-wide trending;
- Assessment of coverage; and
- Results of validation and verification.

In addition to the Phase-1 results, this report describes the process for RBPI development. This process is intended to lead to a set of RBPIs having the characteristics discussed in Section 1.2 of this report.

The Phase-1 RBPI development includes indicators that are related to the initiating events cornerstone, the mitigating systems cornerstone, and the containment portion of the barrier integrity cornerstone. This includes development of potential indicators for:

- Initiating events;
- Reliability and availability performance under the mitigating systems cornerstone;
- Containment barrier performance;
- Performance areas involved in scenarios initiated by fire;
- Performance areas involved in scenarios initiated during shutdown operation.

Areas that are not amenable to RBPI treatment are assessed for potential for trending at the industry level.

The fire, shutdown, and containment indicators are developed consistent with the current state-of-the art models, methods, and data for these areas. Therefore, they will be different in number and nature from those for internal events at power, where the state of the art is more developed.

1.2 Characteristics of RBPIs

As noted in the White Paper, "performance" refers to the conduct of those activities in design, procurement, construction, operation and maintenance that support achievement of the objectives of the cornerstones of safety in the Reactor Oversight Process.

SECY 99-007, "Recommendations for Reactor Oversight Process Improvements" (Ref. 2), Attachment 2, "Technical Framework for Licensee Performance Assessment," lists the key attributes of performance within each cornerstone. RBPIs are performance measures that are logically related to the risk-significant elements of these key attributes. In this development, RBPIs are logically related to elements of risk models.

The RBPIs developed in this report collectively have the following characteristics:

- The RBPIs are compatible with, and complementary to, the risk-informed inspection activities of the oversight process.
- The RBPIs cover all modes of plant operation.
- Within each mode, the RBPIs cover risk-important systems, structures, and components (SSCs) to the extent practical.
- The RBPIs are capable of implementation without excessive burdens to licensees or NRC in the areas of data collection and quantification.
- To the extent practical, the RBPIs identify declining performance before performance becomes unacceptable, without incorrectly identifying normal variations as degradations (i.e., the RBPIs avoid false-positive indications and false-negative indications).
- The RBPIs are amenable to establishment of plant-specific thresholds consistent with the Reactor Oversight Process (ROP).

1.3 Organization of Report

This section is the introduction to the report. Section 2 discusses the RBPI development process in accordance with the development steps from the White Paper. Section 3 presents results of the process steps discussed in Section 2. The results are organized by internal events at power, shutdown events, and external events, because the indicators and thresholds in these areas use similar risk models and insights for each cornerstone. Within each area, each safety cornerstone is discussed. Section 4 analyzes the extent of risk coverage by the RBPIs. Section 5 discusses three aspects of validation and verification of the RBPIs. Section 6 addresses key issues affecting RBPI development and implementation.

2. PROCESS FOR IDENTIFICATION OF RBPIs AND INSPECTION AREAS

2.1 Systematic Process for RBPI Development

The steps in RBPI development are the following:

1. Assess the potential risk impact of degraded performance.
2. Obtain performance data for risk-significant, equipment-related elements.
3. Identify indicators capable of detecting performance changes in a timely manner.
4. Identify performance thresholds consistent with a graded approach to performance evaluation from SECY 99-007.

Figure 2.1 shows this RBPI development process. The following discusses each step of the flowchart in Figure 2.1.

Step 1: Assess the potential risk impact of degraded performance

The processing in this step is shown on Sheet 1 of Figure 2.1.

A performance attribute is suitable for RBPI consideration if the risk significance of changes in performance can be determined using a risk model or risk logic. An example of a performance attribute under the mitigating systems cornerstone that is typically modeled is equipment performance. Reliability and availability of mitigating systems are typically modeled, and the risk impact of performance changes in these areas can be quantified. An example of a performance attribute that is not typically modeled is "procedure quality" under the initiating events cornerstone. Some PRA models reflect procedure quality as performance shaping factors influencing human error probabilities that affect risk, but this kind of modeling is not typical in most PRA/IPEs even for mitigating systems.

The test of risk significance of a performance attribute is whether degraded performance can cause changes in mean core damage frequency (CDF) or mean large early release frequency (LERF) that exceed 1E-6 or 1E-7, respectively. Development of RBPIs and thresholds under the initiating events cornerstone and the mitigating systems cornerstone has been carried out using CDF as the measure of risk significance. Some performance areas under these cornerstones could affect LERF, and this could affect determination of associated RBPI thresholds. Assessment of this will be completed when integrated CDF/LERF models become available to this project. Development of RBPIs and thresholds for the containment barrier under the barrier integrity cornerstone has been initiated based on assessment of published results, using LERF as the measure of risk significance. Completion of this development also requires integrated CDF/LERF models.

Figure 2.1 RBPI Development Process

Sheet 1

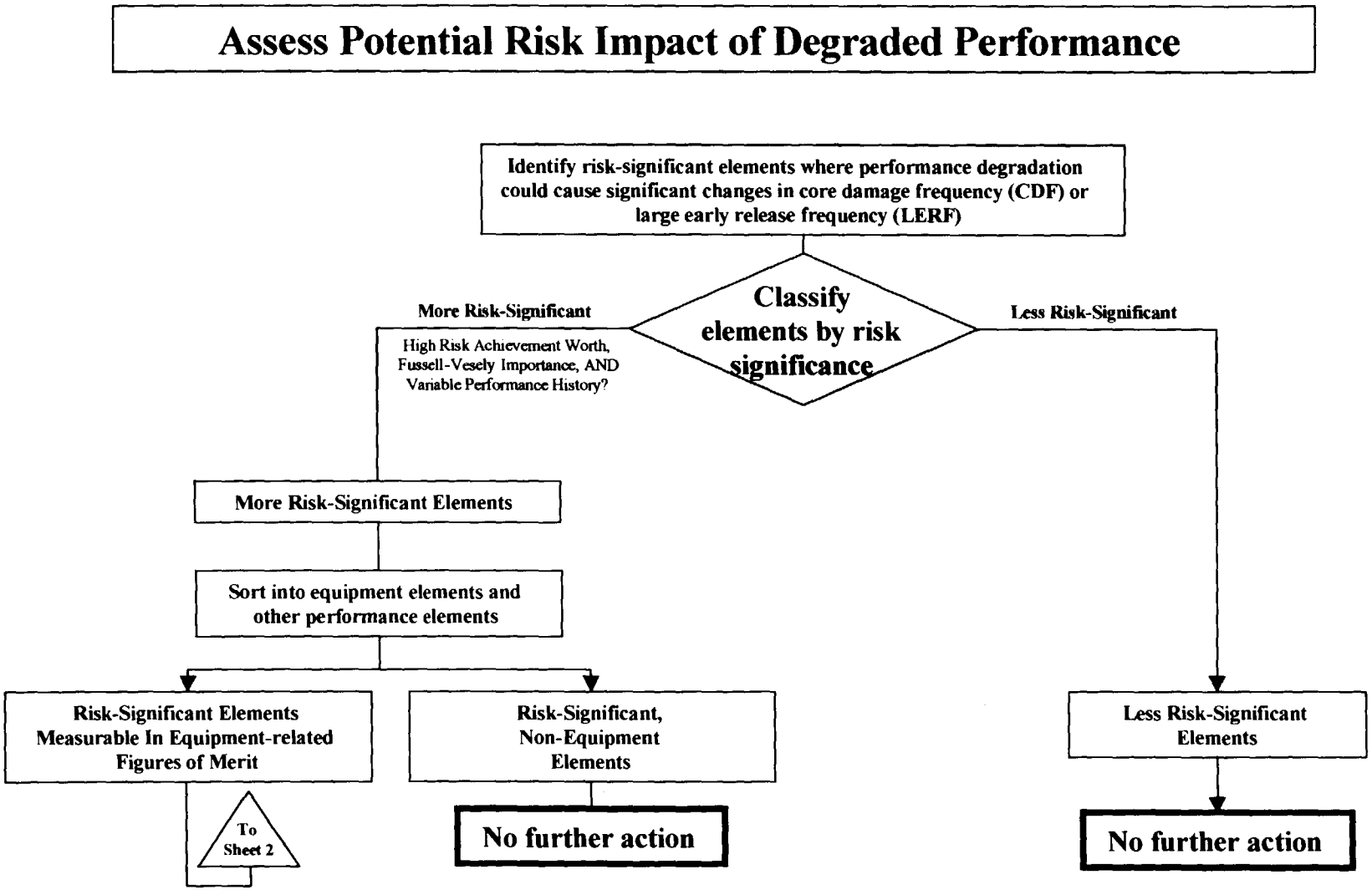


Figure 2.1 RBPI Development Process

Sheet 2

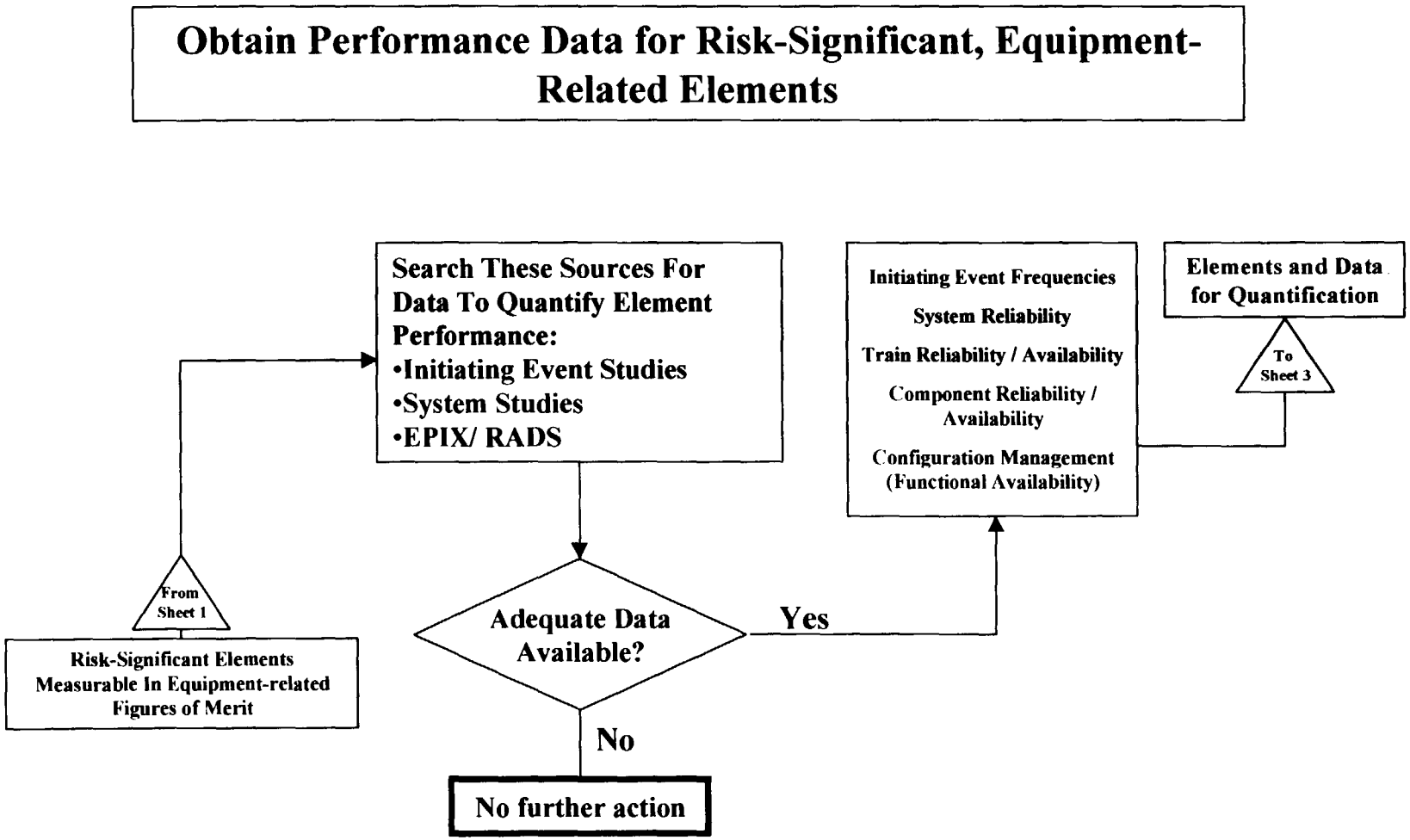


Figure 2.1 RBPI Development Process

Sheet 3

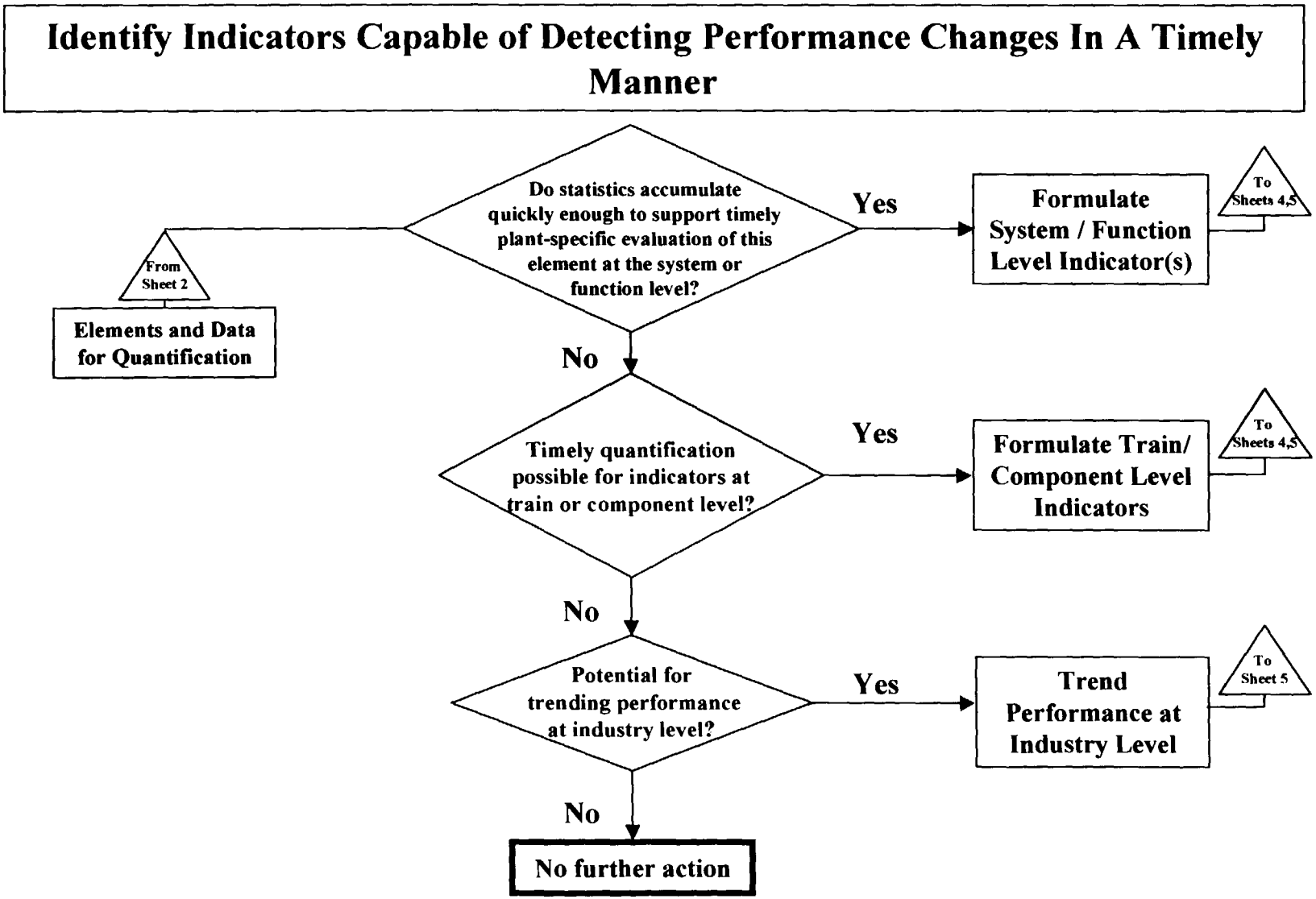


Figure 2.1 RBPI Development Process

Sheet 4

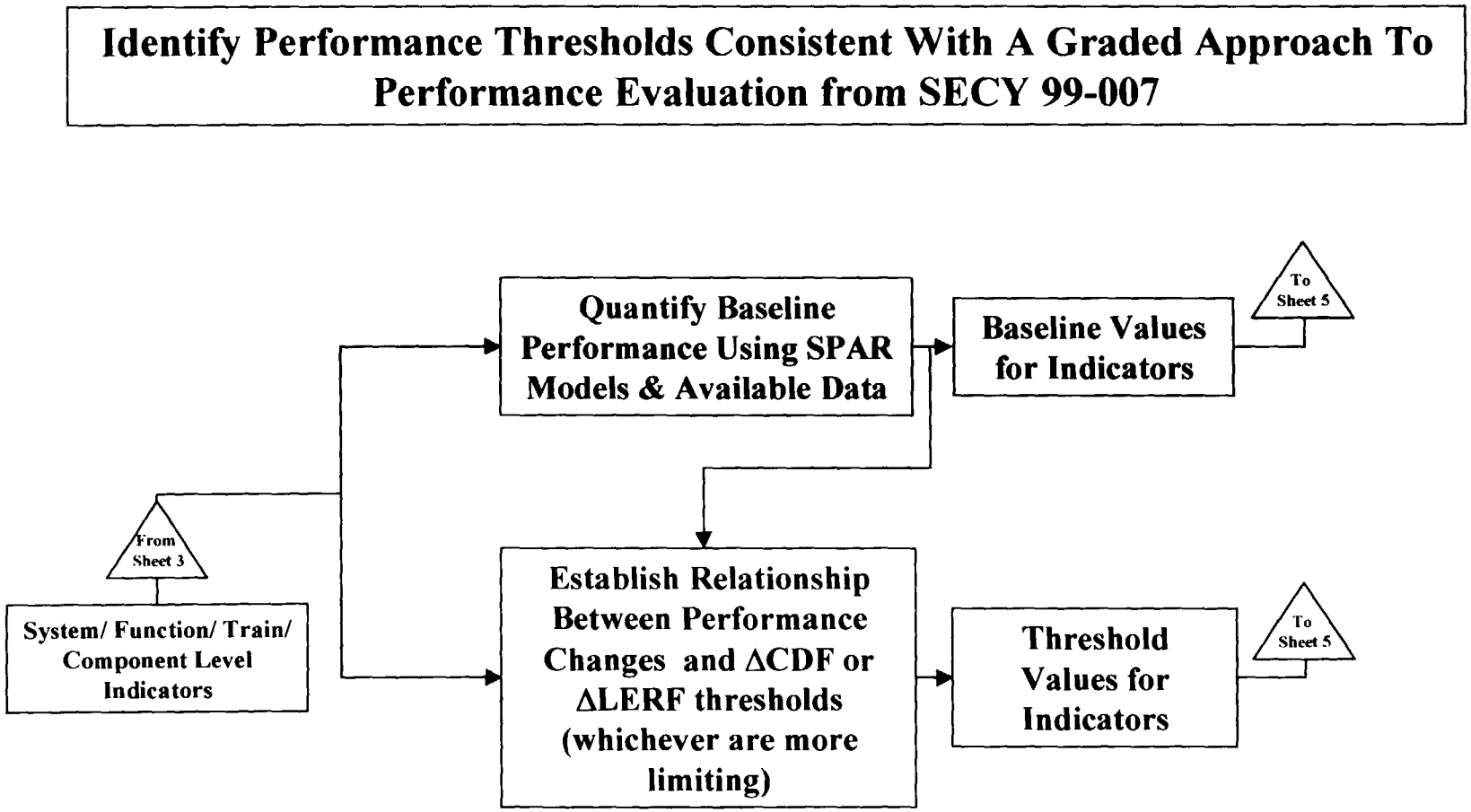
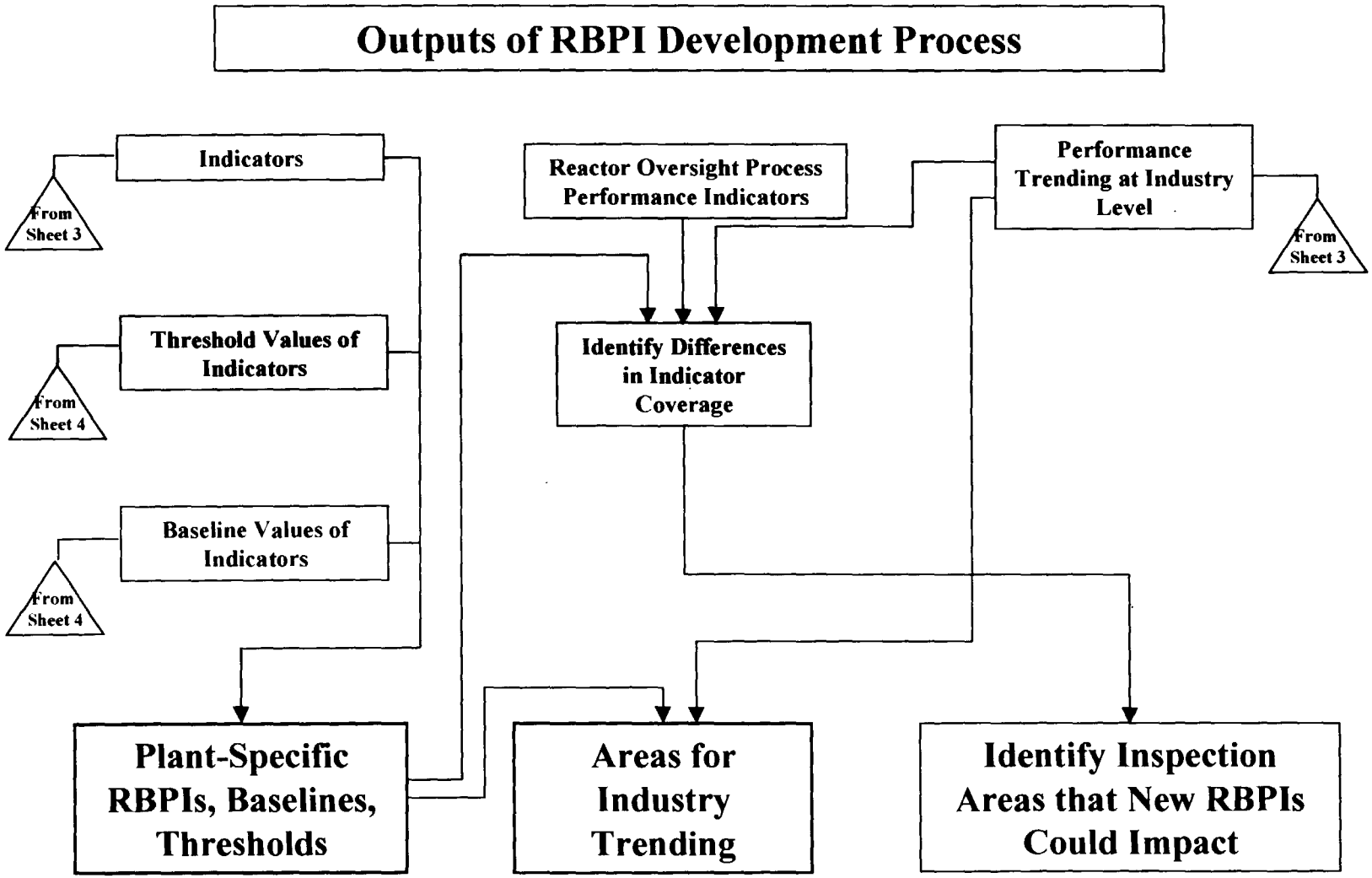


Figure 2.1 RBPI Development Process

Sheet 5



Risk significance of performance attributes can be assessed on the basis of "importance measures" such as Risk Achievement Worth (RAW), Fussell-Vesely (F-V), and Birnbaum. These measures indicate how important an element of the risk model is to the overall result. The RAW of an element indicates how risk might increase if performance degrades, while F-V indicates how much the baseline performance contributes to risk. This is discussed further in Appendix A.

Performance attributes that are not equipment-related are not within the scope of the RBPI development. Some human errors, including post-accident response, are examples of this. However, other aspects of human performance, such as the conduct of maintenance, affect equipment-related figures of merit such as reliability and availability, which are within the scope of RBPI development.

The output from Step 1 is:

- Risk-significant, modeled, and equipment-related elements for which there is potential to develop RBPIs.

Step 2: Obtain Performance Data for Risk-Significant, Equipment-Related Elements

This step is illustrated on Sheet 2 of Figure 2.1.

The output of this step is a set of industry-wide data supporting quantification of the baseline performance of each element. For some elements, this will be reliability / availability / failure frequency information, including both the instances of adverse events (the numerator) and the total number of opportunities for the adverse events (operating hours, number of demands, etc.). For some elements, it may be the time spent in particular plant configurations that are important to risk.

The output from Step 2 is:

- Risk-significant, equipment-related elements and data for quantification.

Step 3: Identify Indicators Capable of Detecting Performance Changes in a Timely Manner

This step is shown on Sheet 3 of Figure 2.1.

This step identifies potential RBPIs to determine whether a high-level indicator (e.g., system / function performance) in each area is capable of detecting significant performance changes in a timely manner, and if not, whether a lower-level indicator (e.g., train / component performance) in that area is capable of detecting performance changes in a timely manner.

In this report, timely detection means that it is unlikely that performance degradation would not be detected using data over the most recent three-year period. It should be noted that the data collection interval can vary depending on the type of RBPI, as explained in Section 5.3 and Appendix F of this report.

Even if a high-level indicator can detect performance changes in a timely manner, it will be necessary to disaggregate the high-level indicator into lower-level indicators if it is not possible to define an appropriate threshold value for the high-level indicator. This is discussed below under Step 4, and discussed more fully in Appendix A, Section 2.1.2.

Risk-significant areas for which it is not practical to detect plant-specific performance changes in a timely manner are considered for industry-wide trending. If performance data accumulate at the industry level quickly enough to allow trends to be identified in a given area, the area is identified as potential for industry-wide trending.

The outputs of this step are the following:

- Potential RBPIs at the system/function level;
- Potential RBPIs at the train/component level;
- Potential industry-wide trending.

Step 4: Identify Performance Thresholds Consistent with a Graded Approach to Performance Evaluation from SECY 99-007

This step is illustrated on Sheet 4 of Figure 2.1.

The purpose of this step is to determine RBPI baseline values and the changes in each RBPI value that correspond to changes in CDF or LERF for the performance bands.

It is not possible to define an appropriate risk threshold for a high-level indicator if the risk significance of its lower-level constituents differs significantly from one to another. A given net change in performance at the higher level can be caused by different sets of performance changes at lower levels having different risk impacts. This situation arises when different trains of a given system depend on different support systems, and therefore play different roles in different accident sequences. It also occurs due to the different impact of CCF on sequence quantification and the different impact of potential recovery actions on unavailability and unreliability. For these reasons, identification of thresholds for potential RBPIs above the train level needs special care. If an appropriate threshold cannot be defined, the potential RBPI must be disaggregated into lower-level elements for which appropriate thresholds can be defined. This is discussed further in Appendix A, Section 2.1.2.

Some elements under the initiating events cornerstone and mitigating systems cornerstone affect LERF as well as CDF. Performance thresholds for the corresponding RBPIs need to be determined in light of both kinds of impacts. In this report, thresholds for RBPIs under the initiating events and mitigating systems cornerstones reflect only the CDF impact of performance changes. Refinement of the RBPI threshold development based on consideration of LERF as well as CDF will be undertaken in ongoing work. Complete characterization of the risk significance of such elements requires integrated models that are still being developed.

After the performance thresholds have been identified for an RBPI, the potential for false positive indications (false indications of declining performance) and false negative indications (failures to

identify declining performance) is evaluated as a function of monitoring time interval. An RBPI parameter model and associated monitoring time interval that adequately minimizes the probabilities of false indications is determined.

The outputs of this step are:

- A parameter definition for each RBPI;
- A set of plant-specific threshold values for each RBPI.

Outputs of RBPI Development Process

Outputs of the RBPI development process are summarized on Sheet 5 of Figure 2.1.

The content of the inspection program is related to the coverage provided by the performance indicators. This process develops some RBPIs that are different from the PIs used in the Reactor Oversight Process. Therefore, the differences are identified and summarized, and this information is evaluated with respect to its implications for the inspection program.

The following outputs of the RBPI development process are obtained:

- Plant-specific RBPI parameter definitions, baseline values, and threshold values
- Performance areas for industry-wide trending
- Inspection areas that new RBPIs could impact

2.2 Risk Perspectives Associated with RBPI Development

The RBPIs are potential improvements to the Reactor Oversight Program (ROP). They are intended to allow the NRC (and licensees) to determine when plant-specific performance in areas relating to cornerstone objectives is degrading in order to take timely corrective actions. The graded approach to regulatory response to changes in licensee performance relies on the principle that agency response is linked to the severity of the changes in performance from a risk perspective. The following discusses that principle and its relationship to the RBPI development.

There are numerous studies estimating the public risks associated with operation of nuclear power plants. These vary in scope from Level 1 estimates of core damage frequency (CDF) for internal initiators during power operations to Level 3 evaluations of an offsite dose from internal and external initiators during both power and shutdown operations. Some useful perspectives relating to public risk can be gleaned from this body of work.

General Risk Insights:

Mean estimates of CDF from Individual Plant Examinations range from low E-6 to mid E-4 per year with an average in the mid E-5 range (NUREG-1560, Ref. 3). NUREG-1150 (Ref. 4) produced similar results. In addition, NUREG-1150 evaluated the probabilities of early fatalities and latent cancer fatalities for the five plants modeled. Other risk studies have done similar

analyses. Using this information, it is possible to make general comparisons with the Quantitative Health Objectives of the Commission's Safety Goal Policy.

The thresholds in the ROP for Performance Indicators and the Significance Determination Process are based on changes in the CDF of approximately E-6, E-5, and E-4 per year. The lower thresholds generally represent a fraction of the currently-estimated total CDF at a plant. The threshold between the yellow and red performance bands is on the same order of magnitude as our current estimates of total CDF. Thus, the ROP thresholds represent a graded approach that treats larger increases in risk with greater regulatory response.

The relationship between total CDF and the probability of early fatalities (the more limiting of the QHOs) is a function of the particular containment design and operation as well as the distribution of population around the plant and the effectiveness of emergency response capability. Using worst-case characteristics from the NUREG-1150 (Ref. 4) analysis and assuming that the baseline mean total CDF is 1E-4 per reactor year, the mean frequency of an individual early fatality is 2E-8 per year. The QHO for early fatalities is approximately 5E-7 per year (a factor of about 25 higher). This QHO is based on the Safety Goal Policy objective that early fatalities should be less than 0.1% (three orders of magnitude, or a factor of 1000 lower) of the existing individual accidental death risk. The individual accidental death rate is approximately 5E-4 per year. Figure 2.2 displays the CDF values related to early fatality on a logarithmic scale. There are two important implications of this perspective on the development of RBPIs.

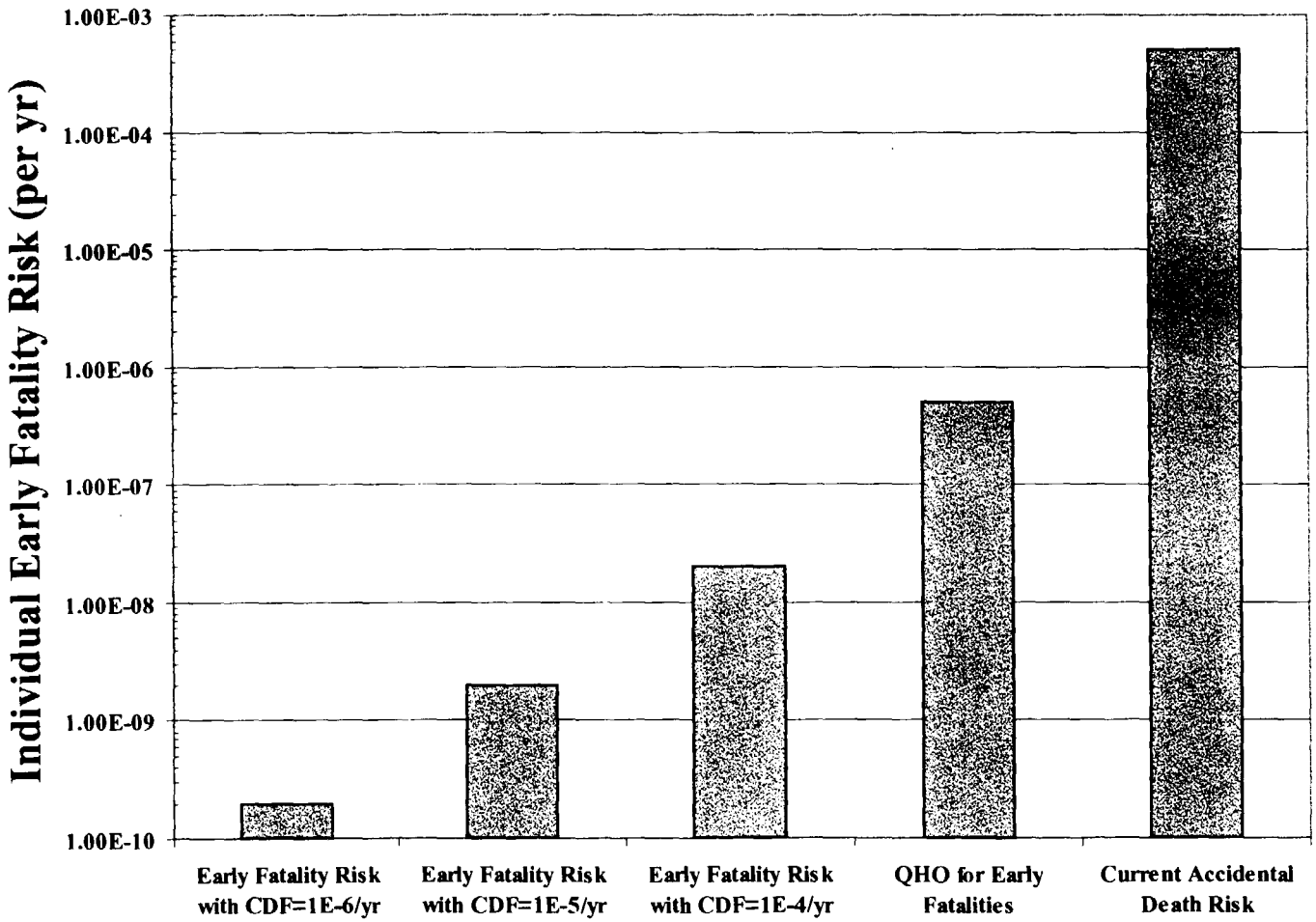
Specific Implications of General Risk Insights on RBPI Development:

The first important implication is that a large margin exists between the risks associated with performance changes at the ROP thresholds and either the QHOs or existing public risk of accidental death. This determines the precision needed to monitor performance parameters and quantify the thresholds. Errors in data, models, and/or calculations would have to be large to result in approaching either the QHO or the existing individual accidental death risk.

The second important implication deals with the ability of the RBPIs to detect potential degradations in a timely manner so that regulatory actions can be taken before the associated risk becomes too large. The ROP red performance band is the "unacceptable" performance area. It is approximately equivalent to an increase in CDF of greater than 1E-4 per year. This would increase the risk of a plant from its baseline to twice its baseline value (assuming the baseline was 1E-4). This would still be substantially below the QHO (a factor of 12 instead of 25) assuming the worst case NUREG-1150 (Ref. 4) assumptions and still far below the existing individual accidental death risk.

An inherent implication of monitoring risk attributes is that there is a time delay between the onset of a change in performance and the ability of the indication to detect that a change has occurred. In this sense, all indicators are "lagging," or at best concurrent with, the performance change being monitored. However, in the case of RBPIs, this is not significant, because each indicator represents one of many elements of risk, for which there is still a large margin to the

Figure 2.2
Margin Between Core Damage Early Fatality Risk, QHOs, and Current Overall Accidental Death Risk



agency-stated public health objective. The issue can be addressed by the question, "If performance were to degrade instantaneously to be in the red performance band, can this change in performance be detected in time to take corrective actions before the accumulation of risk becomes unacceptable?" In answering the question, it is important to note two things.

First, the operating experience does not indicate that the unreliability of equipment nor the frequency of challenges to the safety equipment is likely to change in that manner. For example, in order for the initiating events cornerstone indicator for trips with loss of heat sink to be in the red performance band, the frequency of events would have to change from about one every 5-10 years to more than 15 per year. There is no evidence of plants having that kind of performance. Under mitigating systems, an emergency diesel generator train unreliability change from a nominal performance of 0.04 to about 0.15 per demand is needed to be in the red performance band. NUREG/CR-5500 Vol. 5 (Ref. 5), which evaluated EDG train unreliability and trended industry unreliability performance based on actual demands (losses of normal power to buses) does not indicate any plants with a mean unreliability estimate worse than 0.066. Thus, the failure probability would have to more than double to be in the red performance band, and there is no evidence of plants exhibiting that kind of performance degradations.

Second, even if these scenarios occurred, the RBPIs have been formulated so that the probability of the indication remaining nominal (green zone) while the performance has become unacceptable (red zone) is low. For the two examples given above, the probability of not detecting the performance change was essentially zero for loss of heat sink initiators and was less than one chance in 300 for EDG reliability. (Plant-specific probabilities for these conditions are contained in the Appendices.)

Assuming that the degradation of a single performance indicator occurred immediately following the update of the indicator for the annual performance review and was not evaluated again for a year (unlikely since the data updates are expected quarterly), there could be a maximum undetected risk addition of 1E-4 to the total CDF for one year. It is extremely unlikely that such performance would remain undetected beyond that time.

Performance degradations corresponding to the yellow and white zones constitute a rate of risk accumulation that is 10 to 100 times lower than this example. Thus, for these cases, the risk accumulation from "lagging" indication would be proportionately less.

In summary, the potential degradations in plant performance monitored by the ROP represent a small portion of the existing individual accidental death risk and have a substantial margin to the agency's QHOs. For the events, conditions, and equipment proposed for monitoring in the RBPIs, the likelihood of failing to detect significant degradations in performance before they pose a significant risk relative to the QHOs or the existing individual accidental death risk is small.

3. RESULTS

Within this section, the results are organized by internal events at power, shutdown events, and external events, because the indicators and thresholds in each of these areas use similar risk models and insights for each cornerstone. Within each area, each safety cornerstone is discussed.

3.1 Results for Full Power, Internal Events

Risk-Based Performance Indicators are chosen to reflect changes in licensee performance that are logically related to risk and associated models. They provide performance measures whose impact on core damage frequency (CDF) and large, early release frequency (LERF) can be established through a risk model or risk logic. In developing RBPIs, "performance" refers to activities in design, procurement, construction, operation, and maintenance that support achievement of the objectives of the cornerstones of safety in the ROP. This section summarizes the selection and application of RBPIs at 23 plants.

3.1.1 Initiating Events Cornerstone

3.1.1.1 RBPIs

RBPIs for initiating events were determined through evaluation of the Individual Plant Examination (IPE) submittals and the associated IPE Database (Ref. 6). From this database, initiators with a conditional core damage probability (CCDP) $\geq$ 1E-6 and a contribution to industry-wide CDF $\geq$ 1% were identified as risk-significant. In accordance with the data analysis performed in NUREG/CR-5750 (Ref. 7), three schemes for grouping initiating events were considered; industry-wide, pressurized water reactors (PWRs) and boiling water reactors (BWRs). The complete list of initiators, their industry CDF contributions, and the plant group to which they belong are identified in Appendix A.

The analysis of initiating event data and calculation of initiating event frequencies also relied on several data sources. The three data sources used in the selection, and their contribution to the analysis, of initiating event RBPIs are described below:

- **NUREG/CR-5750, Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 - 1995** (Ref. 7), provided initiating event frequencies calculated for various initiators as well as the definitions of initiators and related functional impact groupings. These initiating event frequencies were incorporated into SPAR models (Ref. 8) as part of the process of establishing plant-specific baseline core damage frequencies.
- **The Sequence Coding and Search System (SCSS)** (Ref. 9) is a database maintained at Oak Ridge National Laboratory that provides access to electronic copies of Licensee Event Reports (LERs). This database was the source of initiating event data for NUREG/CR-5750 and will be used to identify trips and scrams used in future calculations of initiating event frequencies and RBPI thresholds.
- **Monthly Operating Report (MORs)** data as tabulated in INEEL database MORP1 (Ref. 10) provides a source of critical operating hour data used in the calculation of initiating event frequencies reported in NUREG/CR-5750 and subsequently incorporated into the baseline

SPAR models (Ref. 8). This database will be used to identify critical hours used in future calculations of initiating event frequencies and corresponding RBPI thresholds.

In addition to being risk-significant, initiating event performance indicators must be capable of detecting performance changes in a timely manner. The associated monitoring period must be long enough to reduce the probabilities of false negatives and false positives to acceptable levels, but no longer. Statistical analyses were performed with the results, including monitoring periods, documented in Appendices E and F. Finally, the impacts of changes in frequencies of candidate initiating events must be readily quantifiable. Plant-specific baseline models were developed by incorporating generic industry data (through 1996) into plant-specific SPAR (Revision 3i) (Ref. 8) models.

Three initiator/initiator groups (General Transient, Loss of Feedwater, Loss of Heat Sink) meeting the criteria were selected as candidate initiating event RBPIs. The candidate initiating event RBPIs along with representative thresholds are shown in Table 3.1.1-1. Threshold values were calculated using SPAR Revision 3 logic models. There are two thresholds indicated at the green/white interface. The 95% value represents the 95th percentile of the industry baseline values. The other is based on a ΔCDF equal to 1E-6. This value is more consistent with the current significance determination process (SDP). Appendix A provides details of these calculations. This report recommends the use of the ΔCDF method for determination of the green/white interface, the rationale for which is contained in Appendix A. There are three RBPIs for each plant for the initiating events cornerstone. Detailed plant-specific threshold information for all 23 plants evaluated in this phase is contained in Appendix A.

Table 3.1.1-1 Initiating Event RBPIs

RBPIs & Example Thresholds for BWR 3/4 Plant 18					
Initiator RBPI	Baseline Frequency (NUREG/CR-5750)	Green/White 95th%ile	Green/White ΔCDF=1E-6/yr[a]	White/Yellow ΔCDF=1E-5/yr[a]	Yellow/Red ΔCDF=1E-4/yr[a]
General Transient (GT)	1.3 / year[a]	2.2 / year	2.0 / year[a]	7.9 / year[a]	67 / year[a]
Loss of Feedwater (LOFW)	6.8E-2 / year[a]	2.0E-1 / year	3.0E-1 / year[a]	2.5 / year[a]	24 / year[a]
Loss of Heat Sink (LOHS)	2.3E-1 / year[a]	3.1E-1 / year	4.1E-1 / year[a]	3.4 / year[a]	33 / year[a]
RBPIs & Example Thresholds for WE 4-Lp Plant 22					
Initiator RBPI	Baseline Frequency (NUREG/CR-5750)	Green/White 95th%ile	Green/White ΔCDF=1E-6/yr[a]	White/Yellow ΔCDF=1E-5/yr[a]	Yellow/Red ΔCDF=1E-4/yr[a]
General Transient (GT)	1.0 / year[a]	1.8 / year	1.8 / year[a]	8.8 / year[a]	78 / year[a]
Loss of Feedwater (LOFW)	6.8E-2 / year[a]	2.0E-1 / year	8.0E-1 / year[a]	7.2 / year[a]	74 / year[a]
Loss of Heat Sink (LOHS)	9.6E-2 / year[a]	2.6E-1 / year	2.4E-1 / year[a]	1.5 / year[a]	15 / year[a]

a. Year refers to a calendar year assumed to include 7000 critical hours.

3.1.1.2 Industry-Wide Trending

The RBPI development program also provides industry-wide trending of the initiating events that are RBPIs as well as initiating events that are not possible to trend on a plant-specific basis. Since more data are available at the industry level, trends emerging at the industry level may be apparent before plant-specific changes can be determined. To be selected for trending, the

candidate initiators must be risk-significant (i.e., contribute >1% to industry-wide CDF) and have at least one occurrence since 1987 as recorded in NUREG/CR-5750.

The loss of offsite power (LOOP) initiator is an example of a performance element that is difficult to trend at a plant-specific level yet can be trended at the industry level. The IPE results indicate that LOOP is a dominant contributor to risk at U.S. nuclear power plants; however, plant-specific performance indicators are not practical because of the excessive period required to monitor this initiator.

Thirteen initiating event types/groups meet these conditions and are identified as candidates for industry-wide trending. These initiating event types/groups and their respective NUREG/CR-5750 category are listed below:

1. General Transients (Q)
2. Loss of Feedwater Initiators (P1)
3. Loss of Heat Sink Initiators (L)
4. Loss of Offsite Power Events (B1)
5. Steam Generator Tube Rupture (F1)
6. Small/Very Small LOCA (G1, G3)
7. Stuck Open Safety / Relief Valve - BWR (G2)
8. Loss of Vital AC Bus (C1, C2)
9. Loss of Vital DC Bus (C3)
10. Loss of Instrument/Control Air - BWR (D1)
11. Loss of Instrument/Control Air - PWR (D1)
12. Internal Flood (J1)
13. Initiators Evaluated as Accident Sequence Precursors (ASP)

The process and rationale applied to the selection of these initiator types/groups is outlined in more detail in Appendix A. An example plot of LOOP initiating events during power operation is presented below in Figure 3.1.1-1. General transients, loss of feedwater, and loss of heat sink are trended in Table 5.3-6 of this report. Trends associated with the other initiating events are shown in Appendix A.

3.1.1.3 Inspection Areas Covered by New RBPIs

The RBPIs developed in this report for the initiating events cornerstone were compared with the performance indicators in the ROP to identify those RBPIs that are not currently in the ROP. The inspection areas that could be impacted by the new initiating event RBPIs were then determined. The results are summarized in Table 3.1.1-2.

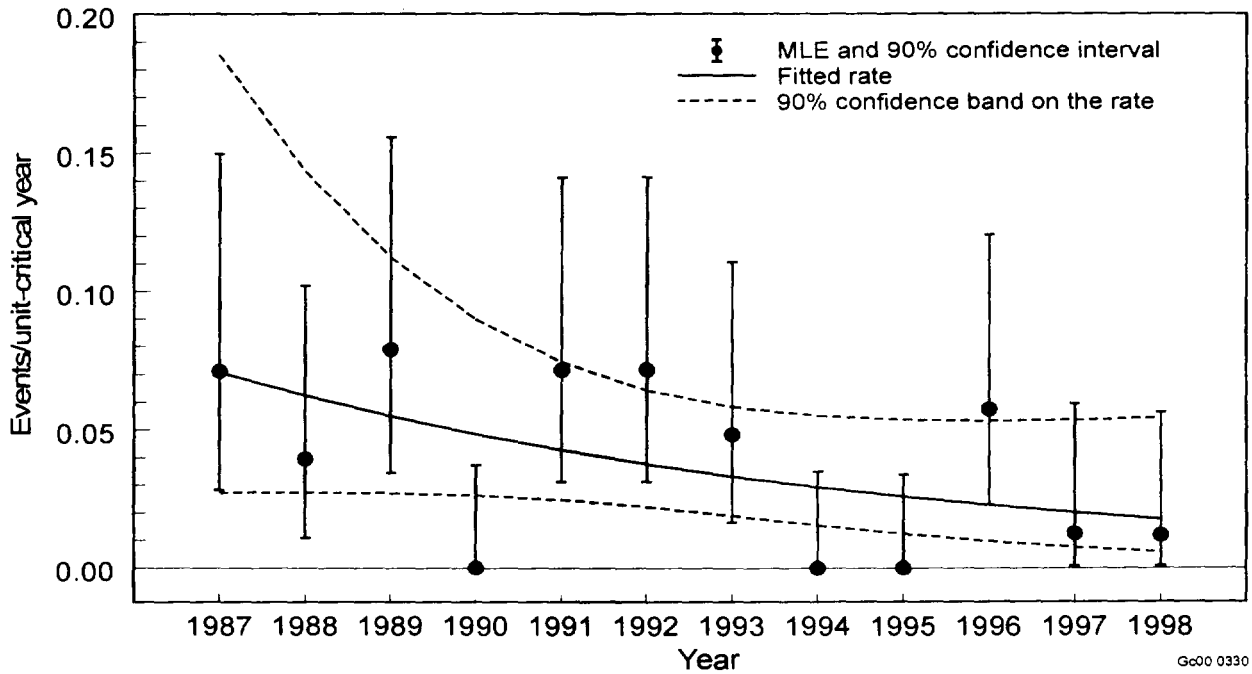


Figure 3.1.1-1 Time-dependent Trending of Loss of Offsite Power Initiating Events

Table 3.1.1-2 Summary of Inspection Areas Impacted by New RBPIs for Initiating Events Cornerstone

RBPI	Attribute	Inspection Area
- General Transient - LOFW - LOHS	- Equipment Performance	71111.12, Maintenance Rule Implementation 71111.08, Inservice Inspection Activities 71152, Identification and Resolution of Problems
	- Human Performance	71111.14, Personnel Performance During Non-routine Evolutions

3.1.2 Mitigating Systems Cornerstone

This section discusses development of RBPIs that address the mitigating systems cornerstone for full power, internal events. External events and non-power modes are addressed in other sections.

3.1.2.1 RBPIs

Risk-significance of mitigating systems was determined through analysis of Revision 3i SPAR models supplemented by quantification results found in the Individual Plant Examination (IPE) submittals and the associated IPE Database (Ref. 6). Specific equipment (i.e., mitigating systems and component classes) was identified as risk-significant based on combinations of importance measure values calculated from these sources. Plant groupings were also identified in a manner to group similar plants so that a given set of RBPIs apply to the entire group based on common sets of risk-significant systems. Due to the limited number of plants for which SPAR Revision 3i

models exist, two distinct plant groups were used (BWR and PWR). Additional plant groups may be developed as more SPAR Revision 3i models are available.

In addition to being risk-significant, candidate mitigating system RBPIs must be capable of detecting performance changes in a timely manner. The associated monitoring period must be long enough to reduce the probabilities of false negatives and false positives to acceptable levels, but no longer. Appendices E and F document the statistical analyses and results, including monitoring periods, of these analyses. Finally, the impacts of changes in mitigating system performance must be readily quantifiable. Plant-specific SPAR (Revision 3i) models, baselined to 1996 performance, were used to quantify the impact of these changes and to calculate corresponding threshold values.

Once risk-significant mitigating systems were identified, elements within those systems amenable to performance monitoring were selected. Two distinct elements of equipment performance, unreliability and unavailability, were selected to be monitored as RBPIs. In the RBPI development, the term unavailability is defined as the ratio of time when the component, train, or system was incapable of meeting its risk-significant safety function divided by the total time that ability to perform the risk-significant function could be needed. The term unreliability is defined as the probability that the component, train, or system would fail to perform its risk- significant safety function (fail to start or fail to run/operate) given that it was available to do so. These elements are compatible with divisions identified in SECY 99-007 and the Maintenance Rule (10 CFR 50.65 (Ref. 11) and Reg. Guide 1.160 (Ref. 12)). These elements can be applied at any of several levels (i.e., system, train, component). The train level was determined to be the best choice and the rationale for selecting this level of monitoring is detailed in Appendix A.

The evaluation of risk-significance also identified several component classes that were important. These were chosen because they can provide plant-wide performance attributes that would potentially reflect performance changes due to "cross-cutting" issues before individual system or train indicators. Unreliability was selected to be the RBPI for each of these component classes. Unavailability was not considered due to the fact that it is normally evaluated and reported at the train level and not at a component level.

Mitigating systems and component classes meeting the criteria were selected as candidate mitigating system to be monitored with RBPIs. Thirteen mitigating system/component class RBPIs were identified at each BWR plant (five in current ROP). For PWR plants, eighteen mitigating system/component class RBPIs were identified (four in current ROP). The candidate mitigating systems and component classes are identified in Table 3.1.2-1. Examples of plant-specific thresholds are identified for two plants in Tables 3.1.2-2 and 3.1.2-3. Detailed plant-specific threshold information for all 23 plants evaluated in this phase is contained in Appendix A.

The analysis of mitigating system performance also relies on several data sources. The primary data sources used in the selection of, and their contribution to, the analysis of mitigating system RBPIs are described below:

- **System Reliability Studies** (Refs. 13-18) contain failure data for several risk-significant mitigating systems. The generic data from these studies were incorporated into the SPAR models as part of the process of establishing plant-specific 'baseline' models and associated core damage frequencies. The data currently reflected in SPAR models were derived from the original system studies; these are currently being updated. In the statistical analysis, false-positive/false-negative evaluations did not consider model uncertainty associated with the SPAR models. The model uncertainty will be addressed as part of the SPAR model verification.
- **The Reliability and Availability Database System (RADS)** (Ref. 19) will provide reliability and availability data and parameter estimation capability for use in periodic evaluations of mitigating system performance. It imports data from INPO's EPIX database (Ref. 20) as well as other established sources such as LERs and MORs.

Table 3.1.2-1 Candidate Mitigating System RBPIs

BWR RBPI SYSTEMS	RBPI Parameter and Level
Emergency AC Power (EPS)	Unreliability and unavailability at the train level.
High Pressure Coolant Injection Systems • High Pressure Coolant Injection (HPCI) • High Pressure Core Spray (HPCS)	Unreliability and unavailability at the train level.
High Pressure Heat Removal Systems • Isolation Condenser (IC) • Reactor Core Isolation Cooling (RCIC)	Unreliability and unavailability at the train level.
Residual Heat Removal (SPC, RHR)	Unreliability and unavailability at the train level.
Service Water (SWS)	Unreliability and unavailability at the train level.
PWR RBPI SYSTEMS	
Auxiliary Feedwater (AFW/EFW) • Motor-driven Pump Train • Turbine-driven Pump Train	 Unreliability and unavailability at the train level. Unreliability and unavailability at the train level.
Component Cooling Water (CCW)	Unreliability and unavailability at the train level.
Emergency AC Power (EPS)	Unreliability and unavailability at the train level.
High Pressure Injection (HPI)	Unreliability and unavailability at the train level.
Power Operated Relief Valve (PORV)	Unreliability at the system level.
Residual/Decay Heat Removal (RHR)	Unreliability and unavailability at the train level.
Service Water (SWS)	Unreliability and unavailability at the train level.
COMPONENT CLASSES (all plants)	
Air-Operated Valves (AOVs)	Unreliability at the component level.
Motor-Operated Valves (MOVs)	Unreliability at the component level.
Motor-Driven Pumps (MDPs)	Unreliability at the component level.

Table 3.1.2-2 BWR Mitigating System RBPIs

RBPIs & Example Thresholds for BWR 3/4 Plant 18					
Mitigating System	Baseline Train Unavailability or Unreliability	Green/White 95th %ile	Green/White ΔCDF =1E-6	White/Yellow ΔCDF =1E-5	Yellow/Red ΔCDF =1E-4
Emergency AC Power	(Unreliability) 4.0E-2	9.9E-2	4.2E-2	5.8E-2	1.5E-1
	(Unavailability) 9.7E-3	1.9E-2	1.4E-2	4.9E-2	3.9E-1
Reactor Core Isolation Cooling	(Unreliability) 7.9E-2	1.7E-1	9.1E-2	2.0E-1	Not Reached.
	(Unavailability) 1.3E-2	4.0E-2	2.8E-2	1.7E-1	Not Reached.
Essential Service Water	(Unreliability) 2.5E-2	8.0E-2	2.7E-2	4.2E-2	1.3E-1
	(Standby Train Unavail.) 1.9E-2	5.4E-2	2.2E-2	5.6E-2	3.9E-1
HPCI	(Unreliability) 2.4E-1	4.3E-1	2.6E-1	4.6E-1	Not Reached.
	(Unavailability) 9.7E-3	3.8E-2	8.2E-2	7.3E-1	Not Reached.
Residual Heat Removal	(Unreliability) 8.8E-3	2.3E-2	2.0E-2	6.8E-2	2.2E-1
	(Unavailability) 1.0E-2	2.5E-2	1.4E-1	Not Reached[1]	Not Reached[1]
AOVs	Component Class Unreliability	N/A	Increase 2.2X	Increase 13X	Increase 83X
MOVs	Component Class Unreliability	N/A	Increase 1.7X	Increase 7.0X	Increase 28X
MDPs	Component Class Unreliability	N/A	Increase 1.2X	Increase 5.1X	Increase 28X

Note 1. This threshold can be reached if the T&M outages associated with this system are not confined to TS allowable combinations

Table 3.1.2-3 PWR Mitigating System RBPIs

RBPIs & Example Thresholds for WE 4-Lp Plant 22					
Mitigating System	Baseline Train Unavailability or Unreliability	Green/White 95th %ile	Green/White ΔCDF =1E-6	White/Yellow ΔCDF =1E-5	Yellow/Red ΔCDF =1E-4
Auxiliary Feedwater	(MDP Train Unreliability) 8.7E-3	2.1E-2	9.8E-3	1.8E-2	5.4E-2
	(TDP Train Unreliability)1.9E-1	3.4E-1	2.0E-1	2.9E-1	Not Reached
	(MDP Train Unavailability) 1.1E-3	2.5E-3	3.7E-3	2.8E-2	2.5E-1
	(TDP Train Unavailability) 4.6E-3	1.8E-2	2.1E-2	1.7E-1	Not Reached
Component Cooling Water	(Unreliability) 1.6E-2	4.7E-2	2.0E-1	6.5E-1	Not Reached
	(Standby Train Unavailability)	4.4E-2	7.8E-1	Not Reached	Not Reached
Emergency AC Power	(Unreliability) 4.2E-2	1.0E-1	4.3E-2	5.5E-2	1.3E-1
	(Unavailability) 9.7E-3	1.9E-2	1.3E-2	3.9E-2	3.0E-1
High Pressure Injection (Includes CVC trains)	(SI Unreliability) 9.7E-3	2.1E-2	8.8E-1	Not Reached	Not Reached
	(SI Unavailability) 4.2E-3	1.6E-2	Not Reached[1]	Not Reached	Not Reached
	(CVC Unreliability) 5.9E-2	1.9E-1	4.3E-1	Not Reached	Not Reached
	(CVC Standby Train Unav) 5.4E-2	1.7E-1	Not Reached[1]	Not Reached	Not Reached
Power Operated Relief Valves	(System Unreliability) 3.2E-2	6.8E-2	5.7E-2	2.6E-1	Not Reached
Residual/Decay Heat Removal	(Unreliability) 1.7E-2	3.8E-2	3.8E-2	1.3E-1	4.7E-1
	(Unavailability) 7.3E-3	2.4E-2	9.3E-2	8.8E-1	Not Reached[1]
Service Water	(Unreliability) 3.2E-2	9.4E-2	1.3E-1	2.1E-1	3.2E-1
	(Standby Train Unav) 2.7E-2	9.0E-2	Not Reached[1]	Not Reached	Not Reached
AOVs	Component Class Unreliability	N/A	Increase 2.2X	Increase 13X	Increase 106X

Table 3.1.2-3 (Continued)

RBPIs & Example Thresholds for WE 4-Lp Plant 22					
Mitigating System	Baseline Train Unavailability or Unreliability	Green/White 95th %ile	Green/White ΔCDF =1E-6	White/Yellow ΔCDF =1E-5	Yellow/Red ΔCDF =1E-4
MOVs	Component Class Unreliability	N/A	Increase 2.4X	Increase 11X	Increase 39X
MDPs	Component Class Unreliability	N/A	Increase 1.2X	Increase 3.2X	Increase 16X

Note 1: This threshold can be reached if the T&M outages associated with this system are not confined to TS allowable combinations.

The risk significance of specific performance degradations varies from plant to plant as a result of factors such as variation in functional redundancy from plant to plant. As a result, some thresholds are not reached at a specific plant because those systems, trains, or components are less risk-significant at that plant, even though they may be more risk-significant at other plants.

3.1.2.2 Industry-Wide Trending

In addition to providing plant-specific information, the RBPI development program provides industry-wide trending, including trending on risk-significant performance elements that are not possible to trend on a plant-specific basis. Since more data are available at the industry level, trends emerging at the industry level may be apparent before plant-specific changes can be determined.

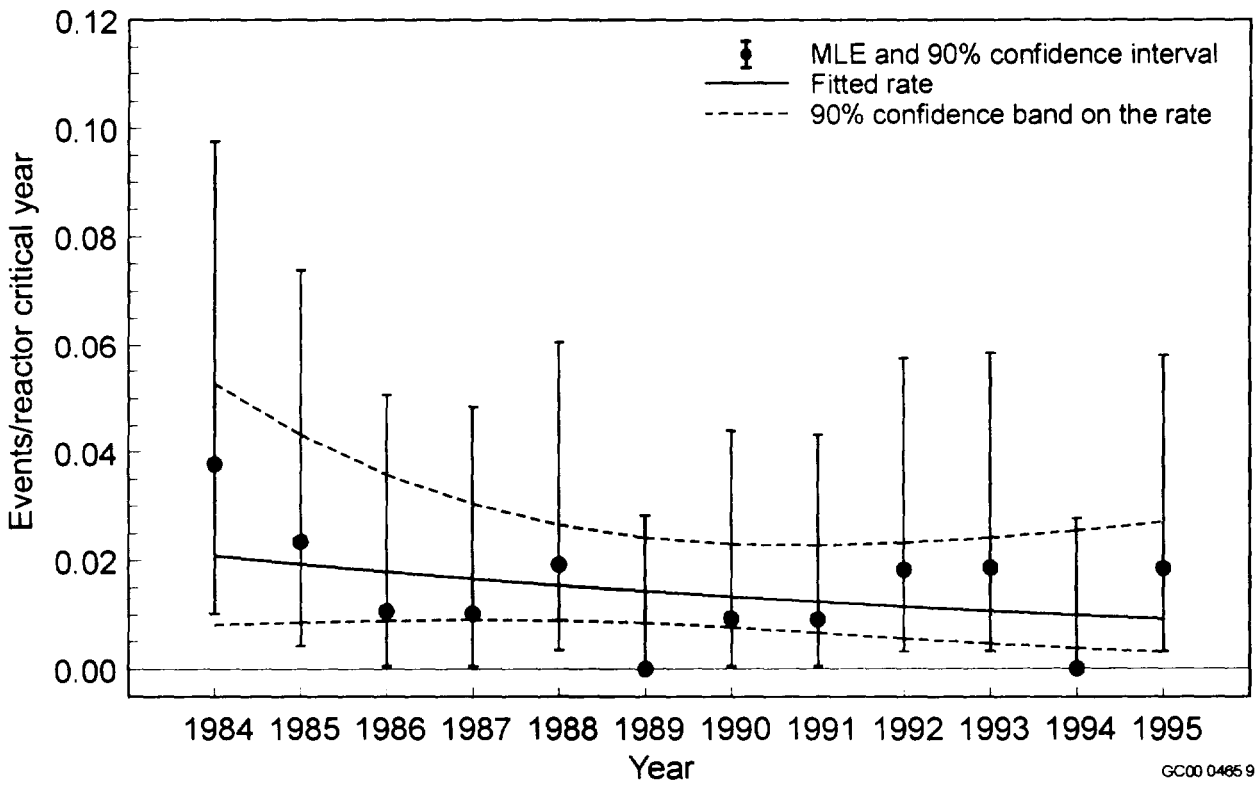


Figure 3.1.2-1 Time-dependent Trending of Emergency Diesel Generator Common Cause Failure Events

Candidates for industry-wide trending must be risk-significant and have at least one occurrence since 1987. In addition to the RBPIs identified in Table 3.1.2-1, three mitigating systems or performance elements meet these conditions and are identified as candidates for industry-wide performance trending. Mitigating systems to be trended are:

- RBPIs from Table 3.1.2-1
- Common Cause Failure Events for Auxiliary Feedwater Pumps
- Common Cause Failure Events for Emergency Diesel Generators
- Common Cause Failure Events for all safety related systems

The process and rationale concerning the selection of the specific mitigating systems and performance elements is outlined in more detail in Appendix A.

3.1.2.3 Inspection Areas Covered by New RBPIs

The RBPIs developed in this report for the mitigating systems cornerstone were compared with the performance indicators in the ROP to identify those RBPIs that are not currently in the ROP. The inspection areas that could be impacted by the new mitigating system RBPIs were then determined. The results are summarized in Table 3.1.2-4.

Table 3.1.2-4 Summary of Inspection Areas Impacted by New RBPIs for Mitigating Systems Cornerstone

RBPI	Attribute	Inspection Area
Full Power:		
Mitigating Systems (UR)	Equipment Performance	71111.04, Equipment Alignment 71111.12, Maintenance Rule Implementation 71111.15, Operability Evaluations 71111.22, Surveillance Testing 71152, Identification and Resolution of Problems
Mitigating Systems (UA)	Equipment Performance	71111.12, Maintenance Rule Implementation
	Human Performance (Pre-Event)	71111.14, Personnel Performance During Nonroutine Evolutions 71152, Identification and Resolution of Problems
	Configuration Control	71111.04, Equipment Alignment 71111.12, Maintenance Rule Implementation 71111.13, Maintenance Risk Assessments and Emergent Work Evaluation 71111.23, Temporary Plant Modifications 71152, Identification and Resolution of Problems

3.1.3 Barrier Integrity Cornerstone: Containment Performance

This section presents RBPI development results that address the containment integrity portion of the barrier integrity cornerstone for full power, internal events. The scope of the structures, systems, and components related to the containment barrier includes the primary and secondary containment buildings (including personnel airlocks and equipment hatches), primary containment penetrations and associated isolation systems, and risk-significant systems and components necessary for containment heat removal, pressure control, and degraded core hydrogen control.

RBPI development for containment integrity uses large, early release frequency (LERF) as the metric for determining the risk significance of changes in containment performance, conditional on CDF performance at the baseline value. Development of the SDP (Ref. 21) has led to classification of kinds of performance elements according to whether they affect both LERF and CDF (Type A), only LERF (Type B), or only CDF. In the terminology of the SDP, the present work on containment has examined Type B findings. Some containment-related features may affect CDF, but assessment of such Type A performance areas is not currently practical because integrated CDF/LERF models are not currently available.

The following factors influence early failure of the containment barrier (Ref. 21). However, most of these factors affecting LERF involve mechanistic phenomena that are not amenable to RBPI development.

- Performance in containment isolation;
- Direct impingement of core debris on important containment elements (Mark I BWRs: liner, structural supports) (affected by presence of water on floor, determined by drywell spray performance);
- Overpressure due to excessive heat loads from ATWS sequences;
- RCS pressure at vessel failure;
- Penetration seal integrity;
- Suppression Pool Bypass;
- Ice Condenser Function.

Many containment barrier mitigation systems affect late containment failure. Treatment of non-LERF risk scenarios is a topic for future discussion with stakeholders (Section 6). The following factors influence late failure of the Containment Barrier (Ref. 3):

- Overpressurization due to loss of containment heat removal (sprays, heat exchangers, ...);
- Overpressurization due to core-concrete interactions;
- Venting.

The following potential containment RBPIs have been identified. Each potential indicator is applicable to specific containment designs:

- Unreliability / unavailability of drywell spray (Mark I BWRs)
- Unreliability / unavailability of large containment isolation valves (PWRs, Mark III BWRs) (valves isolating paths that connect the containment atmosphere directly to the outside atmosphere).

However, for these potential RBPIs, models and data are not available for formulating baseline values and quantifying thresholds. LERF models for setting thresholds are not available for all containment types. In addition, the available models are not compatible with the SPAR Revision 3 models for assessing CDF impacts which are the inputs to the LERF models. Therefore, no containment RBPIs are provided.

Moreover, drywell spray is closely identified with Type A functionality (low pressure injection and suppression pool cooling), so the RBPI and associated thresholds need to be defined within an integrated CDF/LERF perspective (see Section 6.1). Although containment heat removal is not generally an important contributor to LERF, in some PWRs it has a role in core damage prevention and in prevention of large early releases. This, too, is a Type A function, and needs to be examined within an integrated CDF/LERF perspective.

When better models and data are obtained, RBPI development will be completed for these potential RBPIs. In addition, RBPIs previously analyzed under the initiating events and mitigating systems cornerstones will also be re-examined to determine whether LERF considerations alter the findings of Sections 3.1.1 and 3.1.2.

These RBPIs are not among the performance indicators in the ROP. The inspection areas that could be impacted by these RBPIs were determined. The results are summarized in Table 3.1.3-1.

Table 3.1.3-1 Summary of Inspection Areas Impacted by Potential RBPIs for Containment Portion of Barrier Integrity Cornerstone

RBPI	Attribute	Inspection Area
CIV (UR&UA) and Drywell Spray (UR&UA)	Design Control	71111.02, Evaluation of Changes, Tests, or Experiments 71111.17, Permanent Plant Modifications 71111.23, Temporary Plant Modifications 71152, Identification and Resolution of Problems
	Barrier Performance	71111.12, Maintenance Rule Implementation 71111.15, Operability Evaluations 71111.20, Refueling and Outage Activities 71111.22, Surveillance Testing

3.2 Results for Shutdown

The results of the RBPI development process are qualitatively different from full power results for the following reasons.

- Shutdown occupies a much smaller fraction of the year than does full power operation, so shutdown-specific reliability, availability, and frequency metrics accumulate failure data much more slowly than do comparable metrics for full power.

- Configuration management is a more significant factor in shutdown risk than in full power risk.

- Relatively few models for shutdown CDF and LERF are available relative to full power. Therefore, the results presented below are based on risk insights from the representative models available (Refs. 22-25).

3.2.1 Initiating Events Cornerstone

No initiating events accumulate statistics quickly enough to support timely detection of declining performance. Therefore, there are no plant-specific initiating event RBPIs for shutdown operations.

However, industry trending of the following events is warranted based on existing shutdown risk studies:

- Loss of offsite power during shutdown
- Loss of operating train of RHR due either to local fault or loss of support systems
- Loss or diversion of inventory leading to loss of RHR
- Loss of level control when entering mid-loop operation leading to loss of RHR (PWR only)

3.2.2 Mitigating Systems Cornerstone

Most licensees manage shutdown risk in accordance with NUMARC 91-06, "Guidelines for Industry Actions to Assess Shutdown Management" (Ref. 26). They manage defense in depth, through configuration control, for key safety functions (decay heat removal, inventory control, electrical power availability, reactivity control and containment). The proposed RBPIs would directly measure licensee performance in configuration control by measuring the time the plant spent in risk-significant configurations (combinations of equipment unavailabilities and plant conditions with respect to decay heat and RCS inventory).

The proposed RBPIs reflect excess time spent in risk-significant configurations during the observation period. Four categories of configurations are defined: Low, Medium, Early Reduced-Inventory (vented), and High. These are defined in terms of conditional core damage frequency (CCDF) and, in the case of "Early Reduced-Inventory," operational conditions. The baseline for each category (the typical time spent in configurations associated with that category) has been determined by examination of representative outage profiles, as discussed in Appendix B. Spending time over and above the baseline duration in configurations having relatively high CCDF results in core damage probability above the baseline value. The RBPI thresholds follow from the relationship:

Threshold Δt = ΔCDP threshold / Configuration CCDF,

where the ΔCDP thresholds are the standard G/W, W/Y, and Y/R thresholds (1E-6, 1E-5, and 1E-4), and the Configuration CCDF corresponds to the configuration's risk category. As explained in Appendix B, all realizable configurations are classified into configuration categories, corresponding to CCDF ~ 1E-6/day (Low), CCDF ~ 1E-5/day (Medium), and CCDF ~ 1E-4/day (High and Early Reduced-Inventory (vented)). Then, for example, since the "Medium" risk configurations are associated with a CCDF of approximately 1E-5 per day, the G/W, W/Y, and Y/R thresholds for "Medium" are, respectively, .1 day above baseline, 1 day above baseline, and 10 days above baseline. The baselines and thresholds for all three categories are shown in Tables 3.2.2-1 and 3.2.2-2, rounded in some cases to an even number of days or hours for simplicity.

Table 3.2.2-1 Baseline and Thresholds for Time in Risk-Significant Configurations Indicators - PWRs

Configuration Category	Baseline	G/W Threshold	W/Y Threshold	Y/R Threshold
Low	20 days	21 days	30 days	120 days
Medium	2 days	2 days + .08 day (2 hrs)	3 days	12 days
Early Reduced-Inventory (vented)[a]	1 day	1 day	1.08 days (1 day + 2 hrs)	2 days
High	0	0	.08 day (2 hrs)	1 day

a. This configuration category assumes that measures are taken to compensate for the risk associated with early reduced-inventory operations, as explained in Appendix B. If compensatory measures are not taken, these configurations are assigned to the "High" configuration category.

Table 3.2.2-2 Baseline and Thresholds for Time in Risk-Significant Configurations Indicators - BWRs

Configuration Category	Baseline	G/W Threshold	W/Y Threshold	Y/R Threshold
Low	2 days	3 days	12 days	102 days
Medium	0.20 day (5 hrs)	0.29 day (7 hrs)	1 day	10 days
High	0	0	.08 day (2 hrs)	1 day

The configurations are defined in Tables 3.2.2-3 (PWRs) and 3.2.2-4 (BWRs). As explained in Appendix B, the risk associated with these configurations has been assessed based on risk insights from representative models. Illustrative results are provided for a representative PWR (Ref. 23) and a representative BWR (Ref. 25). Risk-significant configurations are characterized by reactor coolant system (RCS) conditions, time after shutdown, and a given set of systems or trains being unavailable, either for maintenance or as a result of equipment failure. The RBPI for each configuration category is the total time spent in configurations assigned to that category during the one-year observation period. A blank entry in a cell means that the indicated configuration in that plant operating state (POS) has a minimal conditional core damage frequency (CCDF) and time spent in that configuration need not be counted. Shaded cells indicate combinations of POS and configuration that are not analyzed, either because the configuration violates the POS definition, or the systems involved play no role in the POS. The intent is that each credible plant configuration correspond uniquely to one cell of that plant type's table, and that conditional core damage frequency (and configuration category) be implied by that cell's characteristics.

Table 3.2.2-3 PWR Shutdown Configurations Risk Classification (Based on a Generic Westinghouse 4-Loop Shutdown PRA Model)

POS				No Maintenance Unavailability	Backup RHR Train Unavail-able	Emergency AC Trains Unavailable			Support Cooling Trains Unavailable		Secondary Cooling Trains Unavailable			Emergency Injection Trains Unavailable			Other Trains Unavailable			
Group	Mode	RCS Boundary	Days After Shutdown		RHR	EDG	EDG(2)	One Safety-Related AC Bus	One train of ESW	One train of CCW	One train of AFW	All AFW	All SGs	RWST	SI(2)[a]	Both Sumps	PORV(2)	SG/ PORV	SG/ RWST	SG/ and Both Sumps
Low Inventory Configurations Occurring Very Early (within the first 5 days) in an Outage																				
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	Intact or isolatable	2	Low	Med	Low	Low	Low	Low	Med	High	High	High	Low	Low	High	Low	High	High	High
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	< 5	ERI-V[b]	ERI-V[b]									ERI-V[b]						
Representative Configurations Occurring in a Typical Outage																				
Pressurized Cooldown	Mode 4 Hot shutdown	Intact	4			Low	Med	Low	Low					Med		Low				
Depressurized RHR Cooldown with Normal Inventory	Mode 5 Cold shutdown	Intact	8				Low	Low			Low	Low	Low	Low		Low		High	High	High
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	Intact or isolatable	12		Low		Low	Low	Low	Low	Med	Med	Med	Low		Low	Low	High	High	High
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	7	Med	Med	Med	Med	High	Med	Med				High	Med	Med				
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	13	Med	Med	Med	Med	High	Med	Med				High	Med	Med				
Refueling Cavity Filled	Mode 6	vented	14													Med				
Low Inventory Configurations Occurring Late in a Typical Outage																				
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	24			Low	Med	Low	Low	Low				Med	Low	Low				

Notes: Shaded cells indicate combinations of POS and configuration that are not analyzed, either because the configuration violates the POS definition, or the systems involved play no role in the POS.

Blank cells represent configurations whose CCDF < 1.0E-6 per day.

a. In this configuration it is assumed that a makeup pump is available.

b. This configuration category assumes that measures are taken to compensate for the risk associated with early reduced-inventory operations, as explained in Appendix B. If compensatory measures are not taken, these configurations are assigned to the "High" configuration category.

Key:

Low	Low Risk Configuration	ERI-V	Early Reduced-Inventory (vented)	RWST	Refueling water storage tank	AFW	Auxiliary feed water
Med	Medium Risk Configuration	RHR	Residual heat removal	EDG	Emergency diesel generator	SI	Safety injection
High	High Risk Configuration	CCW	Component cooling water	ESW	Emergency service water	PORV	Power-operated relief valve

Table 3.2.2-4 BWR Shutdown Configurations Risk Classification (Based on NUREG/CR-6166 Results)

POS			No Maintenance Unavailability	Emergency AC/DC Trains Unavailable					Support Cooling Trains Unavailable			Emergency Cooling Trains Unavailable				Other Trains Unavailable			
Group	Mode	RCS Boundary		EDG I or II	4 EDG I and II	EDG I and III	One BAT division	Two BAT divisions	SSW A	SSW C	SSW A and C	HPCS	LPCS and HPCS	SP empty	SRVs all	SSW A and HPCS	SSW A and CDS	RHR A and all SRVs	SDC A and SP
POS 4	Hot shutdown	Intact		Low	Med	Low		High		Low	Med	Low	Low	Med	Med	Med		High	Med
POS 5	Cold shutdown	Vessel head on		Low	Med	Low	Low	High	Low	Low	Med	Low	Low	High	High	Med	Low	High	High
POS 6	Refueling	Vessel head off (level raised to steam line)												Med					Med
POS 7	Refueling	Upper pool filled									Low			Low		Low			Low

Note: Blank cells indicate combinations of POS and configuration that are not analyzed, either because the configuration violates the POS definition, or the systems involved play no role in the POS.

Key:

Low	Low Risk Configuration
Med	Medium Risk Configuration
High	High Risk Configuration
EDG	Emergency diesel generator
BAT	Battery
SSW	Standby service water
HPCS	High pressure core spray
LPCS	Low pressure core spray
SP	Suppression pool
SRV	Safety relief valve
CDS	Condensate system
SDC	Shutdown cooling

A significant fraction of PWR shutdown risk is associated with certain reduced-inventory operations. Because of high decay heat, Early Reduced-Inventory operations (reduced-inventory operations conducted less than 5 days after shutdown with the RCS vented) have CCDF that is comparable to High CCDF configurations unless compensatory measures are taken. They are the only configurations potentially having "high" CCDF for which a non-zero baseline is assigned. Reduced-inventory operations conducted later in the shutdown may have "medium" CCDF, even if standby systems are nominally available. The baseline for PWRs reflects the need for PWRs to spend some time in reduced-inventory operations (including some time early in the shutdown). The balance of nominal risk from shutdown operation in PWRs derives from lower-risk configurations. The threshold assignments follow directly from the calculated CCDF associated with the indicated configurations. BWR shutdown CDF is generally lower than PWR shutdown CDF; therefore, the baseline values are different.

The RBPIs developed above for shutdown are not currently in the ROP. The inspection areas that could be impacted by the new initiating event RBPIs were determined. The results are summarized below in Table 3.2.2-5.

Table 3.2.2-5 Summary of Inspection Areas Impacted by Potential Shutdown RBPIs for Mitigating Systems Cornerstone

RBPI	Attribute	Inspection Area
Time in High/Medium/Low Risk-Sig. Configurations	Configuration Control	71111.04, Equipment Alignment 71111.13, Maintenance Risk Assessments and Emergent Work Evaluation 71111.20, Refueling and Outage Activities 71111.23, Temporary Plant Modifications

3.2.3 Barrier Integrity Cornerstone: Containment Integrity at Shutdown

Containment performance at shutdown is affected by one issue that does not enter into consideration of full-power RBPIs, namely, that containment may be open during shutdown, and needs to be reclosed expeditiously under certain conditions.

PWRs:

Analysis performed in NUREG-1449 (Ref. 27) shows that timely closure of PWR containment prevents large early release in core damage scenarios initiated at shutdown.

BWRs with Mark-I and Mark-II Containments:

Analysis performed in NUREG-1449 shows that BWR secondary containment alone is not expected to prevent large early release in core damage scenarios. This means that a change in BWR Mark-I and -II shutdown CDF equates to a change in LERF if primary containment is open. This circumstance is offset by generally lower shutdown CDFs for BWRs.

BWRs with Mark-III Containments:

> Analysis performed in NUREG/CR-6143 (Ref. 24) shows that timely closure of these BWR containments prevents large early release in core damage scenarios initiated at shutdown.

This suggests possible containment RBPIs analogous to the possible time-in-risk-significant-configurations RBPIs defined above in 3.2.2. These would be defined for the risk-significant configuration categories introduced for the RBPIs defined for mitigating systems.

Potential RBPI for PWRs and Mark-III BWRs:

> Time spent in risk-significant configurations with containment not closed and preparations for timely closure not complete (timely: before boiling, if the RCS is vented).

Potential RBPI for Mark-I and Mark-II BWRs:

> Time spent in risk-significant configurations with primary containment not intact and not capable of timely closure.

An increase in time spent in a particular configuration with containment not capable of timely closure implies an increase in LERF that is equal to the increase in CDF associated with that configuration. Configurations with negligible conditional CDF are therefore associated with negligible changes in LERF, but risk-significant configurations contribute directly and significantly to LERF if containment is open and timely closure is not provided for. Configurations in which only a short time is available to respond to initiating events are also generally those in which only a short time is available to effect containment closure.

Data and models are not presently available to quantify these indicators. Therefore, neither baselines nor thresholds can be quantified. Quantification of these indicators would require, in addition to the time spent in risk-significant configurations, the time spent with containment in the indicated state during those risk-significant configurations.

3.3 Results for External Events (Fire)

This section provides preliminary RBPI results for fire. Other external events, such as seismic and flood, are not included in the scope of Phase 1 RBPI development.

The results from the Individual Plant Examinations for External Events (IPEEE's) were used to assess the risk-significant performance attributes in accordance with the RBPI development process flowchart shown in Figure 2.1. The IPEEE results are not collated in as comprehensive a way as was done for the IPE program. These studies indicate that fire CDF varies significantly among plants. However, fire CDF is generally high enough that some elements of fire scenarios are risk-significant compared to risk associated with full power internal events or shutdown risk.

Elements of fire-initiated core damage sequences include the following:

- occurrence of fire in specific fire area
- failure of detection/suppression (automatic and/ or manual) systems
- fire damage to plant systems/cables in the fire area
- failure of post-fire safe shutdown systems (typically normal mitigation systems that are not affected by the fire scenario, covered in Section 3.1.2)

Fire occurrence, including conditions leading up to the fire, is within the scope of the initiating events cornerstone. The remaining elements are within the scope of the Mitigating Systems cornerstone.

3.3.1 Initiating Events Cornerstone

No RBPIs are identified under the initiating events cornerstone for fire because the occurrence of fire events is too infrequent to support timely quantification of changes in plant-specific fire frequency. Based on an NRC study of fire events from 1986-1994, AEOD/S97-03 (Ref. 28), the fire initiating event frequencies for these areas range from 6.9E-2 to 8.5E-4. These frequencies (once every 14 years or longer on a plant-specific basis) do not allow for timely quantification of changes in the fire frequencies. The risk-significant fire areas vary from plant to plant. However, the following fire areas are the most common among the list of risk-significant fire areas based on the accident sequences identified in the IPEEE for each plant:

- switchgear room
- control room
- cable spreading room
- auxiliary building (PWR)/reactor building (BWR)
- turbine building
- battery room

However, the occurrence rate of fire events in these areas is sufficient for industry-wide trending. The frequencies of occurrence of fire events in the most commonly risk-significant fire areas listed above will be used for industry-wide trending.

3.3.2 Mitigating Systems Cornerstone

The RBPI development identified fire suppression system reliability and availability as potential RBPIs. The risk significance of fire suppression is highly plant-specific and area-specific, but at many plants, the risk significance of fire suppression is such that performance degradation in fire suppression could cause changes in CDF that are significant compared to the performance thresholds. Monitoring of suppression system reliability and availability could provide feasible plant-specific RBPIs. However, generic data are used in many IPEEEs to estimate core damage frequency, and plant-specific data are not presently available to support quantification of this performance area.

The potential RBPIs covering fire suppression system performance are not currently in the ROP. The inspection area that could be impacted by these RBPIs was determined. The result is summarized in Table 3.3.2-1.

Table 3.3.2-1 Summary of Inspection Areas Impacted by Potential Fire RBPIs for Mitigating Systems Cornerstone

RBPI	Attribute	Inspection Area
Fire Suppression System (UR&UA)	Protection Against External Factors	71111.05, Fire Protection

3.3.3 Barrier Integrity Cornerstone: Containment Performance

The IPEEE's typically only provide a qualitative analysis of barrier integrity, with the general conclusion that the results of the IPE analysis are unchanged as a result of the fire scenarios. Consideration of fire does not lead to any risk-significant LERF scenarios whose containment barrier attributes are not already being addressed under the internal events treatment of the containment barrier.

4. ASSESSMENT OF RISK COVERAGE BY RBPIs

The purpose of this section is to show the extent of risk coverage by RBPIs associated with core damage sequences, to show which risk-significant contributors are not covered by RBPIs, and to indicate briefly why these contributors are not covered by RBPIs.

How Coverage Is Assessed

Two approaches to assessment of the extent of RBPI coverage of core damage frequency have been applied.

One approach is based on Risk Achievement Worth (RAW), which measures how quickly CDF increases if element performance degrades. Given the baseline CDF and the RAW associated with a given element, the magnitude of the CDF increment that could be caused by degradation of the element can be determined. This is done for all basic events appearing in the SPAR model, and the extent of RBPI coverage is then assessed for each basic event whose failure could cause a CDF change greater than 1.0E-6. This assessment is closely related to the method for selecting candidate RBPIs in the first place (Section 3).

In addition, an assessment of RBPI coverage of dominant accident sequences (sequences whose frequency contributes most to overall CDF) was performed. Dominant accident sequences are examined to determine which contributors to risk are covered by an RBPI. This is similar to a Fussell-Vesely importance evaluation.

Results of Coverage Assessment

Table 4-1 shows results for two plants, designated BWR 3/4 Plant 18 and Westinghouse four-loop Plant 22 (WE 4-Lp) for the RAW importance-based assessment of coverage, derived from SPAR models for these plants. For those events whose failure could lead to an increase in CDF > 1.0E-6/y, approximately 40% of the events in the SPAR models are part of the RBPIs. The types of elements in the other 60% are indicated in Table 4-1.

Table 4-1 Coverage of Risk Significant Core Damage Elements from SPAR Models

Category	BWR 3/4 Plant 18	WE 4-Lp Plant 22
Total number of SPAR model elements whose failure can result in $\Delta CDF \geq 1E\text{-}6/y$	178	203
- Initiating events	14	14
- Mitigating system elements	164	189
Elements covered by RBPIs		
- Initiating events	3/14 (21%)	3/14 (21%)
- Initiating events covered by trending	3/14 (21%)	4/14 (29%)
- Mitigating system elements	70/164 (43%)	72/189 (38%)

Table 4-1 (Continued)

Category	BWR 3/4 Plant 18	WE 4-Lp Plant 22
Types of elements not explicitly covered by RBPIs	Batteries Check valves Electrical buses Heat exchangers Post-event human errors Reactor protection system Strainers Tanks	Batteries Check valves Electrical buses Heat exchangers Post-event human errors Reactor protection system Strainers Fans

Tables 4-2a and b show RBPI coverage of dominant accident sequences at the initiating event / system level for the same two plants. The tables are derived from the IPE data base results for these plants. Almost all sequences are covered in part by multiple RBPIs. Most of the elements that are not covered are either not amenable to RBPI treatment, or appear in sequences that contribute a relatively small fraction of core damage frequency. Some are normally operating systems credited for plant-specific reasons that do not appear in enough plant PRAs to have justified generically applicable RBPIs.

Figures 4-1a and b show RBPI coverage of initiating events for BWR 3/4 Plant 18 and Westinghouse four-loop Plant 22, based on relative contribution to core damage frequency (full power, internal events), derived from the IPE data base for these plants. Similar results for other plants are provided in Appendix D.

Many initiating events occur too infrequently to permit timely quantification of declining performance, and RBPIs based on frequency of occurrence of individual initiating events in this category are therefore not defined. However, as discussed in Section 3.1.1, initiating events contributing more than 1% on average to industry-wide CDF and which includes one or more occurrences (industry-wide) since 1987 are included in the industry-wide trending.

Elements Not Covered By RBPIs

There were five initiating events from the IPE data base information in Tables 4-2a and b that were not covered by either RBPIs (indicators of event frequency) or trended initiators. Tables 4-2a and b, prepared using the IPE data base format, display ATWS events as if ATWS were an initiator. "ATWS" as such is not covered by an RBPI, but initiating events potentially leading to ATWS are covered as shown. Medium and large LOCA initiators are not covered because of their very low frequencies. Certain support systems whose loss is an initiating event are monitored under the Mitigating Systems cornerstone (service water and component cooling water in PWRs). Although there is no RBPI directly monitoring the frequency of total loss of these systems, the corresponding initiating events are therefore implicitly monitored at a lower level (the train level rather than the system level).

Table 4-2a RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - BWR 3/4 Plant 18 (IPE Data Base Results)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
1	5.28E-07	T-LOOP	AC	EAC			
2	1.60E-07	S1	HUM				
3	2.70E-08	T-LOOP	HP1	HUM	AC		
4	2.21E-08	T-LOOP	AC	EAC			
5	2.05E-08	T-ATWS	RPS	CONDA	HUM		
6	1.80E-08	T-LOOP	HPCI(HPCS)	RCIC	AC	EAC	
7	1.34E-08	T-LOOP	HP1	HUM	AC		
8	1.16E-08	T-RX	ADS	DC			
9	1.10E-08	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
10	8.96E-09	T-LOOP	HP1	LPCI	SPC	AC	
11	8.12E-09	T-RX	DC				
12	7.76E-09	T-ATWS	RPS	LPCI	CS	CONDA	HUM
13	7.59E-09	T-LOOP	SPC	HUM	AC		
14	7.00E-09	T-LOOP	HP1	SPC	HUM	AC	
15	6.90E-09	T-LOOP	HP1	SPC	HUM	AC	
16	6.72E-09	T-LOOP	HP1	HUM	AC		
17	6.13E-09	T-ATWS	RPS	CONDA	HUM		
18	5.83E-09	T-ATWS	RPS	CONDA	HUM		
19	5.77E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
20	5.66E-09	A	LPCI	CS			
21	5.53E-09	T-LOOP	HPCI(HPCS)	RCIC	HUM	AC	
22	5.43E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
23	5.10E-09	T-RX	HPCI(HPCS)	RCIC	HP1	HUM	
24	5.02E-09	S2	HPCI(HPCS)	HUM			
25	4.60E-09	A	SPC	AC			
26	4.46E-09	T-LOOP	HP1	LPCI	SPC	AC	
27	4.44E-09	T-LOOP	LPCI	SPC	HUM	AC	
28	3.88E-09	T-ATWS	RPS	HP1	CONDA	HUM	
29	3.83E-09	S1	HPCI(HPCS)	HUM			
30	3.78E-09	T-LOOP	SPC	HUM	AC		
31	3.62E-09	T-ATWS	RPS	HPCI(HPCS)	CONDA	HUM	
32	3.46E-09	T-LOOP	HP1	HUM	AC		
33	3.42E-09	T-LOOP	SPC	HUM	AC		
34	3.38E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HP1	HUM

Table 4-2a (Continued)

		IE RBPI			System RBPI		
		Industry-Wide Trending					
SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
35	3.33E-09	T-LOOP	LPCI	SPC	HUM	AC	
36	3.33E-09	T-LOOP	HP1	HUM	AC		
37	2.86E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
38	2.77E-09	T-LOOP	LPCI	SPC	HUM	AC	
39	2.63E-09	T-LOOP	HPCI(HPCS)	RCIC	HUM	AC	
40	2.57E-09	T-RX	HPCI(HPCS)	RCIC	HUM		
41	2.57E-09	A	SPC				
42	2.42E-09	T-LOOP	HP1	LPCI	SPC	HUM	AC
43	2.40E-09	T-LOOP	HUM	AC			
44	2.26E-09	T-LOOP	HP1	HUM	AC		
45	2.21E-09	T-ATWS	RPS	CONDA	HUM		
46	2.16E-09	S2	HPCI(HPCS)	MFW	HUM		
47	2.15E-09	T-LOOP	HPCI(HPCS)	HP1	AC	EAC	
48	2.10E-09	A	HUM				
49	2.08E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HP1	HUM
50	2.05E-09	T-LOOP	HP1	HUM	AC		
51	1.97E-09	T-LOOP	HP1	LPCI	SPC	AC	
52	1.96E-09	T-LOOP	HP1	LPCI	SPC	AC	
53	1.90E-09	T-LOOP	HUM	AC			
54	1.89E-09	T-LOOP	HP1	SPC	HUM	AC	
55	1.82E-09	T-ATWS	RPS	SLC	CONDA		
56	1.79E-09	T-LOOP	HP1	SPC	AC		
57	1.74E-09	T-ATWS	RPS	MFW	CONDA	HUM	
58	1.72E-09	T-LOOP	HP1	SPC	HUM	AC	
59	1.70E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HUM	
60	1.66E-09	T-LOOP	HP1	LPCI	SPC	HUM	AC
61	1.62E-09	T-ATWS	RPS	RECIRC	CONDA		
62	1.50E-09	T-LOOP	HP1	SPC	HUM	AC	
63	1.43E-09	T-ATWS	RPS	MFW	HUM		
64	1.39E-09	A	HUM				
65	1.38E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HP1	HUM
66	1.33E-09	T-LOOP	HP1	HUM	AC		
67	1.19E-09	T-ATWS	RPS	HUM			
68	1.15E-09	T-LOOP	HP1	LPCI	SPC	VENT	AC
69	1.14E-09	T-LOOP	HUM	AC			

Table 4-2a (Continued)

		IE RBPI Industry-Wide Trending			System RBPI		
SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
70	1.13E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
71	1.13E-09	A	LPCI	CS	DC		
72	1.13E-09	T-LOOP	HP1	HUM	AC		
73	1.12E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
74	1.10E-09	T-LOOP	HP1	SPC	HUM	AC	
75	1.10E-09	T-ATWS	RPS	MFW	HP1	CONDA	HUM
76	1.09E-09	T-LOOP	HP1	HUM	AC		
77	1.05E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HUM	
78	1.03E-09	T-LOOP	HP1	SPC	HUM	AC	
79	1.03E-09	T-ATWS	RPS	HPCI(HPCS)	MFW	CONDA	HUM
80	1.03E-09	T-LOOP	HP1	HUM	AC	NSW	
81	1.02E-09	T-LOOP	HP1	HUM	AC		
82	1.01E-09	T-LOOP	HP1	AC			
83	9.90E-10	T-LOOP	HP1	LPCI	SPC	AC	
84	9.80E-10	T-LOOP	HP1	SPC	AC		
85	9.75E-10	T-LOOP	HP1	LPCI	SPC	AC	
86	9.53E-10	S2	HPCI(HPCS)	MFW	HUM		
87	9.41E-10	T-LOOP	HP1	SPC	DWS	HUM	AC
88	9.41E-10	T-LOOP	HP1	HUM	AC		
89	9.18E-10	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
90	9.15E-10	A	SPC	AC			
91	9.03E-10	T-LOOP	HUM	AC			
92	8.85E-10	T-LOOP	HP1	SPC	DWS	AC	
93	8.62E-10	T-ATWS	RPS	CONDA	HUM		
94	8.50E-10	T-LOOP	HP1	SPC	HUM	AC	
95	8.16E-10	T-LOOP	HP1	LPCI	CS	AC	
96	8.00E-10	T-LOOP	AC	EAC			
97	7.93E-10	T-LOOP	LPCI	CS	HUM	AC	
98	7.88E-10	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
99	7.55E-10	A	SPC				
100	7.28E-10	T-LOOP	HP1	HUM	AC		
101	1.52E-07	REMAINDER					
102		T-IFL					

Table 4-2b RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences WE 4-Lp Plant 22 (IPE Data Base Results)

		IE RBPI Industry-Wide Trending		System RBPI	
SEQ	CDF	INITIATOR		ACCIDENT SEQUENCE FAILURES	
1	2.14E-05	T-CCW	HUM	CCW	
2	1.27E-05	S2	HUM		
3	5.99E-06	T-CCW	HUM	CCW	
4	3.98E-06	T-AC	SDAFW	HVAC1	
5	3.26E-06	S2	HUM		
6	2.88E-06	T-SGTR	SGS	HUM	
7	2.56E-06	T-CCW	HUM		
8	2.38E-06	T-AC	ESW		
9	2.12E-06	T-CCW	HUM	CCW	
10	1.90E-06	T-AC	HUM	HVAC1	
11	1.80E-06	T-AC	ESW		
12	1.77E-06	T-AC	HUM	CCW	
13	1.69E-06	T-CCW	HUM	CCW	
14	1.30E-06	S1	HUM		
15	1.29E-06	T-CCW	HUM	CCW	
16	1.22E-06	T-DC	MDAFW	SDAFW	HUM
17	1.16E-06	T-AC	AC	EAC	
18	1.14E-06	T-CCW	HUM	CCW	
19	1.07E-06	T-IFL	ESW		
20	1.06E-06	T-IFL	ESW		
21	9.84E-07	T-CCW	HUM	CCW	
22	9.59E-07	T-LOOP	AC	ESW	
23	9.51E-07	T-ESW	ESW		
24	8.94E-07	T-AC	AC	EAC	
25	8.61E-07	T-RX	ESW		
26	8.50E-07	S2			
27	8.46E-07	S2			
28	7.78E-07	T-TT	ESW		
29	7.70E-07	S2	HUM		
30	7.37E-07	T-DC	MDAFW	SDAFW	HUM
31	7.19E-07	T-CCW	HUM	CCW	
32	5.96E-07	T-AC	HVAC1		
33	5.95E-07	T-CCW	HUM	CCW	
34	5.93E-07	T-LMFW	ESW		

Table 4-2b (Continued)

IE RBPI
Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
35	5.56E-07	T-AC	CCW				
36	5.42E-07	T-AC	ESW				
37	5.39E-07	T-LOOP	AC	EAC			
38	5.34E-07	T-AC	HUM	CCW			
39	5.13E-07	T-LOOP	AC	EAC			
40	5.10E-07	A	ACC				
41	4.99E-07	T-LOOP	SDAFW	HVAC1			
42	4.85E-07	T-SGTR	LPR	HUM			
43	4.84E-07	T-TT	RPS	PPORV	MDAFW	SDAFW	HUM
44	4.77E-07	T-IFL	HVAC1				
45	4.75E-07	T-CCW	HUM	CCW			
46	4.75E-07	T-CCW	HUM	CCW			
47	4.73E-07	T-CCW	HUM	CCW			
48	4.52E-07	T-IFL	CCW				
49	4.32E-07	S2					
50	4.27E-07	T-RX	HVAC1				
51	4.25E-07	T-LOOP	AC	EAC			
52	4.05E-07	A					
53	3.86E-07	T-TT	CCW				
54	3.66E-07	S1	HUM				
55	3.64E-07	T-LOOP	SDAFW	HVAC1			
56	3.62E-07	T-CCW	HUM	CCW			
57	3.58E-07	T-IFL	CCW				
58	3.53E-07	T-MSIV	SDAFW	HVAC1			
59	3.47E-07	T-AC	HUM				
60	3.44E-07	T-RX	HUM	HVAC1			
61	3.42E-07	T-RX	HUM	HVAC1			
62	3.41E-07	T-SGTR	LPR	HUM			
63	3.39E-07	T-CCW	HUM	CCW			
64	3.23E-07	T-SGTR	LPR	HUM			
65	3.21E-07	T-IFL	SDAFW	HVAC1			
66	3.14E-07	T-SGTR	HUM				
67	3.13E-07	T-RX	CCW				
68	3.12E-07	T-LMFW	RPS	PPORV	HUM		
69	3.11E-07	T-TT	HUM	HVAC1			

Table 4-2b (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES		
70	3.09E-07	T-TT	HUM	HVAC1	
71	3.08E-07	T-TT	HUM	CCW	
72	3.06E-07	T-CCW	HUM	CCW	
73	2.94E-07	T-LMFW	ESW		
74	2.85E-07	T-CCW	HUM	CCW	
75	2.83E-07	T-TT	ESW		
76	2.79E-07	T-TT	HUM	CCW	
77	2.76E-07	T-CCW	HUM	CCW	
78	2.73E-07	T-LOOP	ESW		
79	2.68E-07	T-CCW	HUM	CCW	
80	2.63E-07	T-CCW	HUM	CCW	
81	2.63E-07	T-CCW	HUM	CCW	
82	2.56E-07	T-VAC	MDAFW	HUM	
83	2.52E-07	T-DC	MDAFW	SDAFW	HUM
84	2.40E-07	T-MSIV	HUM	HVAC1	
85	2.39E-07	T-AC	AC	EAC	
86	2.37E-07	T-LMFW	RPS	PPORV	
87	2.37E-07	T-LMFW	HUM	HVAC1	
88	2.35E-07	T-LMFW	HUM	HVAC1	
89	2.35E-07	T-CCW	HUM	CCW	
90	2.33E-07	T-SGTR	HUM		
91	2.31E-07	S2	HUM		
92	2.31E-07	S2	HUM		
93	2.31E-07	T-CCW	HUM	CCW	
94	2.31E-07	T-CCW	HUM	CCW	
95	2.28E-07	T-TT	RPS	PPORV	HUM
96	2.27E-07	T-LOOP	ESW		
97	2.25E-07	T-LOOP	ESW		
98	2.24E-07	S2	HUM		
99	2.24E-07	T-CCW	HUM	CCW	
100	2.23E-07	S2	HUM		
102	6.08E-05	REMAINDER			
101	3.06E-06	T-IFL			

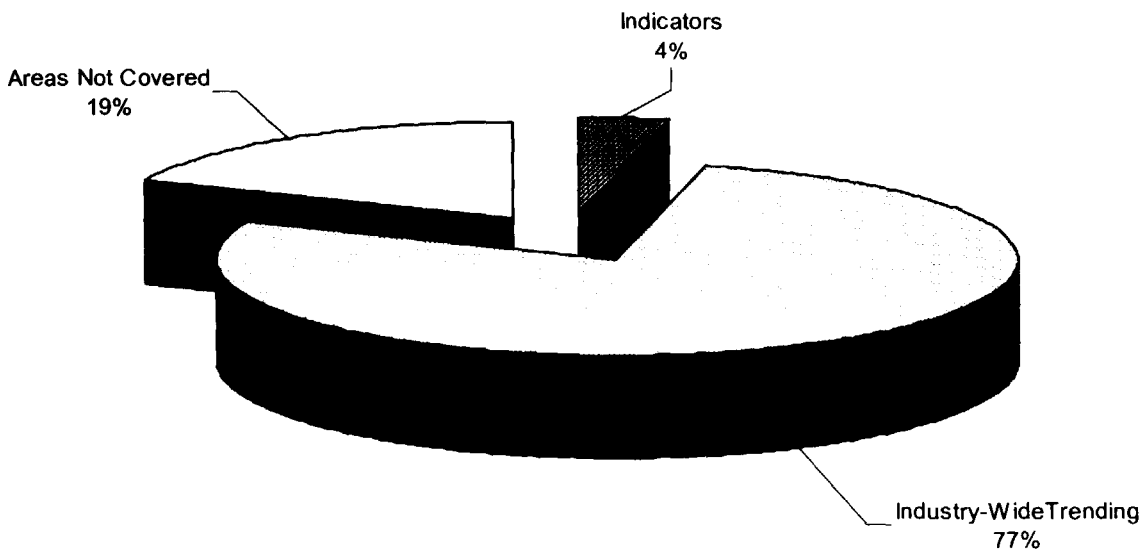


Figure 4-1a RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for BWR 3/4 Plant 18

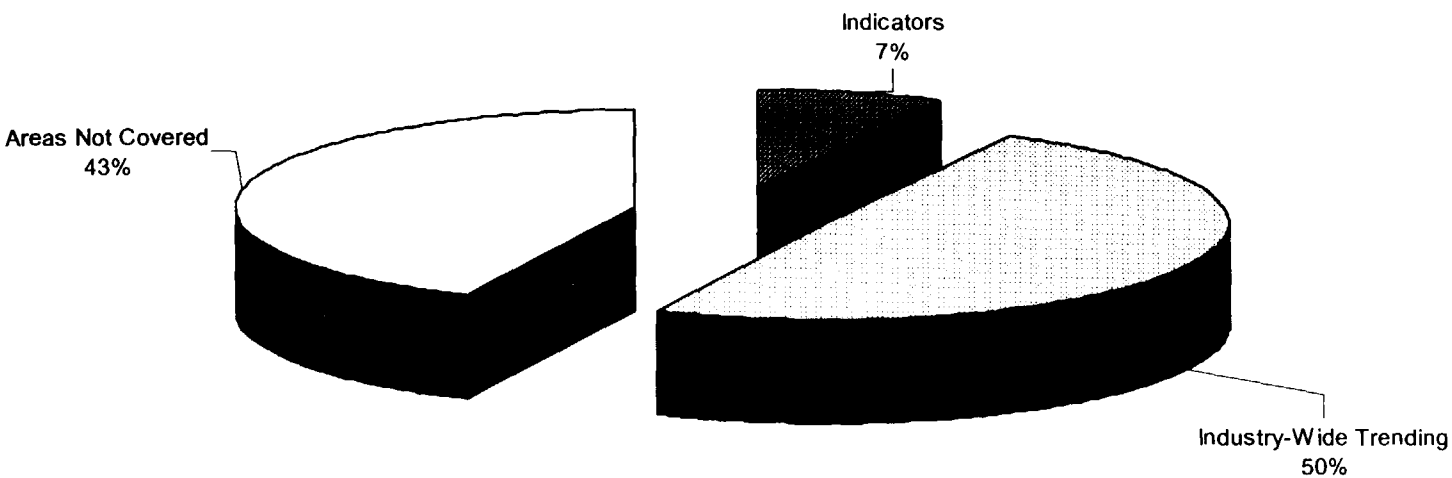


Figure 4-1b RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for WE 4-Lp Plant 22

Table 4-3 lists mitigating system elements appearing in Tables 4-2a and b that are not covered by RBPIs, with an indication of why they are not covered.

Table 4-3 Mitigating System Elements That Appear in Dominant Core Damage Sequences but Are Not Covered by RBPIs

WE 4-Lp Plant 22	
Element	**Reason for No RBPI**
Post-Accident Human Action	Not amenable to PI treatment (timely quantification directly from performance data not practical)
Steam Generator Safety Valves	Not amenable to PI treatment (timely quantification directly from performance data not practical)
Non-Safety AC Power System	Not amenable to PI treatment (timely quantification directly from performance data not practical)
Heating/Ventilation/Air Conditioning	Loss of HVAC with support systems available is not risk-significant at most plants
Reactor Protection System	Not amenable to PI treatment (timely quantification directly from performance data not practical)
Safety Injection System Accumulators	Not amenable to PI treatment (timely quantification directly from performance data not practical)
BWR 3/4 Plant 18	
Element	**Reason for No RBPI**
Post-Accident Human Action	Not amenable to PI treatment (timely quantification directly from performance data not practical)
Reactor Protection System	Not amenable to PI treatment (timely quantification directly from performance data not practical)
Non-Safety AC Power System	Not amenable to PI treatment (timely quantification directly from performance data not practical)
Automatic Depressurization	Risk-significant performance degradation of ADS valves is unlikely
Safe Shutdown Makeup Pump	Not generically important
Low Pressure Coolant Injection	Most hardware shared with Suppression Pool Cooling, which is covered by an RBPI
Main Feedwater	This area is covered by an RBPI under the IE cornerstone but appears here as a system mitigating a reactor trip initiator. For that specific function the data would not accumulate quickly enough to support RBPI quantification.
Non-safety DC	Not amenable to PI treatment (timely quantification directly from performance data not practical)
Drywell Spray	Most hardware shared with Suppression Pool Cooling, which is covered by an RBPI
Venting	Not amenable to PI treatment (timely quantification directly from performance data not practical)

5. VALIDATION AND VERIFICATION

The White Paper discusses two steps of validation and verification (V&V): step 1 activities undertaken as part of the development and testing of RBPIs, and step 2 activities that are an ongoing and integral part of the reactor oversight inspection process. The step 1 V&V presented in this report covers the following:

- process for RBPI identification
- RBPI characteristics
- testing of RBPIs.

5.1 Development of a Systematic Process for RBPI Identification

Sections 2 and 3 of this report describe the process and results for identifying RBPIs. The process for identifying RBPIs is both risk-based and systematic, as indicated by the flowchart presented in Section 2 of this report. Potential RBPIs are identified and then compared with various selection criteria to determine whether the RBPIs can be developed. Results for full power internal events from this systematic process are presented in Appendix A for the 15 sites (23 plants) used in the V&V testing activity.

5.2 Assurance That RBPIs Satisfy Specific Characteristics

Section 1.2 of this report lists six characteristics that RBPIs should have. Each of those characteristics is discussed below:

- RBPIs should be compatible with, and complementary to, the risk-informed inspection activities of the reactor oversight process (ROP).

  The RBPI identification process (flowchart presented in Section 2 of this report) ensures that RBPIs are both compatible with and complementary to inspection activities. Potential RBPIs are identified using a process similar to that used for the ROP. RBPIs are compared to existing ROP indicators and the potentially affected inspection areas are identified.

- RBPIs should cover all modes of plant operation.

  The RBPIs developed in this report cover both full power and shutdown modes of plant operation.

- RBPIs should cover risk-important SSCs to the extent practical.

  Risk coverage is discussed in Section 4 of this report. The RBPI development process ensures that as much of the risk as feasible is covered by the RBPIs.

- RBPIs should be capable of implementation without excessive burdens to licensees or NRC in the areas of data collection and quantification.

  Most of the RBPIs identified in this report can be quantified using existing databases as indicated in Section 5.3. Potential RBPIs were identified in this report that would require additional data collection effort, such as the time spent in risk-significant configurations during shutdown operations, or the unreliability and unavailability of containment barrier systems and fire suppression systems. Quantification of RBPI values for the 23 plants covered in the V&V testing activity and comparison with plant-specific thresholds to determine plant performance (Section 5.3 of this report) requires NRC resources, but this process is expected to be automated to the extent possible as the RBPI development effort continues.

- To the extent practical, RBPIs should identify declining performance before performance becomes unacceptable, without incorrectly identifying normal variations as degradations (i.e., avoid false-positive indications and false-negative indications).

  The suggested misclassification probability criteria are discussed in Appendix F. In general, the RBPIs selected have acceptable false-negative probabilities (less than 5% chance of obtaining a green RBPI indication when performance is actually in the red performance band). Most of the RBPIs also have acceptable false-positive probabilities (less than 20% chance of obtaining a white RBPI indication when performance is actually at its baseline level). However, many of the unreliability RBPIs have a significant chance of obtaining a white RBPI indication when performance is actually at its baseline level. Therefore, for all unreliability RBPIs, when white band performance is indicated, the probability of performance actually being at its baseline value will also be presented. More details can be found in Appendices E and F.

- The RBPIs should be amenable to establishment of plant-specific thresholds consistent with the ROP.

  For the RBPIs presented in this report, plant-specific thresholds were developed using the SPAR Revision 3 core damage frequency models. Results are described in Appendix A of this report.

5.3 Testing of the RBPIs for Practicality of Calculation and Credibility of Results

The RBPIs for internal events while plants are at power were tested by evaluating plant-specific data from 23 plants over the period 1997 – 1999. Baseline SPAR models including industry-average values reflecting 1996 performance were used. The data collection effort to test the RBPIs at 23 plants was accomplished using INPO's EPIX database for unreliability (with RADS as the search and quantification software package), ROP data for unavailability, and NUREG/CR-5750 for initiating events. The overall data collection process was straightforward, although there are areas where data are not presently available (indicated in the tables).

The constrained, non-informative prior and recommended data collection intervals were used (one year for the general transient (GT) initiating event and mitigating system unavailabilities; and three years for the loss of heat sink (LOHS) and loss of feedwater (LOFW) initiators, mitigating system unreliabilities, and component class unreliabilities). This prior and the data collection intervals were identified from the statistical analyses (Appendix F) as most appropriate for the RBPIs being tested. Results are presented in Tables 5.3-1 through 5.3-4 for the initiating event, mitigating system unavailability, mitigating system unreliability, and component class RBPIs. For the RBPIs with available data from 1997 – 1999, approximately 94% of the RBPIs reflect green plant performance, with the other 6% indicating white or yellow performance.

The results in Tables 5.3-1 through 5.3-4 are intended to show that RBPIs can be calculated using readily available data and models to produce potential indicators that reflect plant performance in a manner consistent with the current ROP philosophy. These tables clearly show that performance data can be used to calculate indicators that fit in the ROP concept. They demonstrate the feasibility of the process, but not necessarily the accuracy of the results. In order for these potential indicators to be used in the ROP, implementation issues relating to model fidelity and data quality need to be resolved so that there is sufficient alignment among stakeholders regarding the accuracy of both the thresholds and the calculated performance indicators.

The risk models and associated baseline performance values should be peer reviewed by stakeholders to ascertain that they reasonably reflect the risk profile for the plants modeled. This is required to assure that thresholds derived from the models reasonably represent the risk significance of potential performance degradations. Similarly, the data inputs to the indicator calculations need to have sufficient accuracy to reasonably represent the risk significance of potential performance degradations. The accuracy should be consistent with the nominal uncertainties associated with reliability and risk measurements so that errors in data collection do not result in mischaracterizing risk performance as measured by the ROP (i.e., characterizing green when actually non-green or vice-versa).

Since the models and data in these tables have not been formally peer reviewed, plant-specific inferences regarding "green" or "non-green" performance from these calculations would be inappropriate. The data are presented to demonstrate that the process can be followed to produce potential indicators. The accuracy of the RBPI results sufficient for use in NRC decisionmaking remains to be determined through the ROP change process.

Tables 5.3-1 through 5.3-4 show how performance data can be used along with thresholds derived from risk models to produce indicators that are consistent with the ROP framework. Potential benefits derived from this exercise that relate to the practicality of calculation and credibility of results include:

- more precise accounting for the risk-significant design features of plants
- more plant-specific thresholds
- more appropriate accounting for the risk impact of fault exposure time in indicator formulation

By evaluating indicators at a train level and accounting for diverse design features separately, the RBPIs can more precisely account for the risk significance of design features. For example, turbine-driven, diesel-driven, and/or motor-driven pump trains comprise AFW systems in PWRs. Turbine-driven or diesel-driven trains have risk significance in SBO sequences that motor-driven trains do not. By accounting for these effects separately, rather than combining them in a single indicator, RBPIs can more precisely account for risk-significant design features.

The use of plant-specific models to set thresholds allows the indicators for a plant to more closely reflect the risk significance of potential performance degradations. As noted earlier, the models used in the RBPI development need to be reviewed by licensees and other external stakeholders to determine if they represent a reasonable characterization of the plant risk profile.

Fault exposure time data collection and analysis is one method of estimating the probability of standby components, trains, or systems failing to perform their risk-significant safety function when needed. Assessing the probability through analysis of failure and demand counts is another method. Both methods produce the same result over a long period of time. However, counting fault exposure time over the shorter periods of time typical of the ROP sampling intervals can be problematic due to the increased likelihood of false positive and false negative indication. As noted in Appendix F, the RBPIs process fault exposure data and failure and demand count data in a manner that provides the most timely indication of potential performance degradation without undue occurrence of false positive or false negative indications. In addition, the RBPIs account for fault exposure time impacts on the risk-significant safety functions which can be different from the design-basis functions of components, trains, or systems. For example, many systems have automatic initiation capabilities as design basis features (without credit for manual operation). However, to achieve the risk-significant safety function, either automatic or manual actuation is satisfactory. The RBPIs account for this case in the treatment of fault exposure time so that risk significance of events resulting in fault exposure time accumulation are more appropriately accounted for.

Testing of the RBPIs also included the monitoring of industry-wide performance. Industry-wide trending data are presented in Tables 5.3-5 through 5.3-8. The industry-wide averages were determined using only the 23 plants covered in this study, which include 14 PWRs and 9 BWRs. Statistical trending analyses have not been performed yet because only approximately one-fourth of the entire industry is represented at present, and three years of data are generally not sufficient to discern statistically significant trends, unless performance is changing rapidly. However, almost all of the yearly industry-wide averages lie below the 95th percentile of the distributions of the 1996 industry-average baselines. (The only exception is the AFW motor-driven pump train UA, where the yearly averages range from two to five times the baseline value. In this case the baseline value might need to be modified.) Similar to the testing of the RBPIs on a plant-specific basis, the industry-wide trending was accomplished using existing databases and software. In general, the trending data presented in Table 5.3-5 through 5.3-8 indicate that the values chosen to represent 1996 industry-average performance are reasonable, and that industry performance during 1997 – 1999 was comparable to or better than the 1996 baseline.

INPO's EPIX database, used to support evaluation of mitigating system and component class unreliabilities, is relatively new. A review of the data collection effort indicates that

approximately 15% of the plants considered were missing some data for the four main types of systems considered – EPS, HPI/HPCI/HPCS, AFW/RCIC, and RHR. In addition, approximately 50% of the plants did not have data for the other systems considered – SWS, CCW, and PORV. Therefore, the EPIX database needs to be improved in this area before all of the proposed RBPIs could be implemented.

Unavailability data for the four main types of systems were obtained from the ROP. However, the ROP does not include other systems such as SWS, CCW, and PORV. The industry is considering the inclusion of unavailability data for these systems in the EPIX database. The addition of unavailability data to EPIX would help to support the RBPI program, especially for systems not covered by the ROP.

Table 5.3-1 Plant Performance Bands for Initiating Event RBPIs (1999) [a, c]

	1999		
Plant	GT [b]	LOHS [c]	LOFW [c,d]
PWRs			
WE 4-Lp Plant 1	2.8E-1 (G)	5.9E-2 (G)	5.3E-2 (G)
WE 4-Lp Plant 2	2.1E+0 (W)	5.8E-2 (G)	1.6E-1 (G)
CE Plant 2	1.5E+0 (G)	2.9E-1 (W)	5.2E-2 (G)
CE Plant 3	3.2E-1 (G)	5.9E-2 (G)	5.2E-2 (G)
CE Plant 4	3.0E-1 (G)	5.9E-2 (G)	5.2E-2 (G)
CE Plant 5	1.2E+0 (G)	8.4E-2 (G)	No data (G)
B&W Plant 4	1.6E+0 (W)	6.3E-2 (G)	5.5E-2 (G)
B&W Plant 5	2.8E+0 (Y)	1.8E-1 (W)	5.3E-2 (G)
B&W Plant 6	2.8E-1 (G)	6.0E-2 (G)	5.4E-2 (G)
WE 2-Lp Plant 5	9.3E-1 (G)	1.8E-1 (W)	5.3E-2 (G)
WE 2-Lp Plant 6	2.8E-1 (G)	5.9E-2 (G)	5.4E-2 (G)
CE Plant 12	2.1E+0 (W)	5.9E-2 (G)	1.6E-1 (G)
WE 4-Lp Plant 22	2.8E-1 (G)	5.8E-2 (G)	1.6E-1 (G)
WE 4-Lp Plant 23	2.9E-1 (G)	5.7E-2 (G)	1.5E-1 (G)
BWRs			
BWR 3/4 Plant 5	3.0E-1 (G)	9.2E-2 (G)	5.3E-2 (G)
BWR 3/4 Plant 6	3.4E-1 (G)	9.1E-2 (G)	5.2E-2 (G)
BWR 3/4 Plant 8	1.6E+0 (G)	9.0E-2 (G)	5.2E-2 (G)
BWR 5/6 Plant 2	1.0E+0 (G)	2.7E-1 (G)	5.1E-2 (G)
BWR 3/4 Plant 11	3.3E-1 (G)	9.2E-2 (G)	5.2E-2 (G)
BWR 3/4 Plant 15	9.1E-1 (G)	8.6E-2 (G)	5.1E-2 (G)
BWR 3/4 Plant 16	3.2E-1 (G)	8.8E-2 (G)	5.2E-2 (G)
BWR 3/4 Plant 18	9.4E-1 (G)	9.8E-2 (G)	5.5E-2 (G)
BWR 3/4 Plant 19	3.0E-1 (G)	1.1E-1 (G)	5.8E-2 (G)

a. Plant performance bands are the following: green (G) - $\Delta CDF < 1.0E-6/y$, white (W) - $1.0E-6/y < \Delta CDF < 1.0E-5/y$, yellow (Y) - $1.0E-5/y < \Delta CDF < 1.0E-4/y$, red (R) - $\Delta CDF > 1.0E-4/y$.

b. A one-year data collection interval applies (1999). The 1999 data were obtained from the ROP.

c. A three-year data collection interval applies (1997 – 1999). 1997 and 1998 data were obtained from the initiating events study update (Poloski 2000), while the 1999 data were obtained from the ROP.

d. This RBPI is not covered under the ROP, so the results presented in this table include only 1997 and 1998. (1999 Licensee Event Reports will need to be reviewed to identify scrams that are LOFW, as defined in the initiating events study.)
e. Since the models and data in these tables have not completed formal peer review, plant specific inferences regarding "green" or "non-green" performance from these calculations would be inappropriate.

Table 5.3-2 Plant Performance Bands for Mitigating System Unavailability RBPIs (1999)[b]

Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR	SWS[a]	CCW[a]	PORV[a]
PWRs							
WE 4-Lp Plant 1	3.5E-3 (G)	3.3E-3 (G)	MDP (3.4E-3) DDP (4.3E-2) (Y)	9.1E-5 (G)	No data	No data	No data
WE 4-Lp Plant 2	3.3E-3 (G)	1.5E-2 (G)	MDP (2.4E-3) DDP (1.1E-2) (G)	8.0E-3 (G)	No data	No data	No data
CE Plant 2	6.6E-3 (G)	7.2E-3 (G)	MDP (0.0E+0) TDP (2.9E-3) (G)	1.0E-2 (G)	No data	No data	No data
CE Plant 3	7.5E-3 (G)	1.1E-2 (G)	MDP (2.4E-3) TDP (4.5E-3) (G)	1.4E-2 (G)	No data	No data	No data
CE Plant 4	9.5E-3 (G)	1.3E-3 (G)	MDP (9.8E-4) TDP (6.2E-3) (G)	2.1E-3 (G)	No data	No data	No data
CE Plant 5	1.1E-2 (G)	8.3E-3 (G)	MDP (4.9E-3) TDP (6.4E-3) (W)	4.1E-3 (G)	No data	No data	No data
B&W Plant 4	2.3E-2 (G)	5.3E-3 (G)	MDP (4.0E-3) TDP (0.0E+0) (G)	1.9E-2 (G)	No data	No data	NA
B&W Plant 5	2.4E-2 (G)	3.0E-3(G)	MDP (3.3E-3) TDP (3.1E-3) (G)	1.3E-2 (G)	No data	No data	NA
B&W Plant 6	2.2E-2 (G)	2.5E-3 (G)	MDP (6.8E-3) TDP (8.9E-4) (G)	1.1E-2 (G)	No data	No data	NA
WE 2-Lp Plant 5	1.3E-2 (G)	1.4E-3 (G)	MDP (4.4E-3) TDP (6.7E-3) (G)	1.6E-2 (G)	No data	No data	No data
WE 2-Lp Plant 6	1.0E-2 (G)	1.2E-3 (G)	MDP (4.2E-3) TDP (2.5E-3) (G)	2.6E-3 (G)	No data	No data	No data
CE Plant 12	5.1E-3 (G)	7.3E-3 (G)	MDP (5.3E-3) TDP (4.6E-3) (W)	7.1E-3 (G)	NA	No data	No data
WE 4-Lp Plant 22	9.6E-3 (G)	7.7E-3 (G)	MDP (7.6E-3) TDP (4.0E-3) (W)	4.4E-3 (G)	No data	No data	No data
WE 4-Lp Plant 23	1.2E-2 (G)	4.9E-3 (G)	MDP (1.2E-2) TDP (6.3E-3) (W)	8.2E-3 (G)	No data	No data	No data
BWRs							
BWR 3/4 Plant 5	2.9E-3 (G)	2.4E-3 (G)	5.5E-3 (G)	0.0E+0 (G)	No data	NA	NA
BWR 3/4 Plant 6	1.3E-2 (G)	2.1E-3 (G)	1.0E-2 (G)	8.4E-3 (G)	No data	NA	NA
BWR 3/4 Plant 8	1.9E-2 (G)	2.8E-2 (G)	5.0E-2 (G)	7.8E-3 (G)	No data	NA	NA

Table 5.3-2 (Continued)

Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR	SWS [a]	CCW [a]	PORV [a]
BWR 5/6 Plant 2	3.6E-2 (W)	4.6E-3 (G)	1.5E-2 (G)	4.4E-3 (G)	No data	NA	NA
BWR 3/4 Plant 11	7.4E-3 (G)	1.8E-2 (G)	1.8E-2 (W)	1.2E-2 (G)	No data	NA	NA
BWR 3/4 Plant 15	1.5E-2 (G)	1.6E-2 (G)	8.6E-3 (G)	9.1E-3 (G)	No data	NA	NA
BWR 3/4 Plant 16	2.2E-2 (G)	2.1E-2 (G)	7.9E-3 (G)	1.3E-2 (G)	No data	NA	NA
BWR 3/4 Plant 18	2.1E-2 (W)	4.5E-1 (W)	1.7E-2 (G)	5.4E-3 (G)	No data	NA	NA
BWR 3/4 Plant 19	1.8E-2 (W)	1.7E-2 (G)	1.8E-2 (G)	7.5E-3 (G)	No data	NA	NA

a. Unavailability data are not available (not covered by the ROP) at this time. Eventually, EPIX may contain such data.

b. Since the models and data in these tables have not completed formal peer review, plant specific inferences regarding "green" or "non-green" performance from these calculations would be inappropriate.

Table 5.3-3 Plant Performance Bands for Mitigating System Unreliability RBPIs (1997 - 1999)[e]

Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR[a]	SWS	CCW	PORV
PWRs							
WE 4-Lp Plant 1	< baseline (G)[b]	No data[c]	< baseline (G)	< baseline (G)	No data	No data	No data
WE 4-Lp Plant 2	< baseline (G)	No data	< baseline (G)	< baseline (G)	No data	No data	No data
CE Plant 2	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	No data	No data
CE Plant 3	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	No data	No data
CE Plant 4	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	< baseline (G)
CE Plant 5	< baseline (G)	< baseline (G)	< baseline (G)	No data	No data	< baseline (G)	No data
B&W Plant 4	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	NA
B&W Plant 5	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	NA
B&W Plant 6	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	NA
WE 2-Lp Plant 5	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	< baseline (G)	< baseline (G)
WE 2-Lp Plant 6	< baseline (G)	No data	< baseline (G)	< baseline (G)	< baseline (G)	No data	< baseline (G)
CE Plant 12	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	NA	< baseline (G)	No data
WE 4-Lp Plant 22	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)
WE 4-Lp Plant 23	< baseline (G)	< baseline (G)	1.5E-2 (MDP) (W) (0.13)[d]	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)
BWRs							
BWR 3/4 Plant 5	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	NA	NA
BWR 3/4 Plant 6	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	NA	NA
BWR 3/4 Plant 8	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	NA	NA
BWR 5/6 Plant 2	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	NA	NA
BWR 3/4 Plant 11	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	NA	NA
BWR 3/4 Plant 15	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	NA	NA
BWR 3/4 Plant 16	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	NA	NA
BWR 3/4 Plant 18	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	NA	NA
BWR 3/4 Plant 19	< baseline (G)	< baseline (G)	< baseline (G)	< baseline (G)	No data	NA	NA

a. Reflects pump data. Valve data still need to be collected and evaluated.
b. "< baseline" indicates that there were not enough failures to result in a train unreliability greater than the baseline.
c. "No data" indicates that either EPIX has no data on this system, or the RADS data load of the EPIX file did not include this system.
d. Unreliability RBPIs have the potential for false-positive indications. Therefore, the probability of underlying performance actually being at its baseline (G) value is also presented. The 0.13 probability indicates that there is only a 13% chance that performance is at its baseline value.
e. Since the models and data in these tables have not completed formal peer review, plant specific inferences regarding "green" or "non-green" performance from these calculations would be inappropriate.

Table 5.3-4 Plant Performance Bands for Component Class RBPIs (1997 - 1999)[e]

Plant	AOV	MOV	MDP
PWRs			
WE 4-Lp Plant 1	No data [a]	No data	< baseline (G)[b]
WE 4-Lp Plant 2	No data	No data	< baseline (G)
CE Plant 2	< baseline (G)	< baseline (G)	< baseline (G)
CE Plant 3	1.6E-3 (1.6X) (G)[c]	< baseline (G)	< baseline (G)
CE Plant 4	3.8E-3 (3.8X) (G)[c]	< baseline (G)	< baseline(G)
CE Plant 5	No data	< baseline (G)	< baseline (G)
B&W Plant 4	< baseline (G)	< baseline (G)	< baseline (G)
B&W Plant 5	< baseline (G)	< baseline (G)	< baseline (G)
B&W Plant 6	< baseline (G)	< baseline (G)	< baseline (G)
WE 2-Lp Plant 5	< baseline (G)	< baseline (G)	< baseline (G)
WE 2-Lp Plant 6	< baseline (G)	< baseline (G)	6.0E-3 (1.6X) (W)[c] (0.19)[d]
CE Plant 12	< baseline (G)	1.3E-2 (4.4X) (W)[c] (0.002)[d]	< baseline (G)
WE 4-Lp Plant 22	< baseline (G)	< baseline (G)	< baseline (G)
WE 4-Lp Plant 23	< baseline (G)	< baseline (G)	< baseline (G)
BWRs			
BWR 3/4 Plant 5	No data	< baseline (G)	< baseline (G)
BWR 3/4 Plant 6	No data	< baseline (G)	< baseline (G)
BWR 3/4 Plant 8	No data	< baseline (G)	< baseline (G)
BWR 5/6 Plant 2	< baseline (G)	< baseline (G)	< baseline (G)
BWR 3/4 Plant 11	No data	< baseline (G)	< baseline (G)
BWR 3/4 Plant 15	No data	< baseline (G)	< baseline (G)
BWR 3/4 Plant 16	No data	< baseline (G)	< baseline (G)
BWR 3/4 Plant 18	No data	< baseline (G)	< baseline (G)
BWR 3/4 Plant 19	No data	< baseline (G)	< baseline (G)

a. "No data" indicates that either EPIX has no data on this component class, or the RADS data load of the EPIX file did not include this component class.

b. "< baseline" indicates that there were not enough failures to result in a train unreliability greater than the baseline.

c. The number in parentheses "1.6X" indicates that the unreliability is 1.6 times the baseline.

d. The component class RBPIs have the potential for false-positive indications. Therefore, the probability of the underlying performance actually being at its baseline (G) value is also presented.

e. Since the models and data in these tables have not completed formal peer review, plant specific inferences regarding "green" or "non-green" performance from these calculations would be inappropriate.

Table 5.3-5 Industry Trends for Initiating Event RBPIs (1997 through 1999)

	Industry-Wide Initiating Event Frequency[a]			
Initiating Event	1996 Baseline	1997	1998	1999
General transient (GT)	1.0/y (PWRs) 1.3/y (BWRs)	4.7E-1/y 5.5E-1/y	7.1E-1/y 7.9E-1/y	1.0E+0/y 5.1E-1/y
Loss of Heat Sink (LOHS)	9.6E-2/y (PWRs) 2.3E-1/y (BWRs)	8.1E-2/y 4.2E-2/y	7.7E-2/y 4.5E-2/y	1.2E-1/y 1.2E-1/y
Loss of Feedwater (LOFW)	6.8E-2/y	4.9E-2/y	1.1E-1/y	NA[b]

a. The "industry-wide" results are the average of the 23 plants considered in this data review. For the PWR results, 14 plants are included. The BWR results include 9 plants.
b. Data not available (without a review of the LERs for 1999).

Table 5.3-6 Industry Trends for Mitigating System Unavailability RBPIs (1997 through 1999)

	Industry-Wide Unavailability			
Mitigating System and Level	1996 Baseline	1997	1998	1999
EPS (train)	9.7E-3	1.2E-2	1.1E-2	1.1E-2
PWRs				
HPI (train)	4.2E-3	4.9E-3	4.3E-3	6.1E-3
AFW (MDP train)	1.1E-3	5.5E-3	2.8E-3	5.0E-3
AFW (TDP train)	4.6E-3	4.9E-3	6.4E-3	4.0E-3
AFW (DDP train)	1.5E-2	6.9E-3	1.7E-3	2.7E-2
RHR (train)	7.3E-3	9.3E-3	6.1E-3	8.5E-3
BWRs				
HPCI (train)	9.7E-3	1.3E-2	1.8E-2	1.5E-2
HPCS (train)	3.4E-3	9.0E-3[a]	3.9E-3[a]	4.6E-3[a]
RCIC (train)	1.3E-2	9.0E-3	1.6E-2	3.0E-2
RHR (train)	1.0E-2	1.3E-2	1.5E-2	7.4E-3

a. Only one plant (of the 23 considered) has an HPCS.

Table 5.3-7 Industry Trends for Mitigating System Unreliability RBPIs (1997 through 1999)

	Industry-Wide Unreliability[a]			
Mitigating System and Level	1996 Baseline	1997	1998	1999
EPS (train)	4.1E-2	2.1E-2	1.6E-2	1.4E-2
PWRs				
HPI (train)	7.9E-3	5.2E-3	4.8E-3	5.0E-3
AFW (MDP train)	7.8E-3	5.5E-3	9.7E-3	4.7E-3
AFW (TDP train)	2.0E-1	2.6E-2	5.1E-2	7.9E-2
AFW (DDP train)	5.7E-2	4.1E-2	4.2E-2	4.1E-2
RHR (train)	1.1E-2	?[b]	?	?
BWRs				
HPCI (train)	4.3E-2	3.8E-2	3.8E-2	3.8E-2
HPCS (train)	6.8E-2	6.4E-2	6.4E-2	6.4E-2
RCIC (train)	4.4E-2	3.9E-2	2.8E-2	3.8E-2
RHR (train)	1.6E-2	?[b]	?	?

a. Train unreliability models vary by plant. For the industry-wide trending, the train unreliability was simplified to include the pump FTS and FTR (or EDG FTS, FTLR, and FTR), single-failure valves within the train, and train unavailability (kept at the baseline value). A four-hour mission time was assumed for EDGs, and a 24-hour mission time for all other trains.
b. Valve data still need to be collected to evaluate this properly.

Table 5.3-8 Industry Trends for Component Class RBPIs (1997 through 1999)

	Industry-Wide Unreliability			
Component Class	1996 Baseline	1997	1998	1999
AOV	1.0E-3	1.2E-3	2.1E-3	4.1E-4
MOV	3.0E-3	7.9E-4	1.3E-3	1.4E-3
MDP[a]	3.7E-3	9.3E-4	2.3E-3	4.3E-4
TDP[a]	1.0E-1	3.4E-2	4.2E-2	3.4E-2

a. Unreliability includes FTS (baseline of 3.0E-3) and FTR (baseline λ of 3.0E-5/h and a mission time of 24 hours).

b. TDP is not an RBPI, but is trended at the industry level. Unreliability includes FTS (baseline of 1.4E-2, which is a weighted average of AFW, HPCI, and RCIC TDPs) and FTR (baseline λ of 3.7E-3/h, which is a weighted average, and a mission time of 24 hours).

6. KEY ISSUES AFFECTING RBPI DEVELOPMENT AND IMPLEMENTATION

The following subsections describe issues whose resolutions require inputs from internal and external stakeholders.

This work is part of the development and evolution of performance indicators in the current ROP and is closely coordinated with existing ROP efforts. Changes to the existing ROP indicators are not imminent. There are several key implementation issues summarized in the executive summary and in this section, including the verification of risk models and data. The potential integration of RBPIs into the ROP would follow the guidelines in IMC0608, "Performance Indicator Program." This would include a pilot program prior to the full implementation of RBPIs and interaction with stakeholders to resolve implementation issues raised in this report or from external stakeholders during the review of this report.

6.1 Program Coordination Issues

The following specific issues need to be addressed by the stakeholders:

- Are additional RBPIs needed in the ROP?
- Is the number of potential new indicators appropriate?
- Do the data sources for RBPIs exist and have sufficient quality for use in the ROP?
- Will additional SPAR Revision 3 models be available for setting plant-specific thresholds for all plants?
- Will SPAR LERF models be available for setting thresholds for mitigating and containment systems?

<u>Are any additional performance indicators needed in the ROP?</u>

Interactions with stakeholders commenting on the White Paper indicated differing views on this subject. Industry representatives questioned whether NRC needed to have a broader coverage of risk measured in the ROP indicators, especially if it did not result in a corresponding reduction in the inspection program. Other external stakeholder comments favored more indicators as well as additional inspections. The ROP is in its first year of full implementation. NRR will provide the Commission with its assessment of the process in June 2001. The RBPI development program is focused on demonstrating the technical feasibility of providing additional objective indicators that cover a broader spectrum of risk-significant plant performance. Phase 2 may identify additional candidates.

Is the number of potential new indicators appropriate? / Which of the proposed indicators would be most beneficial?

The RBPI Phase-1 development identified 21 potential indicators for PWRs and 16 potential indicators for BWRs. If all of these performance indicators were implemented, they could potentially replace 8 (3 initiating event and 5 mitigating system) of 18 existing indicators in whole or in part bringing the total number of indicators per plant to about 30. In addition to the issue of the appropriate risk scope of ROP indicators (noted above), it will be necessary to assess whether potentially expanding the total number of indicators to approximately 30 (approximately 25 based on currently available data) per plant is reasonable from a logistics/process point of view. For example, the criteria that result in plants entering various columns of the Action Matrix would have to be reconsidered. If deemed appropriate, future RBPI development will examine the feasibility of developing indicators at a higher level (systems) by combining results of lower level data and models. The program will also examine means to use risk insights to develop a shorter list at the component/train level.

Do the data sources for RBPIs exist and have sufficient quality for use in the ROP?

A significant portion of the RBPIs require access to and use of data from the Equipment Performance and Information Exchange (EPIX) system. These data are voluntarily provided by industry in response to the Commission decision to forgo the Reliability Data Rule. Full industry participation, verification and validation of existing EPIX, and development of guidelines for consistent reporting are important to the feasibility of many RBPIs as potential improvements to the ROP. In addition, certain data for shutdown and containment systems will need to be developed in order to have RBPIs in those areas. The issue of the regulatory mechanisms for certifying the accuracy of data used in RBPIs for the ROP will be dealt with through the ROP change process if a decision is made to proceed with potential implementation of some or all of the identified RBPIs.

Currently, there are seven PWR and nine BWR proposed indicators for which performance data are not readily available from EPIX. The NRC is working with industry groups to expand the reliability data collection in this voluntary system to include data that will support evaluation of performance in these areas.

Will SPAR Revision 3i models be available for setting plant-specific thresholds for all plants?

Approximately 30 Standardized Plant Accident Risk (SPAR) Revision 3i models are currently available. Completion of all 70 SPAR Revision 3i models is scheduled for the end of calendar year 2002. As more models are made available for use in the RBPI development program, it will be possible to determine if plants can be grouped so that a few models can be used to set thresholds for all plants or individual models will be needed for each. The RBPI development program will continue to use the SPAR Revision 3i models as they are developed. External stakeholder comments on the White Paper indicated that peer review by licensees should be included in the development of these models. An additional implementation issue relates to whether licensees or NRC will calculate the thresholds and indicators as well as whether licensee

models (meeting as yet to be developed NRC specifications) could be used instead of the SPAR models.

It is yet to be determined whether a plant-specific model will be required to set performance thresholds for each plant or a representative model is sufficient for a group of plants. Furthermore, it has not been determined whether the calculation for thresholds and indicators will be routinely performed by NRC staff using SPAR Rev 3 models, licensees using SPAR Rev 3 models, or licensees using their own risk models that meet some specifications agreed upon and reviewed by the NRC. These are potential options that will be dealt with through the normal conduct of the ROP change process.

Will LERF models be available for setting thresholds for mitigating and containment systems?

There are a limited number of large, early release frequency (LERF) models available to set thresholds for performance of systems that impact the integrity of the containment barrier. In addition, currently available data are inadequate for establishing performance measures for the containment systems. Also, for some systems under the mitigating systems cornerstone, the thresholds associated with changes in core damage frequency (CDF) due to performance degradations may not be limiting compared to changes in LERF. To assess that condition, LERF models that reflect the impact of potential CDF changes are needed. The current plan for developing LERF models over the next several years will support only limited capability for identifying RBPIs or setting plant-specific LERF thresholds.

6.2 Plant-Specific RBPI Formulation

Based on risk-significance, some systems warrant RBPI coverage only at certain plants. From a risk coverage point of view, it may be desirable to include these systems in RBPI development. However, this leads to different numbers of indicators at different plants, and calls for more performance data to be collected through EPIX.

Options:

- Develop RBPIs for all systems satisfying standard criteria, and upgrade the collection of performance information to support quantification
- Maintain a generic set of RBPIs that are applicable to specific plant groups and can be supported with currently available data and logic models

6.3 Selection of Risk Metrics for Use in Assessing Containment Barrier Performance

Large early release frequency (LERF) is one important metric used for assessing the risk significance of proposed changes to the licensing basis. However, many significant elements of containment barrier performance discussed in SECY 99-007 do not affect either CDF or LERF significantly, although they affect late release frequency or other post-accident considerations such as worker dose. Currently, the graded approach in SECY 99-007 defines performance bands in terms of changes in CDF and LERF. However, if performance bands for large late release

frequency were derived from the QHOs in the same way that performance bands for LERF are derived, then performance thresholds for many of these elements would be implied.

Quantification of thresholds based on changes in late release frequency would require either additional SPAR model development, or formulation of approximate approaches such as those being developed as part of the SDP.

Options:

- Use LERF only
- Develop models and apply to RBPI development addressing large late release frequency (LLRF)

6.4 Formulation of G/W Threshold In Terms of Performance Percentile

In some cases, relatively small changes in element performance are capable of causing a 1E-6 change in CDF. For such elements, placing the G/W threshold at this performance level makes false positive indications more likely. An alternative approach is to define the G/W threshold in terms of performance relative to the operating fleet. However, at some plants, the 95th percentile of system performance corresponds to a ΔCDF in a white or even yellow performance band. The current plan is to continue to apply a ΔCDF threshold of 1E-6, and address high false positive probability on a case-specific basis by supplementing each non-green RBPI indication with an evaluation of the probability of actual performance being at the baseline level, conditional on observed data.

Options:

- Continue to use a ΔCDF threshold of 1E-6, and identify RBPIs with high false positive probabilities
- Use 95th percentile
- Use a different ΔCDF threshold
- Use a different percentile

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Appendix A
RBPI Determination for Internal Events / Full Power Accident Risk

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Appendix A: RBPI Determination for Internal Events / Full Power Accident Risk

A.1 Initiating Events Cornerstone

This section discusses development of RBPIs that address the initiating events cornerstone for full power, internal events. External events and non-power modes are addressed in other sections. Each subsection describes the analyses for the steps from Figure 2.1 of the main report.

A.1.1 Assess the Potential Risk Impact of Degraded Performance

The objective of the initiating events cornerstone is to limit the frequency of those events that upset plant stability and challenge critical safety functions. Six 'key attributes' that contribute to initiating event frequency are identified in SECY 99-007 (Ref. 1). These six attributes consist of configuration control, procedure quality, human performance, protection against external factors, equipment performance, and design.

A.1.1.1 Determine Attributes That Are Risk-Significant and Explicitly Modeled

Identification of 'risk-significant' or 'risk-based' performance indicators necessitates a means of quantifying the impact of that attribute. Initiating events are unique among the cornerstones of safety in that their performance is quantified at the cornerstone level rather than at lower level quantities (i.e., the attribute level). Since initiating events represent the highest level element of risk pertaining to the cornerstone, they are used directly. Risk-significance of initiating events was determined through evaluation of the Individual Plant Examination (IPE) submittals and the associated IPE Database[1]. The IPE Database provides a succinct summary of industry-wide IPE data including initiator specific conditional core damage probabilities (CCDPs) and core damage frequencies (CDF). From this database, initiators with a CCDP $\geq$ 1E-6 and a contribution to industry-wide CDF $\geq$ 1% were identified as risk-significant. The complete list of risk-significant initiating events is shown below in Table A.1.1.1-1. Initiating events contained in this table are grouped according to the convention used in NUREG/CR-5750.

The RBPI white paper (Ref. 3) indicates that RBPI development will be performed in a manner to group similar plants so that a given set of RBPIs apply to the entire group. In accordance with the data analysis performed in NUREG/CR-5750, only three schemes for grouping initiating events were considered; industry-wide, pressurized water reactors (PWRs) and boiling water reactors (BWRs). The list of risk-significant initiating events and the plant groups to which they are generically applicable are listed in Table A.1.1.1-1.

[1] Su, T. M., et al., "Individual Plant Examination Database – User's Guide," NUREG-1603, U.S. NRC, April 1997

Table A.1.1.1-1 Modeled Risk-Significant Initiators

BWR INITIATOR	NUREG/CR-5750 Initiator	CCDP≥1E-6	Industry CDF[1] ≥1%	Timely Detection of Performance Changes at the Plant Level
Flood	J1	YES	YES	NO (Trending Candidate)
High Energy Line Breaks	K	YES	NO	NO
Loss of Heat Sink	L	YES	YES	YES (Candidate RBPI)
Loss of Instrument Air	D1	YES	YES(Note 2)	NO (Trending Candidate)
Loss of MFW	P1	YES	YES	YES (Candidate RBPI)
Loss of Offsite Power	B1	YES	YES	NO (Trending Candidate)
Loss of Vital AC Bus	C1	YES	YES	NO (Trending Candidate)
Loss of Vital 125vdc Bus	C3	YES	YES	NO (Trending Candidate)
Loss of Service Water	E1	YES	YES	NO (Note 3)
Medium LOCA	G6	YES	YES	NO (Note 3)
Stuck Open Safety / Relief Valve	G2, G5	YES	YES	NO (Trending Candidate)
Transients	Q	NO (Note 5)	YES	YES (Candidate RBPI)
PWR INITIATOR	**NUREG/CR-5750 Initiator**	**CCDP≥1E-6**	**Industry CDF[1] ≥1%**	**Timely Detection of Performance Changes at the Plant Level**
Flood (Note 4)	J1	YES	YES	NO (Trending Candidate)
High Energy Line Breaks	K	YES	NO	NO
Large LOCA	G7	YES	YES	NO (Note 3)
Loss of Cooling Water	E1	YES	YES	NO (Note 3)
Loss of Heat Sink	L	YES	YES	YES (Candidate RBPI)
Loss of Instrument Air	D1	YES	YES(Note 2)	NO (Trending Candidate)
Loss of MFW	P1	YES	YES	YES (Candidate RBPI)
Loss of Offsite Power	B1	YES	YES	NO (Trending Candidate)
Loss of Vital 125vdc Bus	C3	YES	YES	NO (Trending Candidate)
Loss of Vital AC Bus	C1	YES	YES	NO (Trending Candidate)
Medium LOCA	G6	YES	YES	NO (Note 3)
Reactor Coolant Pump Seal LOCA	G8	YES	YES(Note 6)	NO (Note 3)
Small/Very-Small LOCA	G1, G3	YES	YES	NO (Trending Candidate)
Steam Generator Tube Rupture	F1	YES	YES	NO (Trending Candidate)
Transients	Q	YES	YES	YES (Candidate RBPI)

1. The 'Industry CDF' value was extracted from the IPE database. It is the summation of the initiator specific CDF contributions from all plants modeling that initiator in their IPE.
2. Several plants did not report CDF contribution by specific initiator but rather combined initiators into groups. In such instances initiator specific CDF contributions cannot be determined, however, industry CDF for this initiator is likely ≥ 1%.
3. To be selected for trending the candidate initiators must be risk-significant and actually occur in the industry (at least one occurrence since 1987 as recorded in NUREG/CR-5750). There were no occurrences of these initiators since 1987.
4. Industry flooding frequency dominated (80%) by single event at Surry
5. Transient initiators did not meet the CCDP criteria, however, their high occurrence frequency in conjunction with their nominal CCDP give them the ability to effect changes into the white and yellow performance bands. Therefore, transient initiators were included in the list of potentially risk-significant initiators.
6. Most RCP seal LOCAs modeled as consequential events.

A.1.2 Obtain Performance Data for Risk-Significant, Equipment-Related Elements

The analysis of initiating event data and calculation of initiating event frequencies also relied on several data sources. The three data sources used in the selection, and their contribution to the analysis, of initiating event RBPIs are described below:

NUREG/CR-5750, Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 - 1995, presents an analysis of initiating event frequencies at U. S. nuclear power plants. This report provides two key sets of information essential to the RBPI process. One set of information consists of generic initiating event frequencies calculated for various initiators. These initiating event frequencies were incorporated into Standardized Plant Analysis Risk (SPAR, Ref. 6) models as part of the process of establishing plant-specific baseline core damage frequencies. Another set of information extracted from the report includes the definitions of initiators and related functional impact groupings. Use of these definitions ensure that initiating event frequencies calculated in future updates are comparable with those used in the baseline SPAR models.

The Sequence Coding and Search System (SCSS) is a database maintained at Oak Ridge National Laboratory that provides access to full text electronic copies of Licensee Event Reports (LERs) dating back to 1980. Per the Code of Federal Regulations 10CFR50.73, LERs are required each time a plant is scrammed. Therefore, LERs present a comprehensive set of data addressing plant scrams. Licensee Event Reports (LERs), accessed through the SCSS database, comprised the primary source of data used in identification of scrams and trips in NUREG/CR-5750. Similarly, this database will be used to identify trips and scrams used in future calculations of initiating event frequencies and corresponding RBPI thresholds.

Advanced features associated with the SCSS database allow screening on various coding schemes to greatly reduce the number of LERs that must be manually reviewed. Review by experienced engineers is then performed to screen and group the data by functional failures. The lag time between the occurrence of the event and its entry into the SCSS database is approximately 10 weeks. LERs can also be obtained directly from the NRC in hard copy form and reduce this process to approximately eight weeks.

Monthly Operating Reports (MORs) are summaries of operating experience that are filed with the NRC on a monthly basis. These reports contain detailed information on plant operation including hours that the reactor was critical and type, duration and cause of shutdowns and power reductions. This information is tabulated in various databases maintained at the INEEL.

Initiating event frequencies reported in NUREG/CR-5750 and subsequently incorporated into the SPAR models are reported in terms of per critical hour/year. Therefore, knowledge of plant-specific critical hour data is essential in calculating these values. NUREG/CR-5750 utilized one of the INEEL databases built on MOR data (MORP1) as the primary data source used in identification of critical hours. Similarly, this database will be used to identify critical hours used in future calculations of initiating event frequencies and corresponding RBPI thresholds.

A.1.3 Identify Indicators Capable of Detecting Performance Changes in a Timely Manner

In addition to being risk-significant (see Table A.1.1.1-1), initiating event performance indicators must be capable of detecting performance changes in a timely manner. An initiating event performance indicator involves collection of data during some monitoring period, and a decision rule, which declares that a plant is in a certain performance band based on observed data. This monitoring period must be long enough to reduce the probabilities of false negatives and false

positives to acceptable levels, but no longer. When only one type of event is considered, such as initiating events, the decision rule is straightforward. It is to estimate the event occurrence rate, compare the estimate to the thresholds of the performance bands, and classify the plant accordingly. These analyses were performed with the results, including monitoring periods, documented in Appendices E and F.

In accordance with the preceding discussions, three initiating events/groups that met the criteria for risk-significance and timely monitoring were selected as candidates to be monitored as Initiating Event RBPIs. These initiators consist of Loss of Main Feedwater (LOFW[2]), Loss of Heat Sink (LOHS[2]), and General Transients. These initiators met the criteria of risk-significance as outlined in section A.1.1. Monitoring periods of reasonable length were also calculated based on acceptable levels of false positives and negatives. Additionally, changes in their frequencies can be readily quantified with the current SPAR models. These three initiator categories account for over 90% of all reactor trips.

The remaining initiators identified in Table A.1.1.1-1 are not considered good candidates for initiating event RBPIs due to the excessive monitoring periods required to yield statistically significant trends in performance. However, because of their potential risk-significance, these initiators cannot be ignored. These initiators account for a very small fraction of the plant trips recorded in the industry yet they are significant contributors to industry risk associated with nuclear power plants. For example, Loss-of-Coolant-Accidents are postulated as significant contributors to risk yet only five LOCA events are identified between 1987 and 1998. These were all 'very-small' LOCAs. There has never been recorded a medium or large LOCA event in the U. S. nuclear power industry. While monitoring these events at the plant level is not practical, trending them at the industry-wide level may provide important insights.

A.1.3.1 Industry-wide Trending of Initiating Events

The RBPI development program also provides industry-wide trends of the initiating events that are RBPIs as well as risk-significant performance elements that are not possible to trend on a plant-specific basis. Since more data are available at the industry level, trends emerging at the industry level may be apparent before plant-specific changes can be determined. The Loss of Offsite Power (LOOP) initiator is an example of a performance element that is difficult to trend at a plant-specific level yet will yield valuable information at the industry level. The IPE results indicate that LOOP is the dominant contributor to risk at U.S. nuclear power plants, however, plant-specific performance indicators are not practicable because of the excessive period required to monitor this initiator.

Initiators evaluated as Accident Sequence Precursors (ASP) will also be trended on an industry-wide basis. ASP events are a set of precursor events screened from the industry that have an increased potential for severe core damage. Trending of these events provides a better

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[2] The impact of LOOP events is indirectly considered within the LOFW and LOHS indicators. Due to the use of functional impact definitions for initiators, a LOOP event precipitates and is also counted within LOFW and LOHS events.

understanding of the risk-significant events occurring at U.S. commercial reactors. The Annual ASP Index for initiating events was selected as the figure of merit to trend. This index is based on the sum of the CCDPs of at power precursors involving initiating events divided by the number of reactor operating years.

To be selected for trending the candidate initiators must be risk-significant and actually occur in the industry (at least one occurrence since 1987 as recorded in NUREG/CR-5750). Thirteen initiating event types/groups meet these conditions and are identified as candidates for industry-wide trending. These initiating event types/groups and their respective NUREG/CR-5750 category are listed below:

1. Internal Flood (J1)
2. General Transients (Q)
3. Stuck Open Safety / Relief Valve - BWR (G2)
4. Initiators Evaluated as Accident Sequence Precursors (ASP)
5. Loss of Feedwater Initiators (P1)
6. Loss of Heat Sink Initiators (L)
7. Loss of Instrument/Control Air - BWR (D1)
8. Loss of Instrument/Control Air - PWR (D1)
9. Loss of Offsite Power Events (B1)
10. Loss of Vital AC Bus (C1, C2)
11. Loss of Vital DC Bus (C3)
12. Small/Very Small LOCA (G1, G3)
13. Steam Generator Tube Rupture (F1)

The Initiating Event RBPIs (General Transients, Loss of Feedwater, and Loss of Heat Sink) are trended in Table 5.3-6 of the main body of the report. Trends associated with non-RBPI events are shown below in Figures A.1.3.1-1 and A.1.3.1-10.

A.1.4 Identify Performance Thresholds Consistent with a Graded Approach to Performance Evaluation from SECY 99-007

A graded approach to identifying performance thresholds is built around four performance bands (green, white, yellow, red) whose boundaries correspond to plant-specific changes in CDF equal to 1E-6/yr, 1E-5/yr and 1E-4/yr. The two higher level thresholds (ΔCDF = 1E-5/yr and 1E-4/yr) were set in accordance with acceptance guidelines outlined in Regulatory Guide 174 (Ref. 7).

SECY 99-007 proposed a lower level threshold determined by choosing a value to no more than two significant figures such that about 95% of the plants would have observed data values that would be in the green zone. This process establishes a generic value that is applied to each plant. The weakness of this method is that it depends only on the number of plants with less than acceptable performance but not on how much their performance exceeds the norm (i.e., actual risk). Additionally, due to the large plant-to-plant variability in the importance of systems, this

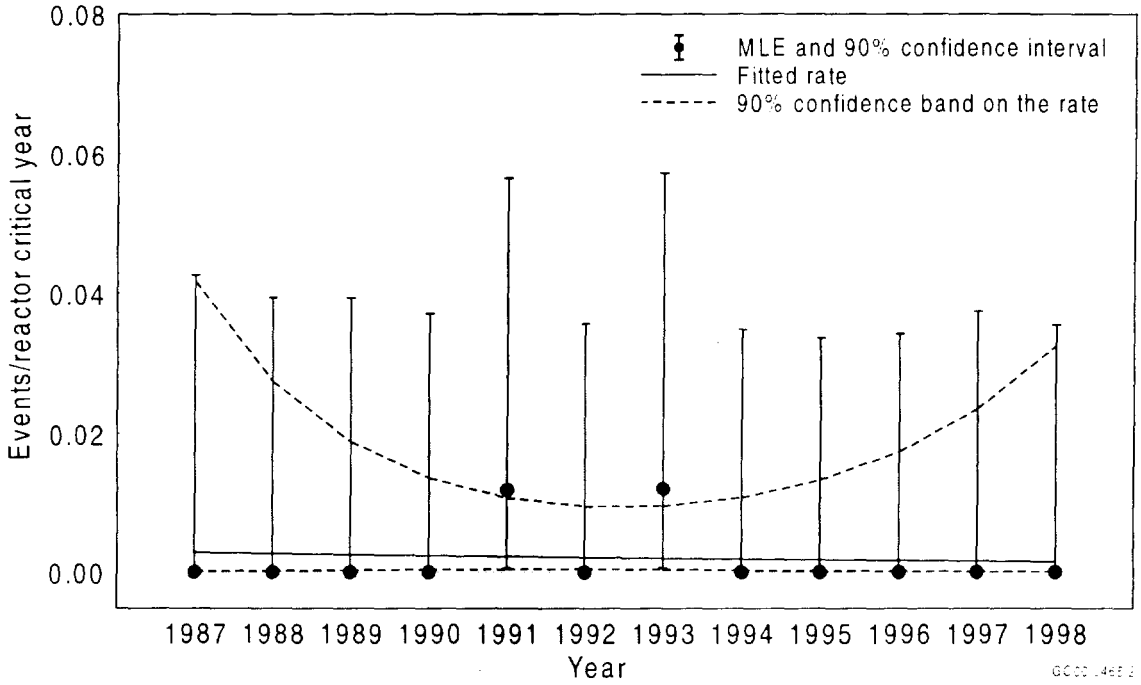

Figure A.1.3.1-1 Time-dependent Trending of Internal Flood Initiating Events (Trend is not close to statistically significant, p-value = 0.8)

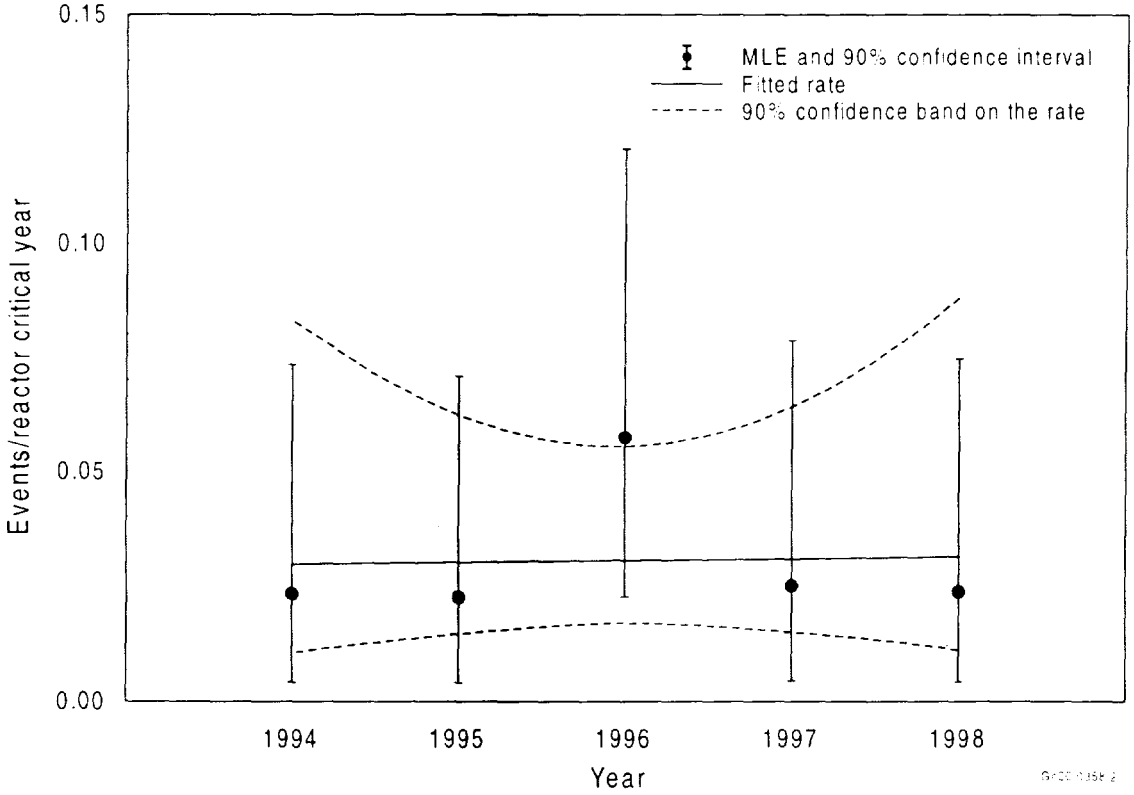

Figure A.1.3.1-2 Time-dependent Trending of Annual Initiating Event ASP Index (The trend is not close to statistically significant, p-value = 0.9)

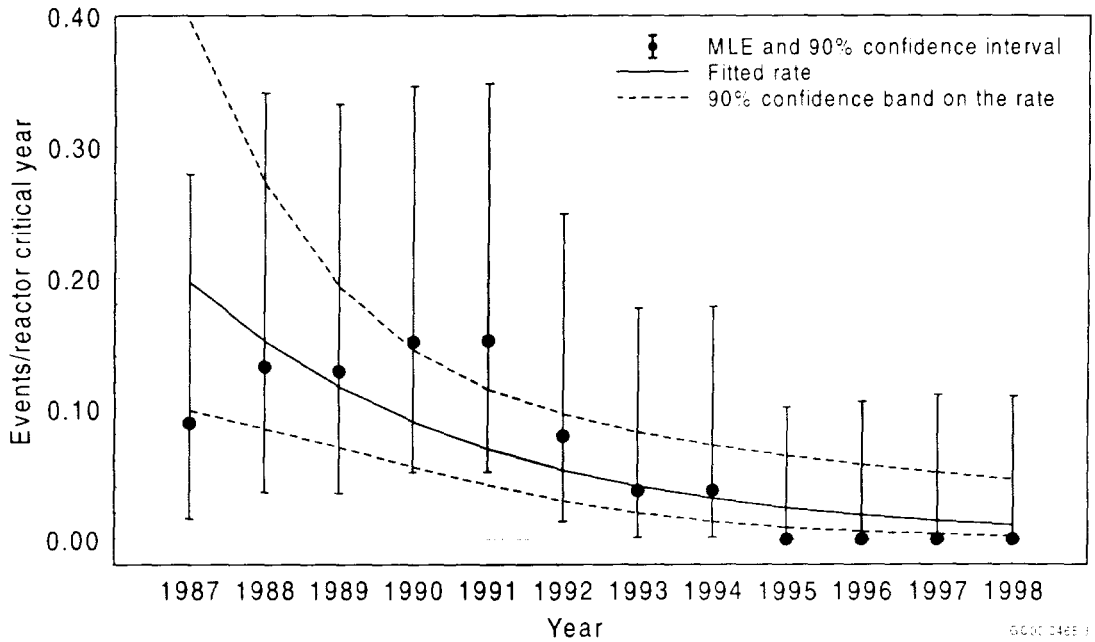

Figure A.1.3.1-3 Time-dependent Trending of Loss of Instrument/Control Air (BWR) Initiators (The trend is statistically very significant, p-value = 0.0016)

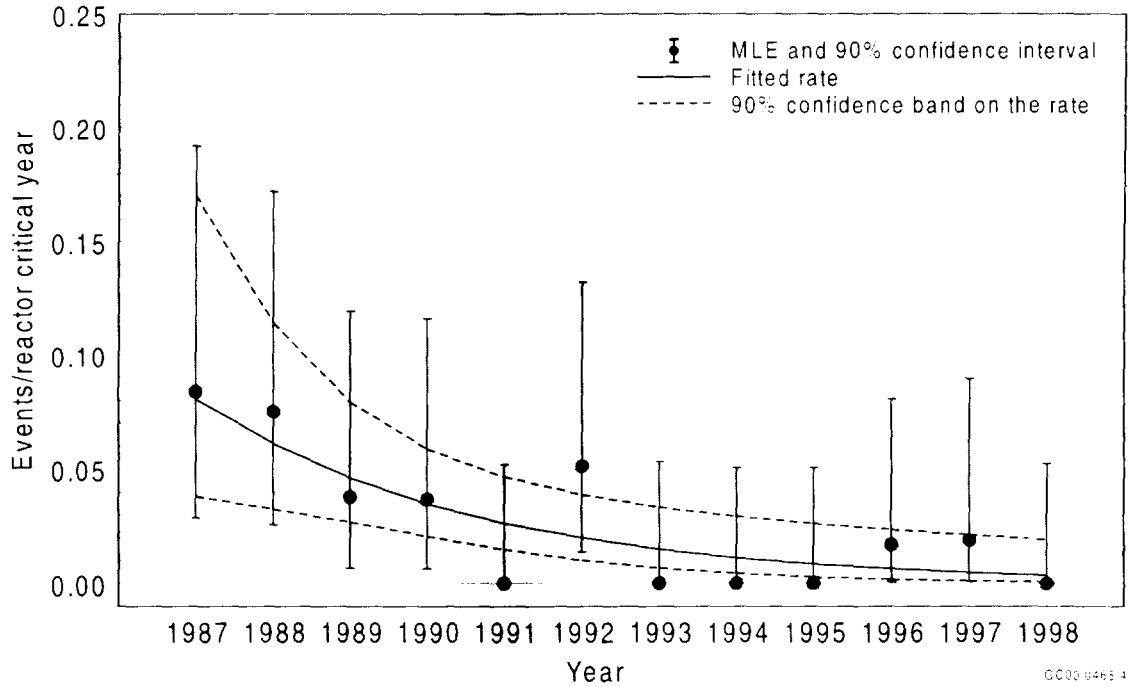

Figure A.1.3.1-4 Time-dependent Trending of Loss of Instrument/Control Air (PWR) Initiators (The trend is statistically very significant, p-value = 0.0016)

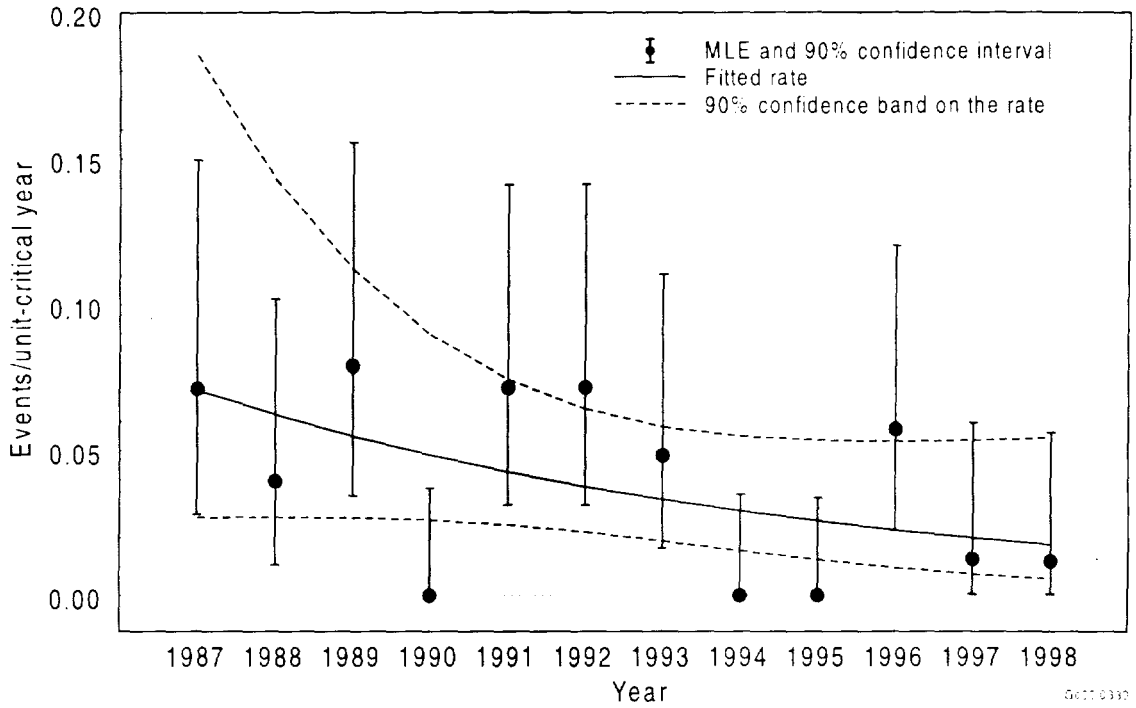

Figure A.1.3.1-5 Time-dependent Trending of Loss of Offsite Power Initiating Events (When extra-Poisson scatter is accounted for, trend is not statistically significant, p-value = 0.10)

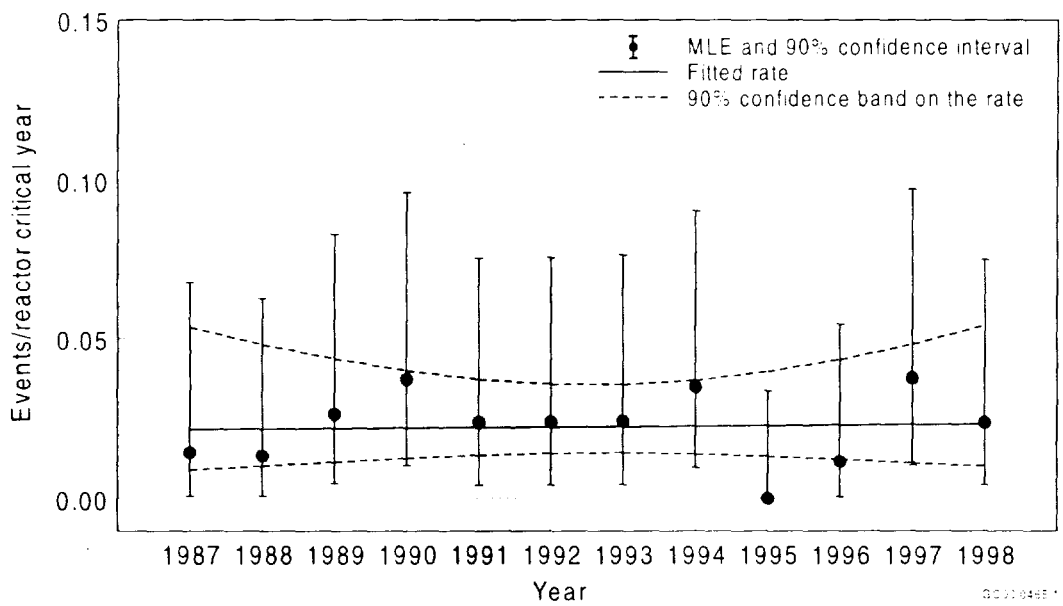

Figure A.1.3.1-6 Time-dependent Trending of Loss of Safety Related Vital AC Bus Initiators (Trend is not close to statistically significant, p-value = 0.9)

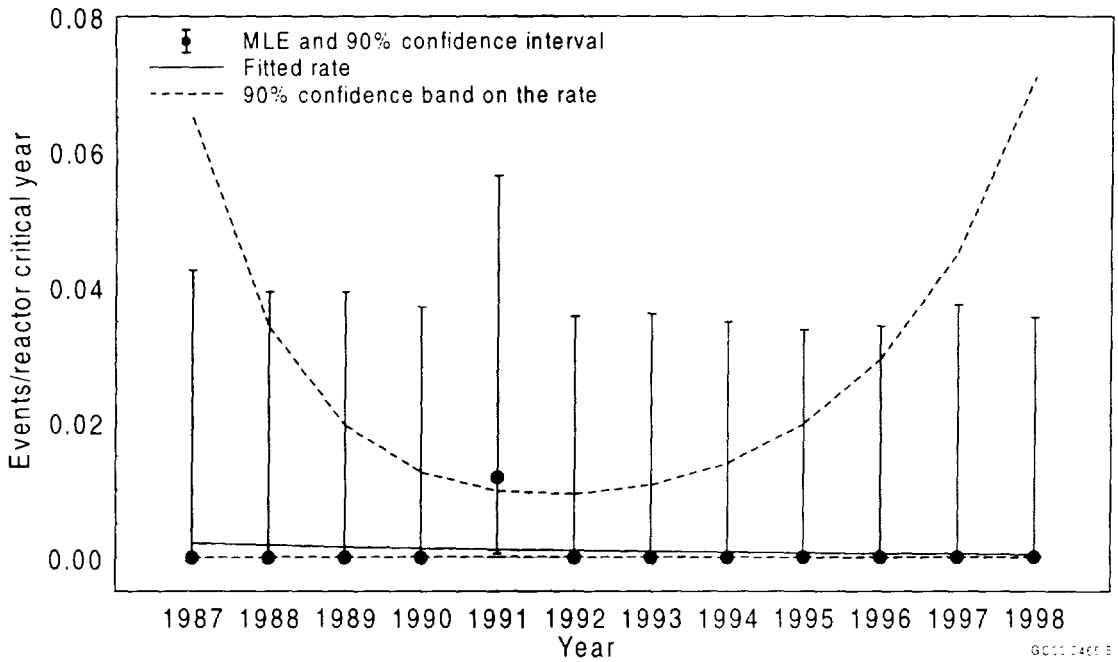

Figure A.1.3.1-7 Time-dependent Trending of Loss of Safety Related Vital DC Bus Initiators (Trend is not close to statistically significant, p-value = 0.6)

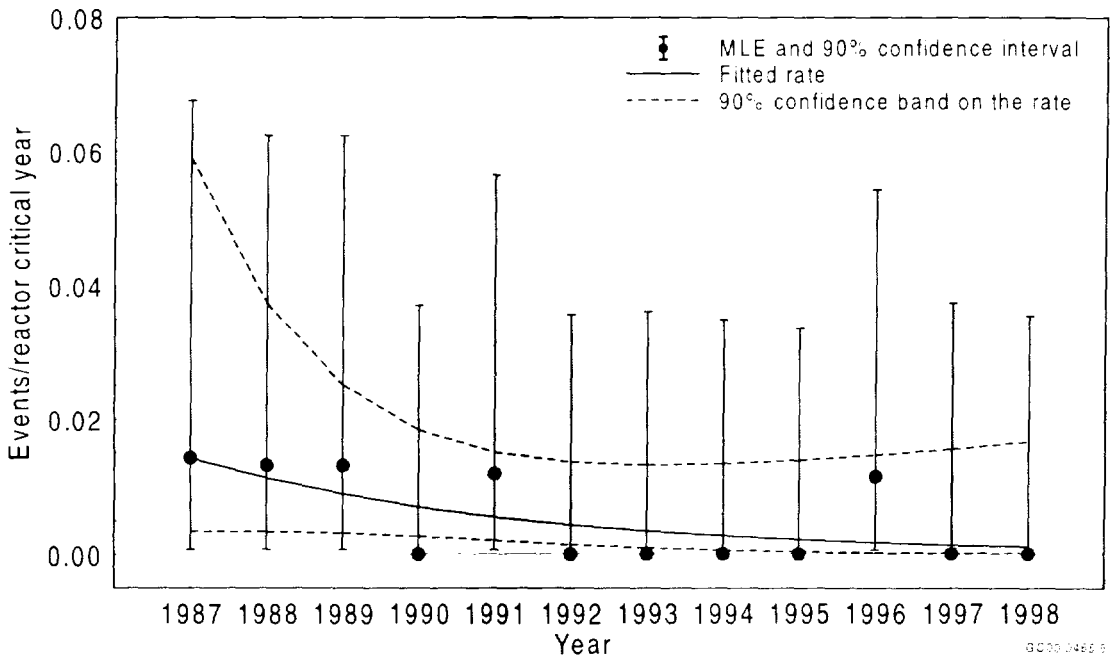

Figure A.1.3.1-8 Time-dependent Trending of Loss of Small/Very Small LOCA Initiators (Trend is not statistically significant, p-value = 0.17)

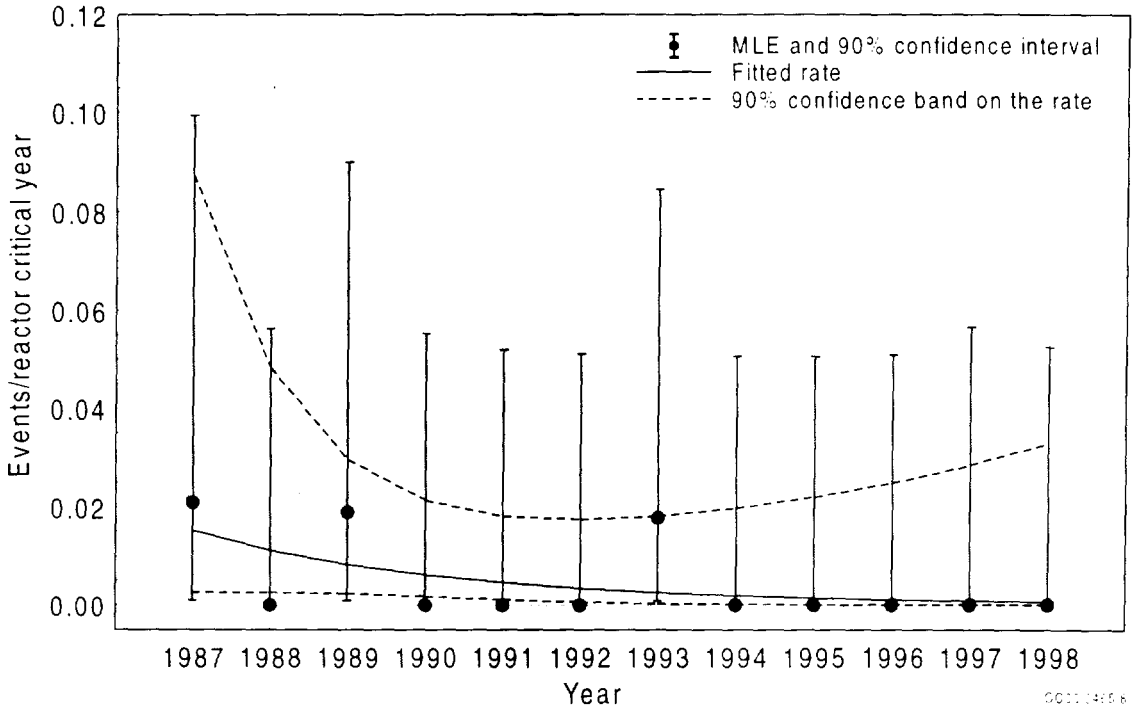

Figure A.1.3.1-9 Time-dependent Trending of Steam Generator Tube Rupture Initiators (Trend is not statistically significant, p-value = 0.17)

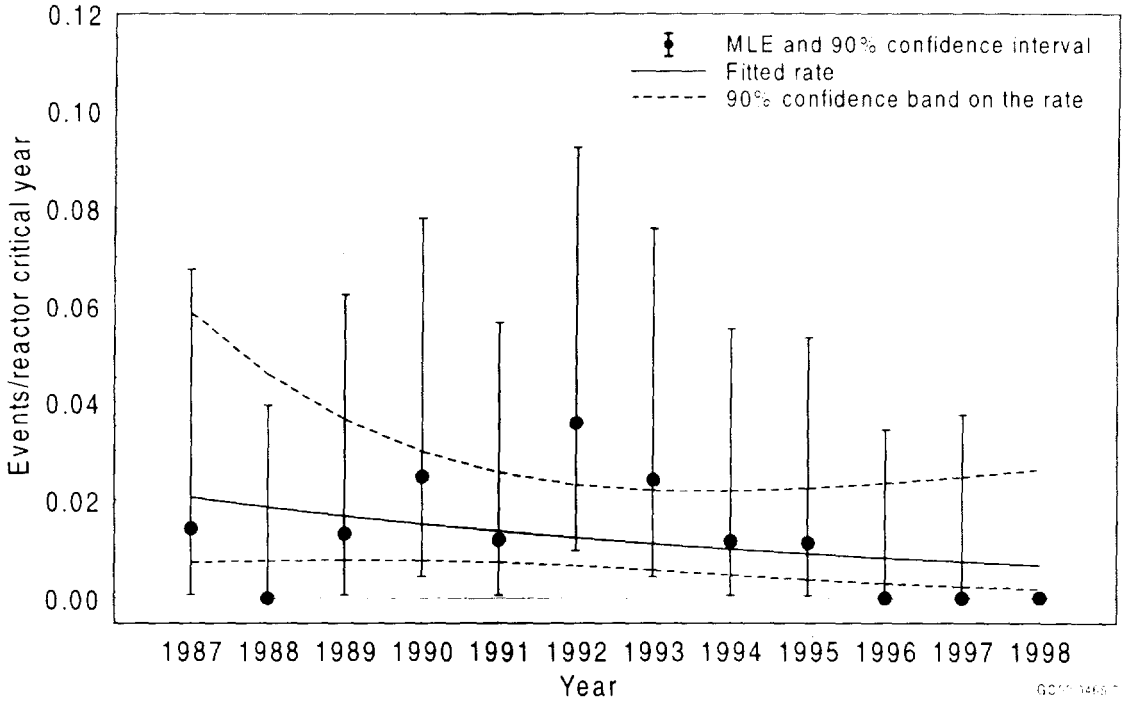

Figure A.1.3.1-10 Time-dependent Trending of Stuck Open Safety/Relief Valve - BWR Initiating Event (Trend is not statistically significant, p-value = 0.24)

value correlates to changes in CDF in excess of 1E-5/year at some plants. After considerable analysis, the alternative lower level threshold (green/white) of ΔCDF = 1E-6/yr was chosen. This value is consistent with the order of magnitude decrements associated with the higher level thresholds. It is also consistent with the green/white interval associated with inspection findings evaluated in the Significance Determination Process (SDP).

To evaluate changes in performance as well as current thresholds and future performance trends, a fixed reference point (i.e., performance baseline) corresponding to current nominal performance is required. To facilitate plant-specific threshold values, a 'baseline' model was constructed for each plant analyzed in the RBPI program. Plant-specific logic (i.e., the SPAR models) was used to allow plant-specific design and operational characteristics to be credited. These models were 'baselined' to 1996 performance by incorporating appropriate unavailability data from the World Association of Nuclear Operators (WANO, Ref. 8), and reliability data from the system reliability studies (References 9, 10, 11, 12, 13, and 14). (Note: EPIX/RADs (References 15 and 16) will provide the failure data used in future performance trending and was the preferred data source for the baseline models.) In some cases minor modifications to the logic were also made to ensure that the logic structure of the models matched the available data.

An iterative technique is employed to determine the exact thresholds. The frequency of the initiator is increased until the plant core damage frequency increases by an amount correlating to the performance action bands limits (i.e., 1E-6, 1E-5, 1E-4). Calculation of the Transient initiating event thresholds is straightforward using this process. Calculation of the LOFW and LOHS initiating event thresholds is obtained in a similar fashion, however, the process is somewhat more complex since they are conditional events within the Transient event tree and do not have their own explicit event trees.

Initiating event RBPIs were selected and their threshold values calculated for fifteen sites (23 plants). These sites are comprised of nine BWR and fourteen PWR plants. Detailed threshold information for each analyzed plant is contained in Tables A.1.4-1 through A.1.4-15.

A.1.5 Inspection Areas Covered by New RBPIs

The RBPIs developed in this report for the initiating events cornerstone were compared with the performance indicators in the ROP to identify those RBPIs that are not currently in the ROP. The inspection areas that could be impacted by the new initiating event RBPIs were then determined. The results are summarized in Table A.1.5-1.

A.2 Mitigating Systems Cornerstone

This section discusses development of RBPIs that address the mitigating systems cornerstone for full power, internal events. External events and non-power modes are addressed in other sections.

Table A.1.4-1 WE 4-Lp Plant 1 Initiating Events Threshold Summary

WE 4-Lp Plant 1 SPAR 3i (1.0E-8/hr, 7.2E-5/calendar year[1]) WE 4-Lp Plant 1 RBPI Baseline (1.1E-8/hr, 7.5E-5/calendar year[1])					
PWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.0 / calendar year	1.8 / calendar year	1.2 / calendar year	2.9 / calendar year	19 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	1.9E-1 / calendar year	1.6 / calendar year	16 / calendar year
Loss of Heat Sink[3]	9.6E-2 / calendar year	2.6E-1 / calendar year	9.7E-2 / calendar year	3.8E-1 / calendar year	3.2 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-2 CE Plant 2 Initiating Events Threshold Summary

CE Plant 2 SPAR 3i (2.6E-9/hr, 1.8E-5/calendar year[1]) CE Plant 2 RBPI Baseline (2.1E-9/hr, 1.4E-5/calendar year[1])					
PWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.0 / calendar year	1.8 / calendar year	8.2 / calendar year	72 /calendar year	720 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	8.0E-1 / calendar year	12 / calendar year	120 / calendar year
Loss of Heat Sink[3]	9.6E-2 / calendar year	2.6E-1 / calendar year	2.8E-1 / calendar year	2.9 / calendar year	28 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-3 BWR 3/4 Plant 5 Initiating Events Threshold Summary

BWR 3/4 Plant 5 SPAR 3i (2.0E-9/hr, 1.4E-5/calendar year[1]) BWR 3/4 Plant 5 RBPI Baseline (2.2E-9/hr, 1.5E-5/calendar year[1])					
BWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.3 / calendar year	2.2 / calendar year	1.6 / calendar year	4.0 / calendar year	28 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	1.4E-1 / calendar year	8.0E-1 / calendar year	8.0 / calendar year
Loss of Heat Sink[3]	2.3E-1 / calendar year	3.1E-1 / calendar year	3.0E-1 / calendar year	9.6E-1 / calendar year	8.0 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-4 BWR 3/4 Plant 6 Initiating Events Threshold Summary

BWR 3/4 Plant 6 SPAR 3i (2.8E-9/hr, 2.0E-5/calendar year[1]) BWR 3/4 Plant 6 RBPI Baseline (2.4E-9/hr, 1.7E-5/calendar year[1])					
BWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.3 / calendar year	2.2 / calendar year	1.6 / calendar year	4.0 / calendar year	30 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	1.5E-1 / calendar year	9.6E-1 / calendar year	8.8 / calendar year
Loss of Heat Sink[3]	2.3E-1 / calendar year	3.1E-1 / calendar year	3.0E-1 /calendar year	9.4E-1 / calendar year	8.0 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-5 CE Plant 4 Initiating Events Threshold Summary

CE Plant 4 SPAR 3i (2.6E-9/hr, 1.8E-5/calendar year[1]) CE Plant 4 RBPI Baseline (2.2E-9/hr, 1.6E-5/calendar year[1])					
PWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.0 / calendar year	1.8 / calendar year	1.9 / calendar year	9.3 / calendar year	88 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	5.4E-1 / calendar year	4.8 / calendar year	48 / calendar year
Loss of Heat Sink[3]	9.6E-2 / calendar year	2.6E-1 / calendar year	2.0E-1 / calendar year	1.1 / calendar year	10 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-6 BWR 5/6 Plant 2 Initiating Events Threshold Summary

BWR 5/6 Plant 2 SPAR 3i (1.2E-9/hr, 8.6E-6/calendar year[1]) BWR 5/6 Plant 2 RBPI Baseline (1.4E-9/hr, 9.9E-6/calendar year[1])					
BWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.3 / calendar year	2.2 / calendar year	1.9 / calendar year	7.3 / calendar year	60 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	2.2E-1 / calendar year	1.7 / calendar year	16 / calendar year
Loss of Heat Sink[3]	2.3E-1 / calendar year	3.1E-1 / calendar year	3.8E-1 / calendar year	1.8 / calendar year	16 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-7 BWR 3/4 Plant 11 Initiating Events Threshold Summary

BWR 3/4 Plant 11 SPAR 3i (4.9E-9/hr, 3.4E-5/calendar year[1]) BWR Plant 11 RBPI Baseline (5.6E-9/hr, 3.9E-5/calendar year[1])					
BWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.3 / calendar year	2.2 / calendar year	1.4 / calendar year	2.5 / calendar year	14 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	1.0E-1 / calendar year	4.3E-1 / calendar year	3.8 / calendar year
Loss of Heat Sink[3]	2.3E-1 / calendar year	3.1E-1 / calendar year	2.6E-1 / calendar year	6.0E-1 / calendar year	4.0 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-8 BWR 3/4 Plant 8 Initiating Events Threshold Summary

BWR 3/4 Plant 8 SPAR 3i (8.7E-10/hr, 6.1E-6/calendar year[1]) BWR 3/4 Plant 8 RBPI Baseline (7.6E-10/hr, 5.3E-6/calendar year[1])					
BWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.3 / calendar year	2.2 / calendar year	3.2 / calendar year	13 / calendar year	113 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	2.6E-1 / calendar year	2.0 / calendar year	19 / calendar year
Loss of Heat Sink[3]	2.3E-1 / calendar year	3.1E-1 / calendar year	4.2E-1 / calendar year	2.1 / calendar year	19 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-9 CE Plant 5 Initiating Events Threshold Summary

CE Plant 5 SPAR 3i (4.0E-9/hr, 2.8E-5/calendar year[1]) CE Plant 5 RBPI Baseline (2.6E-9/hr, 1.8E-5/calendar year[1])					
PWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.0 / calendar year	1.8 / calendar year	1.3 / calendar year	4.1 / calendar year	32 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	2.3E-1 / calendar year	1.8 / calendar year	17 / calendar year
Loss of Heat Sink[3]	9.6E-2 / calendar year	2.6E-1 / calendar year	1.3E-1 / calendar year	4.4E-1 / calendar year	3.6 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-10 B&W Plant 4 Initiating Events Threshold Summary

B&W Plant 4 SPAR 3i (2.1E-9/hr, 1.5E-5/calendar year[1]) B&W Plant 4 RBPI Baseline (2.5E-9/hr, 1.7E-5/calendar year[1])					
PWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.0 / calendar year	1.8 / calendar year	1.2 / calendar year	2.7 / calendar year	17 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	2.0E-1 / calendar year	1.9 / calendar year	17 [4] / calendar year
Loss of Heat Sink[3]	9.6E-2 / calendar year	2.6E-1 / calendar year	1.0E-1 / calendar year	4.0E-1 / calendar year	3.4 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.
4. Estimated value.

Table A.1.4-11 BWR 3/4 Plant 15 Initiating Events Threshold Summary

BWR 3/4 Plant 15 SPAR 3i (5.8E-10/hr, 4.1E-6/calendar year[1]) BWR 3/4 Plant 15 RBPI Baseline (5.3E-10/hr, 3.7E-6/calendar year[1])					
BWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.3 / calendar year	2.2 / calendar year	2.2 / calendar year	10 / calendar year	90 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	3.1E-1 / calendar year	2.6 / calendar year	25 / calendar year
Loss of Heat Sink[3]	2.3E-1 / calendar year	3.1E-1 / calendar year	4.8E-1 / calendar year	2.6 / calendar year	25 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-12 WE 2-Lp Plant 5 Initiating Events Threshold Summary

WE 2-Lp Plant 5 SPAR 3i (2.1E-9/hr, 1.4E-5/calendar year[1]) WE 2-Lp Plant 5 RBPI Baseline (2.1E-9/hr, 1.5E-5/calendar year[1])					
PWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.0 / calendar year	1.8 / calendar year	1.4 / calendar year	4.7 / calendar year	38 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	4.0E-1 / calendar year	3.2 / calendar year	32 / calendar year
Loss of Heat Sink[3]	9.6E-2 / calendar year	2.6E-1 / calendar year	1.7E-1 / calendar year	9.6E-1 / calendar year	8.8 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-13 BWR 3/4 Plant 18 Initiating Events Threshold Summary

BWR 3/4 Plant 18 SPAR 3i (3.7E-9/hr, 2.6E-5/calendar year[1]) BWR 3/4 Plant 18 RBPI Baseline (2.9E-9/hr, 2.0E-5/calendar year[1])					
BWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.3 / calendar year	2.2 / calendar year	2.0 / calendar year	7.9 /calendar year	67 /calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	3.0E-1 / calendar year	2.5 / calendar year	24 / calendar year
Loss of Heat Sink[3]	2.3E-1 / calendar year	3.1E-1 / calendar year	4.1E-1 / calendar year	3.4 / calendar year	33 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-14 CE Plant 12 Initiating Events Threshold Summary

CE Plant 12 SPAR 3i (4.0E-9/hr, 2.8E-5/calendar year[1]) CE Plant 12 RBPI Baseline (2.7E-9/hr, 1.9E-5/calendar year[1])					
PWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.0 / calendar year	1.8 / calendar year	1.6 / calendar year	7.2 / calendar year	62 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	4.2E-1 / calendar year	3.7 / calendar year	35 / calendar year
Loss of Heat Sink[3]	9.6E-2 / calendar year	2.6E-1 / calendar year	1.2E-1 / calendar year	9.6E-1 / calendar year	8.8 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.4-15 WE 4-Lp Plant 22 Initiating Events Threshold Summary

WE 4-Lp Plant 22 SPAR 3i (4.7E-9/hr, 3.3E-5/calendar year[1]) WE 4-Lp Plant 22 RBPI Baseline (4.9E-9/hr, 3.4E-5/calendar year[1])					
PWR Initiator	Baseline IE Frequency (NUREG/CR-5750)	Green/White Threshold 95th%ile	Green/White Threshold (ΔCDF =1E-6/year)	White/Yellow Threshold (ΔCDF =1E-5/year)	Yellow/Red Threshold (ΔCDF =1E-4/year)
Transient Initiator[2]	1.0 / calendar year	1.8 / calendar year	1.8 / calendar year	8.8 / calendar year	78 / calendar year
Loss of Feedwater[3]	6.8E-2 / calendar year	2.0E-1 / calendar year	8.0E-1 / calendar year	7.2 / calendar year	74 / calendar year
Loss of Heat Sink[3]	9.6E-2 / calendar year	2.6E-1 / calendar year	2.4E-1 / calendar year	1.5 / calendar year	15 / calendar year

1. Calendar year is defined as 7000 critical hours.
2. Includes transient, loss of feedwater, and loss of heat sink, to agree with modeling in SPAR.
3. Estimated IE frequency based on conditional core damage frequency of existing SPAR LOHS and LOFW sequences.

Table A.1.5-1 Summary of Inspection Areas Impacted by New RBPIs for Initiating Event Cornerstone

RBPI	Attribute	Inspection Area
General Transient	Equipment Performance	71111.12, Maintenance Rule Implementation 71111.08, Inservice Inspection Activities 71111.20, Refueling and Outage Activities 71152, Identification and Resolution of Problems
	Human Performance	71111.14, Personnel Performance During Non-routine Evolutions
LOFW		None
LOHS	Protection Against External Factors	71111.07, Heat Sink Performance

A.2.1 Assess the Potential Risk Impact of Degraded Performance

The objective of the mitigating system cornerstone is to ensure adequate performance (availability, reliability, and capability) of systems that mitigate initiating events to prevent reactor accidents. Six 'key attributes' that contribute to mitigating system performance are identified in SECY 99-007 (Ref. 1). These six attributes consist of configuration control, procedure quality, human performance, protection against external events, equipment performance, and design.

A.2.1.1 Determine Attributes That Are Risk-Significant and Explicitly Modeled

Determination of 'risk-significant' or 'risk-based' performance indicators necessitates a means of quantifying the impact of that attribute. However, of the mitigating system attributes listed above, only equipment performance and some aspects of human performance (i.e., post initiator actions) are explicitly modeled and can be quantified in currently available risk models (IPE and SPAR). Potential performance indicators are further reduced by the fact that even though human performance is modeled and is shown to be risk-significant, changes in performance are not readily measurable. Currently there is no established method of identifying changes in operator performance and then feeding this information back into the SPAR models. As a result, equipment performance is the only mitigating system attribute that will be evaluated in this analysis.

Risk-significance of modeled mitigating systems was determined through analysis of Revision 3i SPAR models supplemented by quantification results found in the Individual Plant Examination (IPE) submittals and the associated IPE Database (Ref. 5). Risk-significance of mitigating systems was based on importance measures. Importance information resulting from quantification of the models was summarized on a plant-specific basis by system/component and evaluated for importance to overall plant risk. Importance measure values in accordance with those specified in the PSA Applications Guide (Ref. 18) and Regulatory Guide 1.160 (Maintenance Rule, Ref. 19) were utilized in the determination of risk-significance. A system was considered to be risk-significant at the plant level if its system level Fussell-Vesely Importance (FV) > 0.05. A system was also considered risk-significant if a component within that system yielded a Risk Achievement Worth (RAW) > 2.0 in conjunction with a component level FV > 0.005. Systems that met either of these criteria were considered risk-significant at the individual plant level. Support systems identified in the IPE database as contributing in excess of five percent to overall core damage frequency were also considered important at the plant level.

In addition to risk-significant systems, risk-significant component classes were also identified using a similar process. The same importance criteria were used to select component class indicators, however, the system level Fussell-Vesely Importance values were determined using the multi-variable or group function available in SAPHIRE. There are two main benefits for identifying component group RBPIs. The first is that trends and impacts on CDF that might not be detected at the individual system level might be picked up at the component group level. The second benefit is that the component group RBPIs can be trended across plant groups or the entire industry to detect early signs of deteriorating performance. Three component classes were

identified as risk-significant. These classes include air-operated valves (AOVs), motor-driven pumps (MDPs), and motor-operated valves (MOVs).

The RBPI white paper (Ref. 3) indicates that RBPI development will be performed in a manner to group similar plants so that a given set of RBPIs apply to the entire group. This task was performed in two steps. The first step was performed prior to determining risk-significance of specific systems. In this step all plants were grouped according to similarities in configuration and/or design that were expected to result in differences in systems selected as important. This step facilitated identification of a preliminary plant grouping based on systems that may be important at only a subset of plants having a particular design characteristic. The second step was to validate the plant groupings based on actual system importance results obtained from the quantified models. Due to the limited number of plants in the pilot program, only two distinct plant groups were identified and then validated (BWR and PWR). Additional plant grouping are anticipated following evaluation of the remaining plants. Additionally, as more plants are evaluated, it is expected that some mitigating system RBPIs may be eliminated from some plant groups (e.g., CCW). The list of risk-significant mitigating systems and the plant groups to which they are generically applicable are listed in Table A.2.1.1-1. Systems that are risk-significant at only a single plant or a limited number of plants were identified in Tables A.2.4-1 through A.2.4-15 as plant-specific inspection candidates.

Table A.2.1.1-1 Modeled Risk-Significant Mitigating Systems

	Plant Group #1 (BWR)	Plant Group #2 (PWR)	Timely Detection of Performance Changes at the Plant Level and Availability of Performance Data
Auxiliary/Emergency Feedwater		X	Yes
Component Cooling Water		X	Yes[1]
Emergency AC Power	X	X	Yes
High Pressure Coolant Injection Systems (HPCI, HPCS)	X		Yes
High Pressure Heat Removal Systems (RCIC, IC)	X		Yes[2]
High Pressure Safety Injection		X	Yes
Main Feedwater	X		Yes (As LOFW RBPI)
Main Steam/Main Steam Isolation		X	Yes (As LOFW/LOHS RBPI)
Power Conversion System	X		Yes (As LOHS RBPI)
Power Operated Relief Valve		X	Yes[1]
Primary Pressure Relief	X	X	No[3]
Reactor Protection System	X	X	No[4]
Residual/Decay Heat Removal	X	X	Yes
Service Water (To EDG/RHR)	X	X	Yes
Risk-Significant Component Classes			
Air-Operated Valves	X	X	Yes
Motor-Operated Valves	X	X	Yes
Motor-Driven Pumps	X	X	Yes

1 Marginal RBPI candidate, may be removed following evaluation of additional plants and/or data.

2 The Isolation Condenser was provisionally added as a 'Mitigating System' performance indicator at the five units that comprise the BWR 1/2/3 class based on importances calculated in original IPE submittals. The inclusion of this system as an RBPI will be re-evaluated following completion of Revision 3 SPAR models for these plants.

3 Timely detection of performance at the plant level is not feasible due to sparseness of data.

4 The Reactor Protection System (RPS) has substantial safety implications if performance degrades significantly. However, the RPS is not included as a candidate RBPI due to significant differences between the level of detail found in the SPAR 3i logic and level at which failure data is reported in EPIX. The current SPAR 3i models through which the RBPI thresholds are calculated have limited detail in the RPS system logic. The BWR models contain four hardware events and the PWR models contain three events. EPIX contains extensive amounts of failure data associated with dozens of components in the RPS system but at a much lower level of detail. Without significant modification to the SPAR 3i RPS logic to incorporate lower levels of data, it is not feasible to incorporate updated EPIX failure data into the RPS models so that changes in performance can be quantified and tracked.

A.2.1.2 Determine Monitoring Levels for Each Element

Performance can be monitored using indicators at different levels, ranging from the function level comprising multiple systems down to the level of the individual component failure mode. Higher level (e.g., function or system level) indicators have certain positive attributes: they allow for more licensee flexibility than lower level indicators, and provide more apparent coverage per indicator, resulting in fewer indicators for a given level of apparent coverage than would be needed using lower-level indicators. However, in some areas, certain practical considerations compel the selection of indicators at a lower level. In these areas, train-level indicators are used. Train-level indicators are further broken down into unreliability and unavailability indicators. The following discussion addresses the practical considerations that lead to selection of train-level indicators.

The use of a single indicator above the train level is inappropriate for systems with dissimilar trains. Table A.2.1.2-1 illustrates this point with an example of an Auxiliary Feedwater System consisting of a diesel-driven pump train and a motor-driven pump train. The dominant accident scenarios associated with this plant are associated with LOOP events, especially events in which on-site AC power is also lost. If AC motive power is not available, the AC-driven pump train performance is moot, and the diesel-driven pump train performance is especially important. This argument suggests that changes in CDF due to decreases in AFW system performance are much more sensitive to degradation of the diesel driven train performance than to an equivalent change in AFW system performance due to degradation of performance of the motor-driven train. This is reflected in the values in Table A.2.1.2-1. These differences are due to the mission specific nature of the different trains. Therefore, to accurately reflect the risk implications of a given change in performance, separate indicators are required for dissimilar trains of a given system.

For similar reasons, systems that have train specific loads such as emergency AC power lend themselves well to train level unavailability indicators. Many service water and component cooling water systems also have train specific loads (i.e., lack of a single common header) and are better addressed with train level indicators.

Additionally, failures at the train level are much more frequent than system-level failures of multiple-train systems. Thus, the timely detection of performance trends at the train level is typically much more feasible than at the system level.

Table A.2.1.2-1 Auxiliary Feedwater System Example of the Differing Impacts of Dissimilar Trains on CDF

AFW System Top Event Probability	3.7E-4 (Nominal)	5.0E-4	1.0E-3	5.0E-3
ΔCDF Associated with Degradation of Diesel-Driven Pump (DDP) Train Performance Only.	**ΔCDF = 0.0**	**ΔCDF = 5.6E-6**	**ΔCDF = 1.1E-4**	**ΔCDF = 8.7E-4**
ΔCDF Associated with Degradation of Motor-Driven Pump (MDP) Train Performance Only	**ΔCDF = 0.0**	**ΔCDF = 3.5E-7**	**ΔCDF = 6.7E-6**	**ΔCDF = 5.8E-5**

Separate indicators for unreliability and unavailability are also appropriate because the relationship between system performance and CDF is highly dependent on whether reliability or availability is causing the change in system performance. The difference arises because train unavailability is somewhat constrained by Technical Specifications, while reliability is not. In the calculation of CDF, Technical Specifications are assumed to be followed explicitly, and cutsets with disallowed maintenance combinations are eliminated from the CDF cutset tabulations. Table A.2.1.2-2 illustrates the results of this process. This table shows that CDF is more sensitive to EPS reliability than to EPS availability.

Another difference between the significance of unavailability changes and unreliability changes arises as a result of common cause failure (CCF). As modeled, an increase in a specific train's unreliability affects CDF not only through the increased probability of failures of that train, but also through the increased probability of common cause failures of redundant trains. Unavailability does not behave in the same way; as discussed above, concurrent unavailability of redundant trains is limited by technical specifications.

Therefore, a single train-level performance indicator that combines unreliability and unavailability is inadequate to address the risk implications of changing system performance.

Table A.2.1.2-2 Emergency Power System Example of the Differing Impacts of Unavailability and Unreliability on CDF

Emergency Diesel Generator Top Event Probability	4.6E-2 (Nominal)	5.0E-2	1.0E-1	5.0E-1
ΔCDF Associated with Degradation of Diesel Generator Availability (UA) Only	**ΔCDF = 0.0**	**ΔCDF = 6.3E-7**	**ΔCDF = 9.1E-6**	**ΔCDF = 7.6E-5**
ΔCDF Associated with Degradation of Diesel Generator Reliability (UR) Only	**ΔCDF = 0.0**	**ΔCDF = 1.1E-6**	**ΔCDF = 2.4E-5**	**ΔCDF = 5.8E-4**

Other considerations also support the use of train level unavailability indicators. SECY 99-007 also identifies reliability and availability as the two specific elements associated with equipment performance. Maintenance is normally performed on the train level and is intrinsically recognizable as such to plant personnel. This fact is also incorporated in the SPAR models with their placement of test and maintenance events at the train level. Additionally, WANO reports unavailability at the train level.

There are some shortcomings in using train level performance indicators. A few system fault trees in the SPAR models include common cause failures (CCF) at the system level. Since CCF

events are often significant contributors to overall system unreliability, system level unreliability indicators would more closely mimic actual CDF changes. Finally, non-redundant systems are typically best addressed at the system level. For example, the key safety function of PORVs at some plants requires success of 2/2 PORVs, so that if either PORV fails, the function fails.

Table A.2.1.2-3 identifies the risk-significant systems, elements and the level of the associated performance indicator.

Table A.2.1.2-3 Candidate Mitigating System RBPIs and Monitoring Level

BWR RBPI SYSTEMS	RBPI Level
Emergency AC Power (EPS)	Unreliability and unavailability both monitored at the train level.
High Pressure Coolant Injection Systems • High Pressure Coolant Injection (HPCI) • High Pressure Core Spray (HPCS)	Unreliability and unavailability both monitored at the train level.
High Pressure Heat Removal Systems • Isolation Condenser (IC) • Reactor Core Isolation Cooling (RCIC)	Unreliability and unavailability both monitored at the train level.
Residual Heat Removal (SPC, RHR)	Unreliability and unavailability both monitored at the train level.
Service Water (SWS)	Unreliability and unavailability both monitored at the train level.
PWR RBPI SYSTEMS	
Auxiliary Feedwater (AFW/EFW) • Motor-driven Pump Train • Turbine-driven Pump Train	 Unreliability and unavailability both monitored at the train level. Unreliability and unavailability both monitored at the train level.
Component Cooling Water (CCW)	Unreliability and unavailability both monitored at the train level.
Emergency AC Power (EPS)	Unreliability and unavailability both monitored at the train level.
High Pressure Injection (HPI)	Unreliability and unavailability both monitored at the train level.
Power Operated Relief Valve (PORV)	Unreliability monitored at the system level.
Residual/Decay Heat Removal (RHR)	Unreliability and unavailability both monitored at the train level.
Service Water (SWS)	Unreliability and unavailability both monitored at the train level.
COMPONENT CLASSES (all plants)	
Air-Operated Valves (AOVs)	Unreliability monitored at the component level.
Motor-Operated Valves (MOVs)	Unreliability monitored at the component level.
Motor-Driven Pumps (MDPs)	Unreliability monitored at the component level.

A.2.2 Obtain Performance Data for Risk-Significant, Equipment-Related Elements

The analysis of mitigating system performance also relies on several data sources. The primary data sources used in the selection of, and their contribution to, the analysis of mitigating system RBPIs are described below:

The Equipment Performance and Information Exchange database (EPIX) is an industry-sponsored effort to collect performance information for key components in or affecting risk-significant systems as identified in plant maintenance rule programs. EPIX (Ref. 15) is a replacement for the Nuclear Plant Reliability Data System (NPRDS) database. (Data reporting to NPRDS stopped at the end of 1996.) All nuclear utilities have submitted some reliability data for entry into EPIX. The current RBPI pilot effort uses EPIX data to support the evaluation of mitigating system unreliability RBPIs.

The Reliability and Availability Data System (RADS) interfaces with established data sources to provide risk analysis capability for use with risk-informed applications and regulations. RADS (Ref. 16) takes this raw failure, demand, and unavailability information, and manipulates it to yield reliability parameters that can be used in PRA analyses. Availability data will also be available in RADS in the near future. RADS reports these data on a component or train level for a specified selection of key systems and components. RADS also estimates CCF rates and performs trending analyses. Other uses include monitoring maintenance rule implementation, supporting plant-specific licensing actions, and improving accident sequence precursor analyses. The current RBPI pilot effort uses RADs to screen data to support the evaluation of mitigating system unreliability RBPIs.

System reliability studies (Refs. 9, 10, 11, 12, 13 and 14) have been and are being conducted to systematically evaluate operational data of risk-significant systems at nuclear power plants. The primary objectives of the studies are twofold. The first objective is to estimate system unreliability based on operational data and then to compare the results with data, models, and assumptions used in IPEs. The second is to provide an engineering analysis of the factors affecting system unreliability and to determine any trends or patterns. Other objectives include identification of failure trends over time and generation of baseline performance data from which to compare industry-wide and plant-specific performance. In addition to containing the most current data failure available for these systems, the failure data contained in these studies has been extensively analyzed to retain only valid failures and to accurately characterize the nature of those failures. This data was incorporated into the SPAR models as part of the process of establishing plant-specific 'baseline' models and associated core damage frequencies.

A.2.3 Identify Indicators Capable of Detecting Performance Changes in a Timely Manner

In addition to being risk-significant (see Table A.2.1.1-1), mitigating system performance indicators must be capable of detecting performance changes in a timely manner. A mitigating system performance indicator involves collection of data during some monitoring period, and a decision rule, which declares that a plant is in a certain performance band based on observed data. This monitoring period must be long enough to reduce the probabilities of false negatives and false positives to acceptable levels, but no longer. Appendices E and F document these statistical analyses.

In accordance with the preceding discussion and the statistical analyses documented in Appendices E and F, several mitigating systems/component classes met the criteria for risk-significance and timely monitoring and were selected as candidates to be monitored as mitigating system RBPIs. Monitoring periods of reasonable length were also calculated based on acceptable levels of false positives and negatives. Additionally, changes in their frequencies can be readily quantified with the current SPAR models. These systems and component classes are identified in Table A.2.1.2-1.

Some risk-significant systems were considered best monitored as initiating event RBPIs. These systems are discussed in Section A.2.3.1. In addition to these systems, one other risk-significant system identified in Table A.2.1.1-1 was not considered to be a good candidate for mitigating system RBPIs. This system, the primary pressure relief system, was excluded due to the

sparseness of data and the resulting excessive monitoring periods. It will be consigned to risk-informed baseline inspections.

A.2.3.1 Treatment of Systems Whose Function Is Monitored under Initiating Event RBPIs

Main feedwater, power conversion and main steam are risk-significant systems whose functions are best monitored under the LOHS and LOFW initiating event RBPIs. Several factors combine to prevent these systems from being good mitigating system RBPI candidates and lead to monitoring of their performance within the LOHS and LOFW RBPIs.

First, these systems are continuously operational during normal power operations and function with little or no redundancy. This lack of redundancy precludes generating an unavailability indicator since there is no standby equipment. Additionally, since there is no standby equipment, some types of failure data associated with testing of standby equipment (e.g., failure to start) is sparse. Finally, failure of any major component within these systems results in an immediate plant trip or shutdown. The impact of these trips and shutdowns is explicitly monitored through the LOHS and LOFW RBPIs.

A.2.3.2 Industry-wide Trending of Mitigating Systems

Similar to mitigating system RBPIs, candidates for industry-wide trending must also be risk-significant. In addition to the mitigating system RBPIs identified in Table A.2.1.2-1, common cause failure (CCF) events were also included as potential candidates for industry-wide trending. Analysis of the SPAR model results indicate that CCF events associated with Auxiliary/ Emergency Feedwater pumps and emergency diesel generators are significant contributors to risk. Since these events do not occur frequently enough to track on a plant-specific basis they will be trended industry-wide. Other system specific CCF categories may be added as additional plants are evaluated. Finally, CCF events associated with all systems are as a group very risk-significant and will also be trended. The mitigating system industry-wide trending candidates are listed below:

- All systems and component classes identified in Table 3.1.2.1 as RBPIs
- Common Cause Failure Events for Auxiliary Feedwater Pumps
- Common Cause Failure Events for Emergency Diesel Generators
- Common Cause Failure Events for All Systems

The mitigating system RBPIs are trended in Table 5.3-7 of the main body of the report. Trends associated with non-RBPI events (Common Cause Failures) are shown below in Figures A.2.3.2-1 through A.2.3.2-3.

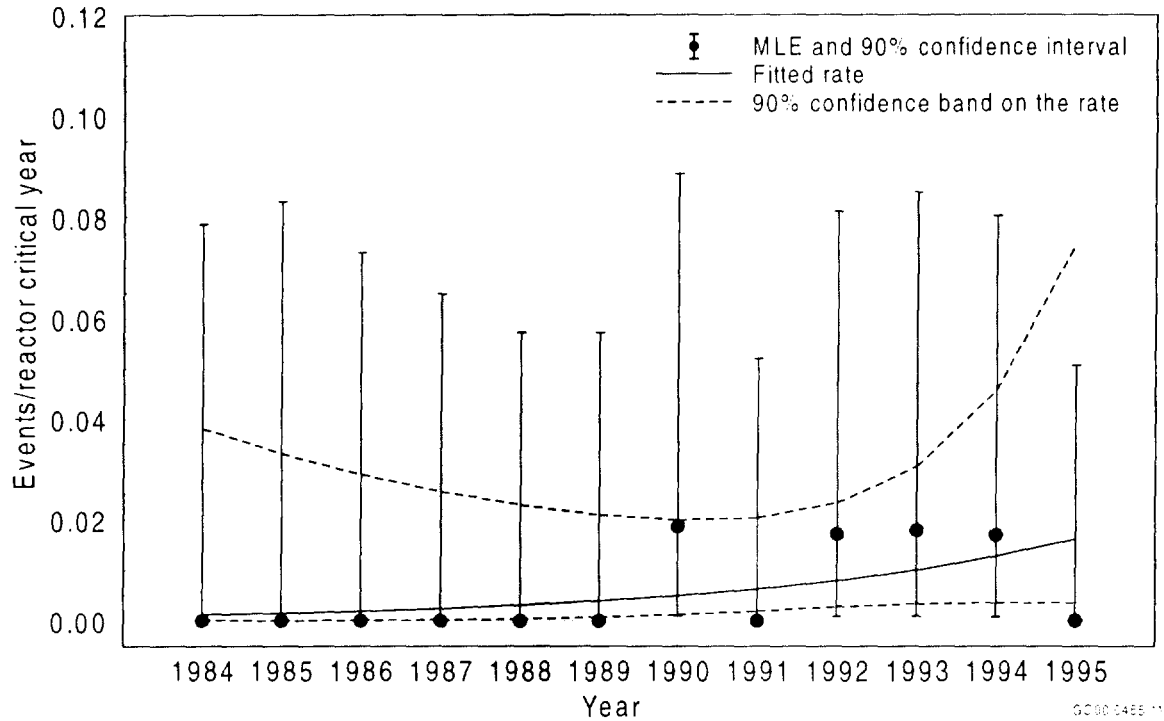

Figure A.2.3.2-1 Time-dependent Trending of CCF Events for Auxiliary Feedwater Pumps (Trend is not statistically significant, p-value = 0.2.)

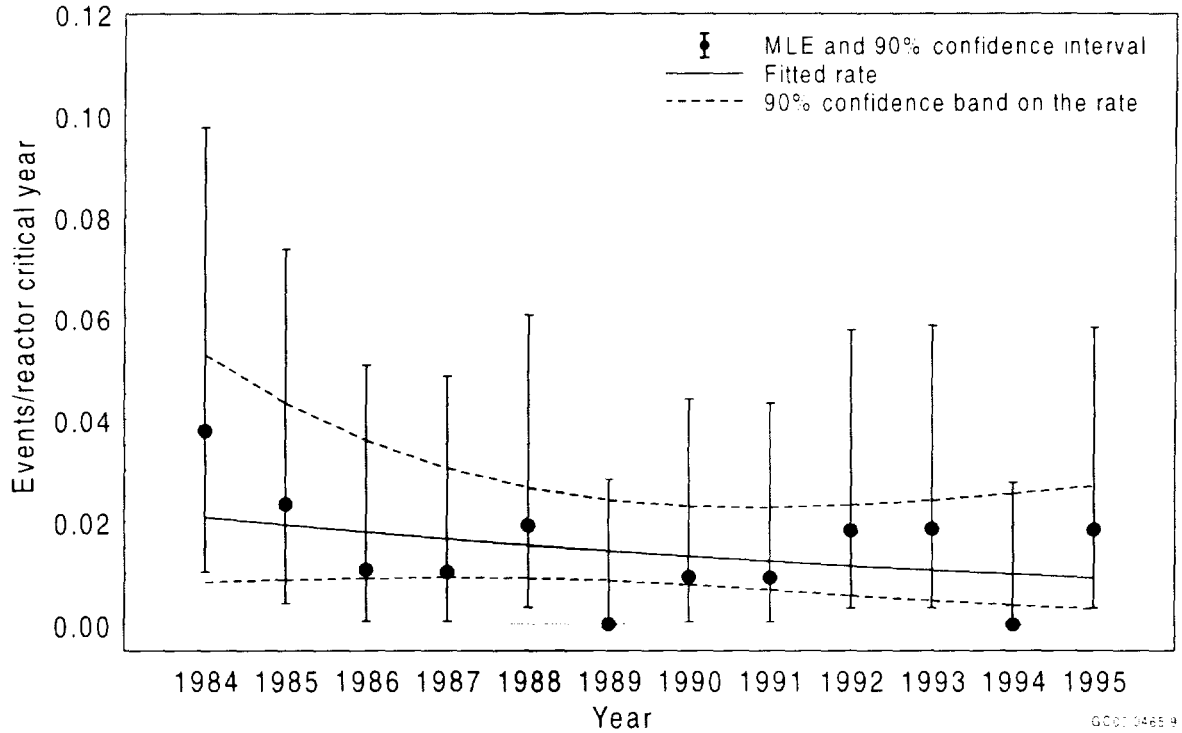

Figure A.2.3.2-2 Time-dependent Trending of CCF Events for Emergency Diesel Generators (Trend is not statistically significant, p-value = 0.3.)

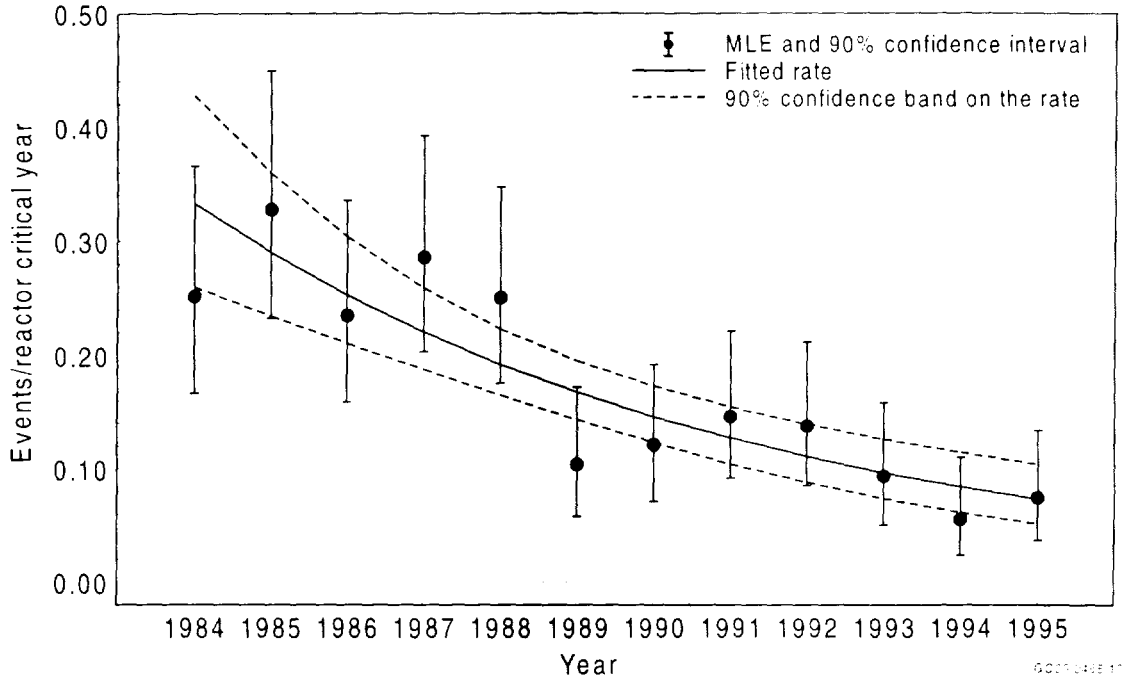

Figure A.2.3.2-3 Time-dependent Trending of CCF Events for All Systems (Trend is statistically very significant, p-value < 0.0001.)

A.2.4 Identify Performance Thresholds Consistent with a Graded Approach to Performance Evaluation from SECY 99-007

The same graded approach outlined in Section A.1.4 for Initiating Event RBPI thresholds is also used for setting mitigating system RBPI thresholds. This graded approach is built around four performance bands (green, white, yellow, red) whose boundaries correspond to plant-specific changes in CDF equal to 1E-6/yr, 1E-5/yr and 1E-4/yr.

Again, the same 'baseline' models defined in Section A.1.4 and used to identify Initiating Event thresholds are also used to identify mitigating system thresholds. An iterative technique was once more employed to determine the exact mitigating system thresholds. System specific unavailability thresholds were determined by simultaneously increasing all train level test and maintenance probabilities within the subject system until the appropriate change in CDF was reached. Unreliability thresholds were determined by simultaneously increasing the random failure probabilities of all system specific equipment tracked in EPIX until the appropriate change in CDF was reached.

Once the performance action band boundary is reached, the unreliability threshold value is calculated by quantifying the fault tree gate that corresponds to that train/system. The unavailability threshold is calculated similarly to the unreliability threshold except that only the test and maintenance (T&M) events are increased and the value of the T&M event then becomes the threshold. "Not Reached" in the threshold summary tables indicates an inability to reach the subject performance action band boundary with the train/system failed. In some instances

(identified with an accompanying footnote), a "Not Reached" corresponding to an unavailability threshold indicates an inability to reach the subject performance action band boundary while staying within allowable Technical Specification maintenance combinations.

Mitigating system RBPIs were selected and their threshold values calculated for fifteen sites (23 plants). These sites are comprised of nine BWR and fourteen PWR plants. Detailed threshold information for each analyzed plant is contained in Tables A.2.4-1 through A.2.4-15.

A.2.5 Inspection Areas Covered by New RBPIs

The RBPIs developed in this report for the mitigating system cornerstone were compared with the performance indicators in the ROP to identify those RBPIs that are not currently in the ROP. The inspection areas that could be impacted by the new mitigating system RBPIs were then determined. The results are summarized in Table A.2.5-1.

A.3 Barrier Integrity Cornerstone: Containment

This section presents the background for the preliminary RBPI development results that address the containment integrity portion of the barrier integrity cornerstone for full power, internal events. The scope of the structures, systems, and components related to the containment barrier includes the primary and secondary containment buildings, primary containment penetrations and associated isolation systems, and risk-significant systems and components necessary for containment heat removal, pressure control, and degraded core hydrogen control. This section is focused on the containment barrier itself, and bypass of the containment barrier (for example, by steam generator tube rupture) is not considered in this section.

The section is structured in a manner similar to that for Section A.2, Mitigating Systems Cornerstone, and follows the RBPI development process described in the main report. A special subsection is added, Section A.3.6, that addresses:

- The definition of LERF
- The justification for using LERF

In discussion of the initiating events cornerstone and the mitigating systems cornerstone, emphasis was placed on CDF as the metric for defining the risk significance of changes. In this section, LERF is used as the metric for determining the risk significance of changes in containment performance. However, the burden of this section is containment integrity, not LERF in general. Many influences on LERF need to be addressed under other cornerstones. To clarify this point, it is useful to classify hardware and human performance elements according to a recent development carried out for the SDP (Ref. 22).

Table A.2.4-1 WE 4-Lp Plant 1 Mitigating Systems Threshold Summary

WE 4-Lp Plant 1 SPAR 3i (1.0E-8/hr, 7.2E-5/calendar year[1]) WE 4-Lp Plant 1 RBPI Baseline (1.4E-8/hr, 9.8E-5/calendar year[1])					
System/Component	Baseline Train Unavailability and Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[6]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[6]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[6]
Auxiliary Feedwater	(MDP Train Unreliability[2]) 8.5E-3	2.0E-2	1.1E-2	2.9E-2	2.2E-1
	(DDP Train Unreliability[2]) 3.5E-2	7.7E-2	3.6E-2	4.0E-2	8.4E-2
	(MDP Train Unavailability[1]) 1.1E-3	2.5E-3	7.4E-3	6.3E-2	6.0E-1
	(DDP Train Unavailability) 1.5E-2	TBD[5]	1.6E-2	2.0E-2	6.6E-2
Component Cooling Water	(Train Unreliability[2]) 2.7E-2	3.1E-2	1.4E-1	3.9E-1	8.4E-1
	(Train Unavailability[1]) 2.2E-2	TBD[5]	Not Reached[7]	Not Reached[7]	Not Reached
Emergency AC Power (Train)	(Train Unreliability[2]) 4.3E-2	2.2E-1	4.6E-2	6.8E-2	2.0E-1
	(Train Unavailability) 9.7E-3	1.9E-2	1.6E-2	7.3E-2	6.3E-1
High Pressure Injection (Includes CVCS trains)	(SI Train Unreliability[2]) 9.6E-3	2.2E-2	2.6E-2	1.6E-1	Not reached.
	(CVCS Train Unreliability[2]) 7.7E-3	1.3E-2	1.0	Not reached.	Not reached.
	(SI Train Unavailability) 4.2E-3	1.6E-2	2.8E-2	1.9E-1	Not reached.
	(CVCS Train Unavail.) 2.4E-3	TBD[5]	Not reached.	Not reached.	Not reached.
Power Operated Relief Valves	(System Unreliability) 3.2E-2	6.8E-2	3.9E-2	9.2E-2	5.2E-1
	(Train Unavailability) N/A[4]	N/A[4]	N/A[4]	N/A[4]	N/A[4]
Residual/Decay Heat Removal	(Train Unreliability[2]) 1.9E-2	4.9E-2	3.0E-2	8.4E-2	2.8E-1
	(Train Unavailability) 7.3E-3	2.4E-2	4.5E-2	3.6E-1	Not Reached[7]
Essential Service Water	(Train Unreliability[2]) 1.1E-2	1.6E-2	1.4E-2	4.2E-2	1.9E-1
	(Train Unavailability) 5.9E-3	TBD[5]	1.4E-1	Not Reached[6]	Not Reached
AOVs[3]	Component Class Unreliability	N/A	Increase 100X	Increase 235X	Not Reached
MOVs	Component Class Unreliability	N/A	Increase 2.5X	Increase 10X	Increase 36X
MDPs	Component Class Unreliability	N/A	Increase 1.2X	Increase 3.1X	Increase 20X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. Total unreliability, includes T&M.
3. AOVs component class does not include failure to re-close the reliefs.
4. N/A, T&M events not included in SPAR logic.
5. The corresponding unavailability event in the SPAR model does not include a probability distribution.
6. Multiplier used to develop the associated system threshold.
7. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.4-2 CE Plant 2 Mitigating Systems Threshold Summary

CE Plant 2 SPAR 3i (2.6E-9/hr, 1.8E-5/calendar year[1]) Ce Plant 2 RBPI Baseline (2.1E-9/hr, 1.4E-5/calendar year[1])					
System/Component	Baseline Train Unavailability and Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[5]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[5]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[5]
Emergency Feedwater	(MDP Train Unreliability[4]) 8.0E-3	2.0E-2	1.7E-2	8.8E-2	3.5E-1
	(TDP Train Unreliability[4]) 1.9E-1	3.5E-1	2.0E-1	3.0E-1	8.0E-1
	(MDP Train Unavailability) 1.1E-3	2.5E-3	3.4E-2	1.9E-1	4.6-1
	(TDP Train Unavailability) 4.6E-3	1.8E-2	2.8E-2	2.3E-1	Not reached[6]
Component Cooling Water	(Train Unreliability[4]) 1.6E-2	5.0E-2	1.6E-1	4.3E-1	9.8E-1
	(Standby Train Unavailability) 1.1E-2	4.4E-2	Not Reached	Not Reached	Not Reached
Emergency AC Power	(Train Unreliability[4]) 4.2E-2	1.0E-1	5.1E-2	9.2E-2	2.0E-1
	(Train Unavailability) 9.7E-3	1.9E-2	2.4E-2	1.1E-1	4.7E-1
High Pressure Injection	(Train Unreliability[4]) 9.2E-3	2.0E-2	1.8E-2	8.9E-2	3.8E-1
	(Train Unavailability) 4.2E-3	1.6E-2	1.5E-2	1.1E-1	Not reached[6]
Power Operated Relief Valves	(System Unreliability) 4.4E-2	5.0E-2	5.4E-2	1.4E-1	7.0E-1
	(Train Unavailability) N/A[3]	NA[3]	NA[3]	NA[3]	NA[3]
Salt Water System	(System Unreliability[4]) 5.1E-2	1.2E-1	8.1E-2	2.8E-1	8.6E-1
	(Standby Train Unavailability) 2.7E-2	1.0E-1	Not reached[6]	Not reached[6]	Not reached[6]
Shutdown Cooling /RHR/LPI	(Train Unreliability[4]) 1.3E-2	3.4E-2	2.8E-2	1.4E-1	Not Reached
	(Train Unavailability) 7.3E-3	2.4E-2	4.4E-1	Not reached[6]	Not Reached
AOVs[2]	Component Class Unreliability	N/A	Increase by 5.0X	Increase by 33X	Increase by 155X
MOVs	Component Class Unreliability	N/A	Increase by 2.4X	Increase by 13X	Increase by 60X
MDPs	Component Class Unreliability	N/A	Increase by 2.75X	Increase by 14X	Increase by 47X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. AOVs does not include failure to re-close of the reliefs.
3. N/A, T&M events not included in SPAR logic.
4. Total unreliability, includes T&M
5. (X#) – System related multipliers.
6. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.4-3 BWR 3/4 Plant 5 Mitigating Systems Threshold Summary

BWR 3/4 Plant 5 SPAR 3i (2.0E-0/hr, 1.4E-5/calendar year[1]) BWR 3/4 Plant 5 RBPI Baseline (2.2E-9/hr, 1.5E-5/calendar year[1])					
System/Component	Baseline Train Unavailability And Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[6]	White/Yellow Threshold (ΔCDF=1E-5)[1] (X#)[6]	Yellow/Red Threshold (ΔCDF=1E-4)[1] (X#)[6]
Emergency AC Power	(Train Unreliability[2]) 4.5E-2	2.2E-1	5.0E-2	7.9E-2	2.4E-1
	(Train Unavailability) 9.7E-3	1.9E-2	1.7E-2	8.5E-2	7.2E-1
Reactor Core Isolation Cooling[5]	(Train Unreliability[2]) 7.9E-2	1.0E-1	1.1E-1	3.2E-1	Not Reached
	(Train Unavailability) 1.3E-2	4.0E-2	5.0E-2	3.7E-1	Not Reached
Service Water (ESW to EDGs and RHR)	(Train Unreliability[2]) 2.3E-2	7.4E-2	2.8E-2	6.6E-2	2.3E-1
	(Train Unavailability) 1.8E-2	5.6E-2	2.6E-2	1.1E-1	8.4E-1
High-Pressure Coolant Injection	(Train Unreliability[2]) 2.2E-1	4.2E-1	2.3E-1	3.0E-1	Not Reached
	(Train Unavailability) 9.7E-3	3.8E-2	6.3E-2	5.3E-1	Not Reached
Residual Heat Removal (SPC)	(Train Unreliability[2,3]) 5.0E-3	9.9E-3	6.5E-3	1.8E-2	8.6E-2
	(Train Unavailability) 1.0E-2	2.5E-2	2.2E-2	1.2E-1	Not Reached[7]
AOVs	Component Class Unreliability	N/A	Increase 3.0X	Increase 19X	Increase 115X
MOVs[4]	Component Class Unreliability	N/A	Increase 1.2X	Increase 2.6X	Increase 7.3X
MDPs	Component Class Unreliability	N/A	Increase 1.6X	Increase 6.2X	Increase 38X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. Total unreliability includes test and maintenance (TM) contribution.
3. RHR train for UA is defined at the heat exchanger (2 pump) level; RHR train for UR is defined at the individual pump level.
4. HPCI injection valve reopening failure was excluded from consideration due to its unique failure mechanism and probability.
5. RCIC turbine restart failure was excluded from consideration due to its unique failure mechanism and probability.
6. Multiplier used to determine the associated system threshold.
7. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.4-4 BWR 3/4 Plant 6 Mitigating Systems Threshold Summary

BWR 3/4 Plant 6 SPAR 3i (2.8E-9/hr, 2.0E-5/calendar year[1]) BWR 3/4 Plant 6 RBPI Baseline (2.4E-9/hr, 1.7E-5/calendar year[1])					
System/Component	Baseline Train Unavailability And Unreliability	Green/White Threshold 95th %ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[3]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[3]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[3]
Emergency AC Power	(Train Unreliability[2]) 3.9E-2	2.3E-1	4.5E-2	8.8E-2	2.8E-1
	(Train Unavailability) 9.7E-3	1.9E-2	2.3E-2	1.5E-1	Not Reached[6]
Reactor Core Isolation Cooling	(Train Unreliability[2]) 7.9E-2	1.6E-1	1.7E-1	7.6E-1	Not Reached
	(Train Unavailability) 1.3E-2	4.0E-2	5.3E-2	Not Reached[6]	Not Reached
Essential/Emergency Service Water (to EDGs)	(Train Unreliability[2]) 2.5E-2	8.3E-2	2.7E-2	4.4E-2	1.6E-1
	(Train Unavailability) 1.9E-2	7.7E-2	2.3E-2	5.9E-2	1.6E-1
High-Pressure Coolant Injection (HPCI)	(Train Unreliability[2]) 2.4E-1	4.4E-1	2.8E-1	6.3E-1	Not Reached
	(Train Unavailability) 9.7E-3	3.8E-2	9.0E-2	8.1E-1	Not Reached
Residual Heat Removal (SPC, includes SSW)	(System Unreliability[2]) 1.7E-2	3.2E-2	2.2E-2	6.6E-2	3.0E-1
	(Train Unavailability) 1.0E-2	2.5E-2	3.9E-2	3.8E-1	Not Reached[6]
AOVs	Component Class Unreliability	N/A	Increase by 1.25X	Increase by 3.5X	Increase by 17X
MOVs[4]	Component Class Unreliability	N/A	Increase by 1.54X	Increase by 5.3X	Increase by 21X
MDPs	Component Class Unreliability	N/A	Increase by 1.27X	Increase by 3.5X	Increase by 17X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. Total unreliability; includes test and maintenance (TM) contribution.
3. Multiplier used to determine the associated system threshold.
4. HPCI Injection valve reopening failure was excluded from consideration due to its unique failure mechanism and probability.
5. RCIC turbine restart failure was excluded from consideration due to its unique failure mechanism and probability.
6. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.4-5 CE Plant 4 Mitigating Systems Threshold Summary

CE Plant 4 SPAR 3i (2.6E-9/hr, 1.8E-5/calendar year[1]) CE Plant 4 RBPI Baseline (2.2E-9/hr, 1.6E-5/calendar year[1])					
System/Component	Baseline Train Unavailability and Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[5]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[5]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[5]
Emergency Feedwater	(DDP Train Unreliability[2]) 8.3E-2	1.5E-1	9.8E-2	2.2E-1	Not Reached
	(MDP Train Unreliability[2]) 8.1E-3	2.0E-2	1.3E-2	4.0E-2	5.4E-1
	(TDP Train Unreliability[2]) 1.9E-1	3.5E-1	2.3E-1	5.2E-1	Not Reached
	(DDP Train Unavailability) 1.5E-2	3.6E-2	3.4E-2	1.9E-1	Not Reached
	(MDP Train Unavailability) 1.1E-3	2.5E-3	8.8E-3	8.0E-2	7.8E-1
	(TDP Train Unavailability) 4.6E-3	1.8E-2	5.1E-2	4.6E-1	Not Reached
Component Cooling Water	(Train Unreliability) 1.6E-2	5.2E-2	Not Reached	Not Reached	Not Reached
	(Train Unavailability) 1.1E-2	4.4E-2	Not Reached	Not Reached	Not Reached
Emergency AC Power	(Train Unreliability[2]) 4.1E-2	9.8E-2	4.6E-2	7.8E-2	2.3E-1
	(Train Unavailability) 9.7E-3	1.9E-2	1.7E-2	8.7E-2	7.8E-1
High Pressure Injection	(Train Unreliability[2]) 9.2E-3	2.1E-2	2.4E-2	1.4E-1	5.1E-1
	(Train Unavailability)4.2E-3	1.6E-2	2.6E-2	2.3E-1	Not Reached
Power Operated Relief Valves	(Train Unreliability) 2.2E-3	5.0E-3	3.0E-2	2.1E-1	Not Reached
	(Train Unavailability[2]) N/A[4]	N/A[4]	N/A[4]	N/A[4]	Not Reached
Raw Water System (RWS)	(Train Unreliability[2]) 3.2E-2	1.1E-1	1.6E-1	5.1E-1	9.8E-1
	(Standby Train Unavailability) 2.7E-2	8.0E-2	Not Reached	Not Reached	Not Reached
Shutdown Cooling/RHR	(Train Unreliability[2]) 6.7E-3	1.4E-2	1.5E-2	8.4E-2	5.6E-1
	(Train Unavailability) 7.3E-3	2.4E-2	9.5E-1	Not Reached[6]	Not Reached[6]
AOVs[3]	Component Class Unreliability	N/A	Increase by 3.9X	Increase by 25X	Increase by 120X
MOVs	Component Class Unreliability	N/A	Increase by 3.2X	Increase by 22X	Increase by 115X
MDPs	Component Class Unreliability	N/A	Increase by 1.7X	Increase by 8.0X	Increase by 55X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. Total unreliability, includes T&M
3. AOVs does not include failure of the reliefs to re-close.
4. N/A – T&M events not included in SPAR logic.
5. Multiplier used in determining the associated system thresholds.
6. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

General Note: Loss of HVAC initiators contribute ~6% to the IPE CDF. This is a candidate system for enhanced/ increased inspection.

Table A.2.4-6 BWR 5/6 Plant 2 Mitigating Systems Threshold Summary

BWR 5/6 Plant 2 SPAR 3i (1.2E-9/hr, 8.6E-6/calendar year[1]) BWR 5/6 Plant 2 RBPI Baseline (1.4E-9/hr, 9.9E-6/calendar year[1])					
System/Component	Baseline Train Unavailability And Unreliability	Green/White Threshold 95th %ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[3]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[3]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[3]
Emergency AC Power	(Train Unreliability[2]) 4.1E-2	9.9E-2	4.8E-2	9.9E-2	3.7E-1
	(Train Unavailability) 9.7E-3	1.9E-2	3.2E-2	2.2E-1	Not Reached[4]
High-Pressure Core Spray (HPCS)	(Train Unreliability[2]) 1.0E-1	1.4E-1	1.5E-1	5.0E-1	Not Reached
	(Train Unavailability) 3.4E-3	1.2E-2	6.1E-2	5.4E-1	Not Reached
Reactor Core Isolation Cooling (RCI)	(Train Unreliability[2]) 7.9E-2	1.6E-1	1.4E-1	5.7E-1	Not Reached
	(Train Unavailability) 1.3E-2	4.0E-2	8.3E-2	7.0E-1	Not Reached
Residual Heat Removal (RHR, SPC)	(Train Unreliability[2]) 2.4E-2	4.2E-2	2.9E-2	7.1E-2	3.3E-1
	(Train Unavailability) 1.0E-2	2.5E-2	1.5E-2	5.9E-2	4.9E-1
Standby Service Water (SSW)	(Train Unreliability[2]) 1.5E-2	3.0E-2	2.0E-2	5.2E-2	2.2E-1
	(Train Unavailability) 2.0E-3	7.5E-3	2.8E-2	1.4E-1	Not Reached
AOVs	Component Class Unreliability	N/A	Increase by 1.7X	Increase by 7.5X	Increase by 55X
MOVs	Component Class Unreliability	N/A	Increase by 1.2X	Increase by 2.3X	Increase by 6.9X
MDPs	Component Class Unreliability	N/A	Increase by 1.5X	Increase by 5.0X	Increase by 21X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. Total unreliability; includes test and maintenance (TM) contribution.
3. Multiplier used to determine the associated system threshold.
4. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.4-7 BWR 3/4 Plant 11 Mitigating Systems Threshold Summary

BWR 3/4 Plant 11 SPAR 3i (4.9E-9/hr, 3.4E-5/calendar year[1]) BWR 3/4 Plant 11 RBPI Baseline (5.6E-9/hr, 3.9E-5/calendar year[1])					
System/Component	Baseline Train Unavailability And Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[4]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[4]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[4]
Emergency AC Power	(Train Unreliability[2]) 4.6E-2	1.0E-1	5.2E-2	9.2E-2	2.6E-1
	(Train Unavailability) 9.7E-3	1.9E-2	1.9E-2	1.1E-1	9.5E-1
Reactor Core Isolation Cooling	(Train Unreliability[2]) 7.9E-2	1.8E-1	8.2E-2	1.0E-1	3.2E-1
	(Train Unavailability) 1.3E-2	4.0E-2	1.6E-2	4.7E-2	3.6E-1
Safety Auxiliaries Cooling Water (SACs) (Cools EDGs & RHR)	(Train Unreliability[2]) 3.8E-3	8.8E-3	2.2E-2	1.3E-1	3.8E-1
	(Train Unavailability) N/A[3]	N/A[3]	N/A[3]	N/A[3]	N/A[3]
High-Pressure Coolant Injection (HPCI)	(Train Unreliability[2]) 2.4E-1	4.4E-1	2.4E-1	2.7E-1	5.4E-1
	(Train Unavailability) 9.7E-3	3.8E-2	2.4E-2	3.1E-1	9.9E-1
Residual Heat Removal (SPC)	(Train Unreliability[2]) 2.2E-2	3.8E-2	3.8E-2	1.3E-1	4.5E-1
	(Train Unavailability) 1.0E-2	2.5E-2	2.6E-2	1.8E-1	Not Reached[8]
Station Service Water (SSW)	(Train Unreliability[2]) 3.2E-2	8.5E-2	3.5E-2	5.9E-2	1.6E-1
	(Train Unavailability) 1.8E-2	6.8E-2	2.3E-2	6.5E-2	4.9E-1
AOVs[5]	Component Class Unreliability	N/A	Increase by 1.2X	Increase by 3.3X	Increase by 23X
MOVs[6]	Component Class Unreliability	N/A	Increase by 1.1X	Increase by 2.2X	Increase by 8.4X
MDPs	Component Class Unreliability	N/A	Increase by 1.4X	Increase by 4.0X	Increase by 17X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. Total unreliability; includes test and maintenance (TM) contribution.
3. N/A – T&M events not included in SPAR logic.
4. Multiplier used in determining the associated system threshold.
5. AOVs System do not include failure of the reliefs to re-close.
6. HPCI Injection valve reopening failure was excluded from consideration due to its unique failure mechanism and probability.
7. RCIC turbine restart failure was excluded from consideration due to its unique failure mechanism and probability.
8. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.4-8 BWR 3/4 Plant 8 Mitigating Systems Threshold Summary

BWR 3/4 Plant 8 SPAR 3i (8.7E-10/hr, 6.1E-6/calendar year[1]) BWR 3/4 Plant 8 RBPI Baseline (7.6E-10/hr, 5.3E-6/calendar year[1])					
System/Component	Baseline Train Unavailability And Unreliability	Green/White Threshold 95th %ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[6]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[6]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[6]
Emergency AC Power	(Train Unreliability[2]) 4.5E-2	2.3E-1	6.3E-2	1.7E-1	4.3E-1
	(Train Unavailability) 9.7E-3	1.9E-2	2.4E-1	Not Reached[7]	Not Reached[7]
Reactor Core Isolation Cooling[5]	(Train Unreliability[2]) 7.9E-2	1.6E-1	1.2E-1	3.9E-1	Not Reached
	(Train Unavailability) 1.3E-2	4.0E-2	6.4E-2	5.3E-1	Not Reached
Essential Service Water (ESW to EDGs)	(Train Unreliability[2]) 2.3E-2	7.9E-2	2.9E-2	6.9E-2	2.5E-1
	(Train Unavailability) 1.8E-2	6.5E-2	6.5E-3	5.0E-2	Not Reached[7]
High-Pressure Coolant Injection (HPCI)	(Train Unreliability[2]) 2.4E-1	4.4E-1	2.7E-1	5.4E-1	Not Reached
	(Train Unavailability) 9.7E-3	3.8E-2	1.2E-1	Not Reached[7]	Not Reached
Residual Heat Removal (SPC)	(Train Unreliability[2]) 5.1E-3	1.0E-2	2.4E-2	9.18E-2	2.7E-1
	(Train Unavailability) 1.0E-2	2.5E-2	1.4E-1	Not Reached[7]	Not Reached[7]
RHR Service Water (HSW)	(Train Unreliability[2,3]) 2.2E-2	7.7E-2	5.5E-2	2.1E-1	4.7E-1
	(Train Unavailability) 1.8E-2	7.1E-2	Not Reached[7]	Not Reached[7]	Not Reached[7]
AOVs	Component Class Unreliability	N/A	Increase by 3.5X	Increase by 24X	Increase by 170X
MOVs	Component Class Unreliability	N/A	Increase by 2.4X	Increase by 8.4X	Increase by 21X
MDPs	Component Class Unreliability	N/A	Increase by 2.0X	Increase by 9.9X	Increase by 30X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. Total unreliability includes test and maintenance (TM) contribution.
3. RHR train for UA is defined at the heat exchanger (2 pump) level; RHR train for UR is defined at the individual pump level.
4. HPCI injection valve reopening failure was excluded from consideration due to its unique failure mechanism and probability.
5. RCIC turbine restart failure was excluded from consideration due to its unique failure mechanism and probability.
6. Multiplier used in determining the associated system thresholds.
7. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.4-9 CE Plant 5 Mitigating Systems Threshold Summary

CE Plant 5 SPAR 3i (4.0E-9/hr, 2.8E-5/calendar year[1]) CE Plant 5 RBPI Baseline (2.6E-9/hr, 1.8E-5/calendar year[1])					
System/Component	Baseline Train Unavailability and Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[5]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[5]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[5]
Emergency Feedwater	(MDP Train Unreliability[4]) 1.6E-2	2.9E-2	1.7E-2	2.5E-2	8.5E-2
	(TDP Train Unreliability) 2.0E-1	3.4E-1	2.2E-1	4.1E-1	Not Reached
	(MDP Train Unavailability[4]) 1.1E-3	2.5E-3	3.2E-3	2.2E-2	2.2E-1
	(TDP Train Unavailability[4]) 4.6E-3	1.8E-2	3.2E-2	2.8E-1	Not Reached
Component Cooling Water	(Train Unreliability[4]) 4.4E-2	7.8E-2	3.2E-1	7.8E-1	1.0
	(Train Unavailability) 1.1E-2	4.4E-2	Not Reached	Not Reached	Not Reached
Emergency AC Power	(Train Unreliability[4]) 5.1E-2	1.2E-1	6.0E-2	1.1E-1	2.7E-1
	(Train Unavailability) 9.7E-3	1.9E-2	5.8E-2	4.9E-1	Not Reached[6]
High Pressure Injection	(Train Unreliability[4]) 4.3E-2	5.9E-2	8.8E-2	3.7E-1	9.1E-1
	(Train Unavailability)4.2E-3	1.6E-2	2.6E-2	2.2E-1	Not Reached[6]
Power Operated Relief Valves	(System Unreliability) 1.3E-1	1.4E-1	1.5E-1	3.7E-1	Not Reached
	(Train Unavailability[4]) N/A[3]	NA[3]	NA[3]	NA[3]	NA[3]
Service Water System	(Train Unreliability[4]) 6.0E-2	1.2E-1	8.4E-2	1.8E-1	3.7E-1
	(Standby Train Unavail.) 2.7E-2	8.5E-2	Not Reached	Not Reached	Not Reached
Shutdown Cooling / Residual Heat Removal	(Train Unreliability[4]) 2.7E-2	5.2E-2	3.5E-2	1.0E-1	Not Reached
	(Train Unavailability) 7.3E-3	2.4E-2	5.8E-1	Not Reached[6]	Not Reached
AOVs[2]	Component Class Unreliability	N/A	Increase 1.9X	Increase 9.0X	Increase 43X
MOVs	Component Class Unreliability	N/A	Increase 3.1X	Increase 20X	Increase 91X
MDPs	Component Class Unreliability	N/A	Increase 1.2X	Increase 2.4X	Increase 10X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. AOVS does not include failure to re-close the reliefs.
3. N/A, T&M events not included in SPAR logic.
4. Total unreliability, includes T&M
5. Multiplier used to determine the associated system threshold.
6. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

General Note: DC switchgear cooling (DCV) is an inspection candidate due to its importance in the IPE.

Table A.2.4-10 B&W Plant 4 Mitigating Systems Threshold Summary

B&W Plant 4 SPAR 3i (2.1E-9/hr, 1.5E-5/calendar year[1]) B&W Plant 4 RBPI Baseline (2.5E-9/hr, 1.7E-5/calendar year[1])					
System/Component	Baseline Train Unavailability and Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[4]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[4]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[4]
Emergency Feedwater	(MDP Train Unreliability[3]) 1.0E-2	2.3E-2	1.6E-2	5.2E-2	1.9E-1
	(TDP Train Unreliability[3]) 2.0E-1	3.5E-1	2.8E-1	8.9E-1	Not Reached
	(MDP Train Unavailability) 1.1E-3	2.5E-3	3.0E-2	2.8E-1	Not Reached[5]
	(TDP Train Unavailability) 4.6E-3	1.8E-2	1.0E-1	9.9E-1	Not Reached
Component Cooling System (CCS)	(Train Unreliability[3]) 1.6E-2	5.1E-2	Not Reached	Not Reached	Not Reached
	(Train Unavailability) 1.1E-2	4.4E-2	Not Reached	Not Reached	Not Reached
Emergency AC Power	(Hydro Train Unreliability[3]) 1.1E-3	1.6E-3	2.4E-3	1.4E-2	1.3E-1
	(Hydro Train Unavailability) 1.4E-2	TBD[6]	1.4E-1	Not Reached[5]	Not Reached[5]
High Pressure Injection (HPI)	(Train Unreliability[3]) 1.3E-2	2.5E-2	6.0E-2	1.8E-1	5.1E-1
	(Train Unavailability) 4.2E-3	1.6E-2	5.5E-1	Not Reached[5]	Not Reached[5]
Decay Heat Removal (DHR)	(Train Unreliability[3]) 2.2E-2	5.5E-2	3.0E-2	1.1E-1	4.9E-1
	(Train Unavailability) 7.3E-3	2.4E-2	3.9E-1	Not Reached[5]	Not Reached[5]
Low Pressure Service Water (LSW)	(Train Unreliability[3]) 3.2E-2	9.2E-2	5.6E-2	1.5E-1	4.5E-1
	(Standby Train Unavailability) 2.7E-2	1.0E-1	5.4E-1	Not Reached	Not Reached
AOVs[2]	Component Class Unreliability	N/A	Increase 4.5X	Increase 25X	Increase 110X
MOVs	Component Class Unreliability	N/A	Increase 2.0X	Increase 8.7X	Increase 30X
MDPs	Component Class Unreliability	N/A	Increase 1.8X	Increase 6.7X	Increase 26X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. AOVs does not include failure to re-close of the reliefs.
3. Total unreliability, includes T&M
4. Multiplier used to determine the associated system threshold.
5. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.
6. The corresponding unavailability event in the SPAR model does not include a probability distribution.

Table A.2.4-11 BWR 3/4 Plant 15 Mitigating Systems Threshold Summary

BWR Plant 15 SPAR 3i (5.8E-10/hr, 4.1E-6/calendar year[1]) BWR Plant 15 RBPI Baseline (5.3E-10/hr, 3.7E-6/calendar year[1])					
System/Component	Baseline Train Unavailability And Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[3]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[3]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[3]
Emergency AC Power	(Train Unreliability[2]) 3.9E-2	9.5E-2	1.4E-1	3.2E-1	6.7E-1
	(Train Unavailability) 9.7E-3	1.9E-2	7.5E-1	Not Reached[6]	Not Reached[6]
Reactor Core Isolation Cooling (RCI)	(Train Unreliability[2]) 7.9E-2	1.6E-1	2.0E-1	8.5E-1	Not Reached
	(Train Unavailability) 1.3E-2	4.0E-2	2.0E-1	Not Reached[6]	Not Reached
Essential/Emergency Service Water (to EDGs)	(Train Unreliability[2]) 8.5E-3	2.1E-2	6.3E-2	1.5E-1	3.5E-1
	(Train Unavailability) 2.0E-3	7.8E-3	5.8E-1	Not Reached[6]	Not Reached[6]
High-Pressure Coolant Injection (HPCI)	(Train Unreliability[2]) 2.4E-1	4.5E-1	3.2E-1	7.5E-1	Not Reached
	(Train Unavailability) 9.7E-3	3.8E-2	2.6E-1	Not Reached[6]	Not Reached
Residual Heat Removal (SPC)	(Train Unreliability[2]) 1.2E-2	2.7E-2	5.7E-2	2.3E-1	4.7E-1
	(Train Unavailability) 2.0E-3	8.0E-3	Not Reached[6]	Not Reached[6]	Not Reached[6]
High Pressure Service Water (HSW)	(Train Unreliability[2]) 8.2E-3	1.9E-2	2.7E-2	1.5E-1	4.1E-1
	(Train Unavailability) 2.0E-3	8.5E-3	5.8E-1	Not Reached[6]	Not Reached[6]
AOVs	Component Class Unreliability	N/A	Increase 1.7X	Increase 8.1X	Increase 59X
MOVs[4]	Component Class Unreliability	N/A	Increase 3.5X	Increase 14X	Increase 35X
MDPs	Component Class Unreliability	N/A	Increase 3.4X	Increase 17X	Increase 47X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. Total unreliability; includes test and maintenance (TM) contribution.
3. Multiplier used to determine the associated system threshold.
4. HPCI Injection valve reopening failure was excluded from consideration due to its unique failure mechanism and probability.
5. RCIC turbine restart failure was excluded from consideration due to its unique failure mechanism and probability.
6. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.4-12 WE 2-Lp Plant 5 Mitigating Systems Threshold Summary

WE 2-Lp Plant 5 SPAR 3i (2.1E-9/hr, 1.4E-5/calendar year[1]) WE 2-Lp Plant 5 RBPI Baseline (2.1E-9/hr, 1.5E-5/calendar year[1])					
System/Component	Baseline Train Unavailability and Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[4]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[4]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[4]
Auxiliary Feedwater	(MDP Train Unreliability[6]) 8.7E-3	2.1E-2	1.2E-2	3.4E-2	5.4E-1
	(TDP Train Unreliability[6]) 1.9E-1	3.5E-1	2.5E-1	7.6E-1	Not Reached
	(MDP Train Unavailability) 1.1E-3	2.5E-3	8.0E-3	6.6E-2	6.6E-1
	(TDP Train Unavailability) 4.6E-3	1.8E-2	7.6E-2	7.0E-1	Not Reached
Component Cooling Water	(Unreliability[6]) 6.4E-2	1.2E-1	9.7E-2	2.7E-1	8.6E-1
	(Unavailability) 1.1E-2	4.4E-2	1.1E-1	9.9E-1	Not Reached
Emergency AC Power	(Unreliability[6]) 4.0E-2	9.8E-2	5.5E-2	1.3E-1	2.9E-1
	(Unavailability) 9.7E-3	1.9E-2	1.3E-1	Not Reached[5]	Not Reached[5]
High Pressure Injection	(Unreliability[6]) 9.3E-3	2.8E-2	2.6E-2	1.1E-1	4.6E-1
	(Unavailability) 4.2E-3	1.6E-2	8.8E-2	8.4E-1	Not Reached[5]
Power Operated Relief Valves	(System Unreliability) 3.3E-2	3.4E-2	5.6E-2	2.4E-1	9.9E-1
	(Unavailability) N/A[3]	N/A[3]	N/A[3]	N/A[3]	N/A[3]
Residual/Decay Heat Removal	(Unreliability[6]) 2.4E-2	4.7E-2	3.2E-2	8.7E-2	3.8E-1
	(Unavailability) 7.3E-3	2.4E-2	6.6E-2	5.8E-1	Not Reached
Service Water	(MDP Train Unreliability[6]) 3.2E-2	9.2E-2	5.2E-1	1.0	Not Reached
	(DDP Train Unreliability[6]) 7.6E-2	2.0E-1	3.0E-1	9.6E-1	Not Reached
	(MDP Train Unavailability) 2.7E-2	9.0E-2	Not Reached	Not Reached	Not Reached
	(DDP Train Unavailability) 5.5E-2	1.7E-1	Not Reached[5]	Not Reached	Not Reached
AOVs[2]	Component Class Unreliability	N/A	Increase 32X	Increase 185X	Not Reached
MOVs	Component Class Unreliability	N/A	Increase 1.9X	Increase 7.4X	Increase 27X
MDPs	Component Class Unreliability	N/A	Increase 1.4X	Increase 4.0X	Increase 16X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. AOVs does not include failure to re-close of the reliefs.
3. N/A, T&M events not included in SPAR logic.
4. Multiplier used to determine the associated system threshold.
5. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.
6. Total unreliability, includes T&M

General Note: Loss of Instrument Air initiators contribute 6.4% to the IPE CDF. This is a candidate system for enhanced/increased inspection.

Table A.2.4-13 BWR 3/4 Plant 18 Mitigating Systems Threshold Summary

BWR 3/4 Plant 18 SPAR 3i (3.7E-9/hr, 2.6E-5/calendar year[1]) BWR 3/4 Plant 18 RBPI Baseline (2.9E-9/hr, 2.0E-5/calendar year[1])					
System/Component	Baseline Train Unavailability and Unreliability	Green/White Threshold 95th % ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[8]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[8]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[8]
Emergency AC Power	(Train Unreliability[2]) 4.0E-2	9.9E-2	4.2E-2	5.8E-2	1.5E-1
	(Train Unavailability) 9.7E-3	1.9E-2	1.4E-2	4.9E-2	3.9E-1
Reactor Core Isolation Cooling (RCIC)	(Train Unreliability[2,5]) 7.9E-2	1.7E-1	9.1E-2	2.0E-1	Not Reached
	(Train Unavailability) 1.3E-2	4.0E-2	2.8E-2	1.7E-1	Not Reached
Essential/Emergency Service Water (to EDGs)	(Train Unreliability[2]) 2.5E-2	8.0E-2	2.7E-2	4.2E-2	1.3E-1
	(Standby Train Unavail.) 1.9E-2	5.4E-2	2.2E-2	5.6E-2	3.9E-1
High-Pressure Coolant Injection (HPCI)	(Train Unreliability[2,4]) 2.4E-1	4.3E-1	2.6E-1	4.6E-1	Not Reached
	(Train Unavailability) 9.7E-3	3.8E-2	8.2E-2	7.3E-1	Not Reached
Residual Heat Removal (SPC)	(Train Unreliability[7]) 8.8E-3	2.3E-2	2.0E-2	6.8E-2	2.2E-1
	(Train Unavailability) 1.0E-2	2.5E-2	1.4E-1	Not Reached[6]	Not Reached[6]
Insp. Candidate #1 Containment Venting	(System Unreliability[2]) 5.0E-3	1.1E-2	1.0E-2	5.6E-2	4.0E-1
	(System Unavailability) N/A[3]	N/A	N/A[3]	N/A[3]	N/A[3]
AOVs	Component Class Unreliability	N/A	Increase by 2.2X	Increase by 13X	Increase by 83X
MOVs[4]	Component Class Unreliability	N/A	Increase by 1.7X	Increase by 7.0X	Increase by 28X
MDPs	Component Class Unreliability	N/A	Increase by 1.24X	Increase by 5.1X	Increase by 28X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. Total unreliability; includes test and maintenance (TM) contribution.
3. TM not modeled in this system.
4. HPCI Injection valve reopening failure was excluded from consideration due to its unique failure mechanism and probability
5. RCIC turbine restart failure was excluded from consideration due to its unique failure mechanism and probability.
6. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.
7. RHR train for UA is defined at the heat exchanger (2 pump) level; RHR train for UR is defined at the individual pump level.
8. Multiplier used to determine the associated system threshold.

Table A.2.4-14 CE Plant 12 Mitigating Systems Threshold Summary

CE Plant 12 SPAR 3i (4.0E-9/hr, 2.8E-5/calendar year[1]) CE Plant 12 RBPI Baseline (2.7E-9/hr, 1.9E-5/calendar year[1])					
System/Component	Baseline Train Unavailability and Unreliability	Green/White Threshold 95th %ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[5]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[5]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[5]
Emergency Feedwater	(MDP Train Unreliability[4]) 8.1E-3	2.0E-2	9.2E-3	1.8E-2	8.8E-2
	(TDP Train Unreliability[4]) 2.0E-1	3.5E-1	2.1E-1	3.4E-1	Not Reached
	(MDP Train Unavailability) 1.1E-3	2.5E-3	3.3E-3	2.3E-2	2.2E-1
	(TDP Train Unavailability) 4.6E-3	1.8E-2	3.0E-2	2.5E-1	Not Reached
Component Cooling Water	(Train Unreliability[4]) 6.0E-2	9.5E-2	1.4E-1	5.0E-1	1.0
	(Train Unavailability) 4.4E-2	8.8E-2	1.0E-1	6.2E-1	Not Reached[6]
Emergency AC Power	(Train Unreliability[4]) 3.8E-2	1.4E-1	4.2E-2	7.3E-2	2.2E-1
	(Train Unavailability) 9.7E-3	1.9E-2	1.8E-2	9.3E-2	8.6E-1
High Pressure Injection	(Train Unreliability[4]) 1.3E-2	2.5E-2	2.7E-2	1.1E-1	4.5E-1
	(Train Unavailability) 4.2E-3	1.6E-2	7.1E-2	6.8E-1	Not Reached[6]
Power Operated Relief Valves	(System Unreliability) 4.4E-2	4.5E-2	6.7E-2	2.5E-1	Not Reached
	(Train Unavailability) N/A[3]	NA[3]	NA[3]	NA[3]	NA[3]
Shutdown Cooling / Residual Heat Removal	(Train Unreliability[4]) 2.5E-2	4.7E-2	6.5E-2	2.3E-1	6.7E-1
	(Train Unavailability) 7.3E-3	2.4E-2	3.3E-1	Not Reached[6]	Not Reached[6]
AOVs[2]	Component Class Unreliability	N/A	Increase 7.5X	Increase 65X	Not Reached
MOVs	Component Class Unreliability	N/A	Increase 1.4X	Increase 4.5X	Increase 22X
MDPs	Component Class Unreliability	N/A	Increase 1.2X	Increase 2.9X	Increase 14X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. AOVs does not include failure to re-close of the reliefs.
3. N/A, T&M events not included in SPAR logic.
4. Total unreliability, includes T&M.
5. Multiplier used to determine the associated system threshold.
6. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.4-15 WE 4-Lp Plant 22 Mitigating Systems Threshold Summary

WE 4-Lp Plant 22 SPAR 3i (4.7E-9/hr, 3.3E-5/calendar year[1]) WE 4-Lp Plant 22 RBPI Baseline (4.9E-9/hr, 3.4E-5/calendar year[1])					
System	Baseline Train Unavailability and Unreliability	Green/White Threshold 95th %ile	Green/White Threshold (ΔCDF =1E-6)[1] (X#)[6]	White/Yellow Threshold (ΔCDF =1E-5)[1] (X#)[6]	Yellow/Red Threshold (ΔCDF =1E-4)[1] (X#)[6]
Auxiliary Feedwater	(MDP Train Unreliability[5]) 8.7E-3	2.1E-2	9.8E-3	1.8E-2	5.4E-2
	(TDP Train Unreliability[5])1.9E-1	3.4E-1	2.0E-1	2.9E-1	Not Reached
	(MDP Train Unavailability) 1.1E-3	2.5E-3	3.7E-3	2.8E-2	2.5E-1
	(TDP Train Unavailability) 4.6E-3	1.8E-2	2.1E-2	1.7E-1	Not Reached
Component Cooling Water	(Train Unreliability[5]) 1.6E-2	4.7E-2	2.0E-1	6.5E-1	Not Reached
	(Standby Train Unavail.) 1.1E-2	4.4E-2	7.8E-1[4]	Not Reached	Not Reached
Emergency AC Power	(Train Unreliability[5]) 4.2E-2	1.0E-1	4.3E-2	5.5E-2	1.3E-1
	(Train Unavailability) 9.7E-3	1.9E-2	1.3E-2	3.9E-2	3.0E-1
High Pressure Injection (Includes CVCS trains)	(SI Train Unreliability[5]) 9.7E-3	2.1E-2	8.8E-1	Not Reached	Not Reached
	(SI Train Unavailability) 4.2E-3	1.6E-2	Not Reached[7]	Not Reached	Not Reached
	(CVCS Train Unreliability[5]) 5.9E-2	1.9E-1	4.3E-1	Not Reached	Not Reached
	(CVCS Train Unavailability) 5.4E-2	1.7E-1	Not Reached[7]	Not reached	Not Reached
Power Operated Relief Valves	(System Unreliability) 3.2E-2	6.8E-2	5.7E-2	2.6E-1	Not Reached
	(Train Unavailability) N/A[3]	N/A	N/A[3]	N/A[3]	N/A[3]
Residual/Decay Heat Removal	(Train Unreliability[5]) 1.7E-2	3.8E-2	3.8E-2	1.3E-1	4.7E-1
	(Train Unavailability) 7.3E-3	2.4E-2	9.3E-2	8.8E-1	Not Reached[7]
Service Water	(Train Unreliability[5]) 3.2E-2	9.4E-2	1.3E-1	2.1E-1	3.2E-1
	(Standby Train Unavail.) 2.7E-2	9.0E-2	Not Reached[7]	Not Reached	Not Reached
AOVs[2]	Component Class Unreliability	N/A	Increase 2.2X	Increase 13X	Increase 106X
MOVs	Component Class Unreliability	N/A	Increase 2.4X	Increase 11X	Increase 39X
MDPs	Component Class Unreliability	N/A	Increase 1.2X	Increase 3.2X	Increase 16X

1. Calendar year is defined as 7000 critical hours. (ΔCDF is calculated in calendar years).
2. AOV component class does not include failure to re-close of the reliefs.
3. N/A, T&M events not included in SPAR logic.
4. Two normally running CCW trains with one train in standby.
5. Total unreliability, includes T&M.
6. Multiplier used to determine the associated system threshold.
7. This threshold can be reached if the T&M outages associated with this system are not confined to TECH SPEC allowable combinations.

Table A.2.5-1 Summary of Inspection Areas Impacted by New RBPIs for Mitigating System Cornerstone

RBPI	Attribute	Inspection Area
Full Power:		
Mitigating Systems (UR)	Equipment Performance	71111.04, Equipment Alignment 71111.12, Maintenance Rule Implementation 71111.15, Operability Evaluations 71111.22, Surveillance Testing 71152, Identification and Resolution of Problems
Mitigating Systems (UA)	Equipment Performance	71111.12, Maintenance Rule Implementation
	Human Performance (Pre-Event)	71111.14, Personnel Performance During Nonroutine Evolutions 71152, Identification and Resolution of Problems
	Configuration Control	71111.04, Equipment Alignment 71111.12, Maintenance Rule Implementation 71111.13, Maintenance Risk Assessments and Emergent Work Evaluation 71111.23, Temporary Plant Modifications 71152, Identification and Resolution of Problems

- Type A elements are those that have an effect on LERF, at least partly because they have an effect on CDF. For example, the change in CDF associated with degradation of a mitigation system that plays a role in key accident sequences (transients and SBLOCAs involving high RCS pressure) could carry over directly to a change in LERF.
- Type B elements are those that have an effect on LERF, but largely independent of CDF. An example of this is the containment isolation function, the degradation of which usually has no modeled effect on CDF.

Given a model that comprehensively addresses a Type A element's impact on CDF, its impact on LERF can be assessed using the methodology described in Ref. 22, using the relationship:

$$\Delta LERF = (Factor) \times (\Delta CDF \text{ affecting LERF sequences}),$$

where the "Factor," ranging from 0.2 to 10, is given in Table 2 of the Ref. 22. The "Factor" is acknowledged to be conservative.

For some Type A mitigating systems or initiating events, it may be found that LERF is more limiting than CDF for purposes of determining the performance thresholds of RBPIs associated with these elements. This has not been assessed so far, due to the lack of integrated CDF/LERF models available to this project.

The present emphasis under the Containment Integrity portion of the Barrier Integrity cornerstone is on Type B elements. In ongoing work, Type A elements will be more comprehensively assessed, based if necessary on the approximate treatment developed for the SDP.

A.3.1 Assess the Potential Risk Impact of Degraded Performance

Unlike the analyses that address initiating events and mitigating systems, there are no functioning SPAR models for directly calculating changes to LERF resulting from element performance changes. This is a major limitation on proceeding with the RBPI development process. Nevertheless, a scoping assessment has been made, based on the Individual Plant Examination (IPE) submittals and the associated IPE Database (Ref. 5), supplemented by the NUREG-1150 (Ref. 20) assessments, the review of the IPEs in NUREG-1560 (Ref. 21), and other containment analyses.

General insights were obtained from Refs. 20 and 21. The general assessment of the LERF-significance of Type B elements is summarized for the five containment types in Table A.3.1-1.

Table A.3.1-1 Assessment of Elements of LERF-Significant Containment Barrier Attributes for PWRs with Large-Dry Containments

Plant Type	Element	LERF Significance
PWRs with Large Dry Containments	Containment Isolation	Major
PWRs with Ice Condenser Containments	Containment Isolation Ice Condenser Function	Major Major
BWRs with Mark I Containments	Suppression pool bypass Isolation condenser (for some Mark I's) Drywell spray Operator actions (drywell spray) EOPs	Intermediate Intermediate Intermediate Intermediate Not Modeled but "Intermediate"
BWRs with Mark I Containments	Suppression pool bypass EOPs	Intermediate Not Modeled but "Intermediate"
BWRs with Mark III Containments	Containment Isolation Suppression pool bypass	Intermediate Intermediate

Although containment heat removal is not generally considered to be highly significant to LERF, it is modeled at some PWRs as playing a role in core damage prevention and in prevention of large early releases. This, too, is a Type A function, and needs to be examined within an integrated CDF/LERF perspective. Ongoing work (examining all remaining plants) will establish whether this function is risk-significant at enough plants to warrant RBPI treatment.

An examination of selected IPE results tabulated in Ref. 5 has been carried out by determining the containment-barrier-related elements affecting particular plant damage states, and using this information to try to infer how plant damage state frequency (and therefore release frequency) would change if element performance changed. Where this can be quantified, it is presented as a worst-case estimate of the change in LERF, i.e., it assumes complete degradation of element performance. In some cases, information presented in the IPE Database is not sufficiently detailed and explicit to confirm the importance of elements that were described above as important to LERF; this is indicated in the tables as an insufficiency of information presented. The IPE Database presents results, but was not intended to support requantification exercises of this kind. This approach is therefore limited. Nevertheless, some results are obtainable; they are provided in Tables A.3.1-2 to A.3.1-6.

Table A.3.1-2 Assessment of Potential Changes in LERF Due to Element Performance Changes for PWRS with Large-Dry Containments (Including Sub-Atmospheric)

Plant	Containment Failure Mode and Frequency		Element	Maximum ΔLERF†
ANO-2	Large Bypass	3.78E-7	Containment isolation	3.01E-5
	Large Isolation	7.82E-7		
	Large Early	1.53E-6		
	Small Early	1.39E-6		
	Late	4.73E-6		
	None	2.48E-5		
			RCS depressurization	0*
Braidwood 1&2	Large Bypass	0	Containment isolation	2.66E-5
	Large Isolation	0		
	Large Early	0		
	Small Early	0		
	Late	2.73E-6		
	None	2.39E-5		
Wolf Creek	Large Bypass	7.31E-8	Containment isolation	4.18E-5
	Large Isolation	4.95E-8		
	Large Early	3.83E-8		
	Small Early	0		
	Late	1.37E-6		
	None	4.05E-5		

* For cases involving LERF, RCS depressurization is either unavailable, or occurs due to a hot leg or surge line break (ref. ANO-2 IPE, Section 4.6.5, and CETs)

† Maximum ΔLERF is the change in LERF that would be caused by total failure of the element in question.

Table A.3.1-3 Assessment of Potential Changes in LERF Due to Element Performance Changes for PWRs with Ice Condenser Containments

Plant	Containment Failure Mode and Frequency		Element	Maximum ΔLERF
Catawba 1&2	Large Bypass	1.03E-7	Containment isolation	5.77E-5
	Large Isolation	2.9E-8		
	Large Early	3.53E-8		
	Small Early	0		
	Late	2.72E-5	Ice condenser*	(Insufficient Information)
	None	3.05E-5		
D.C. Cook 1&2	Large Bypass	7.11E-6	Containment isolation	5.51E-5
	Large Isolation	6.26E-9		
	Large Early	9.25E-7		
	Small Early	1.58E-9		
	Late	1.13E-6		
	None	5.4E-5	Ice condenser*	(Insufficient Information)

Table A.3.1-3 (Continued)

Plant	Containment Failure Mode and Frequency		Element	Maximum ΔLERF
McGuire 1&2	Large Bypass	9.48E-7	Containment Isolation	3.86E-5
	Large Isolation	1.28E-7		
	Large Early	0		
	Small Early	8.10E-7		
	Late	1.62E-5	Ice condenser*	(Insufficient Information)
	None	2.17E-5		
Sequoyah 1&2	Large Bypass	7.99E-6	Containment Isolation	1.59E-4
	Large Isolation	0		
	Large Early	2.73E-6		
	Small Early	0		
	Late	8.32E-5	Ice condenser*	(Insufficient Information)
	None	7.60E-5		
Watts Bar	Large Bypass	2.46E-5	Containment Isolation	2.8E-4
	Large Isolation	8.91E-6		
	Large Early	8.14E-6		
	Small Early	0		
	Late	7.1E-5	Ice condenser*	(Insufficient Information)
	None	2.18E-4		

* IPE insufficient to determine ΔLERF

Table A.3.1-4 Assessment of Potential Changes in LERF Due to Element Performance Changes for BWRs with Mark I Containments

Plant	Containment Failure Mode and Frequency		Element	Maximum ΔLERF
Peach Bottom 2&3	Large Bypass	6.64E-9	Drywell spray/ flooding systems	0[1]
	Large Isolation	0		
	Large Early	2.57E-7		
	Small Early	0		
	Late	1.40E-6	Suppression pool bypass	0[2]
	None	2.57E-6		
Quad Cities 1&2	Large Bypass	6E-10	Drywell spray/ flooding systems	Insufficiently Modeled
	Large Isolation	0		
	Large Early	1.38E-7		
	Small Early	3.52E-8		
	Late	6.62E-7	Suppression pool bypass	Insufficiently Modeled
	None	2.53E-7		
Vermont Yankee	Large Bypass	4.3E-8	Drywell spray/ flooding systems	Insufficiently Modeled
	Large Isolation	0		
	Large Early	1.11E-6		
	Small Early	0	2. Suppression pool bypass	Insufficiently Modeled
	Late	9.89E-7		
	None	1.16E-6		

Table A.3.1-4 (Continued)

Note: For some BWR Mark I plants, isolation condenser performance may be a key element, but is not part of containment barrier performance

[1]Coolant injection to drywell or initiation of containment flooding is important for PDSs where there is low vessel pressure

[2]For some PDSs, suppression pool bypass typically results in late releases; therefore, ΔLERF will not increase. For other PDSs, if the suppression pool is not bypassed, the release is small early; however, when the suppression pool is bypassed, the release is large early. Therefore, for these PDSs, the ΔLERF can increase by some fraction of the small early release when the suppression pool was not bypassed

Table A.3.1-5 Assessment of Potential Changes in LERF Due to Element Performance Changes for BWRs with Mark II Containments

Plant	Containment Failure Mode and Frequency		Element	Maximum ΔLERF
Nine Mile Point 2	Large Bypass	2.79E-8	Suppression pool bypass	(Insufficiently modeled)
	Large Isolation	0		
	Large Early	1.58E-6		
	Small Early	1.08E-6		
	Late	2.04E-5		
	None	8.30E-6		
WNP 2	Large Bypass	2.98E-8	Suppression pool bypass	(Insufficiently modeled)
	Large Isolation	2.26E-7		
	Large Early	4.89E-6		
	Small Early	0		
	Late	5.30E-6		
	None	6.83E-6		

Table A.3.1-6 Assessment of Potential Changes in LERF Due to Element Performance Changes for BWRs with Mark III Containments

Plant	Containment Failure Mode and Frequency		Element	Maximum ΔLERF
Grand Gulf 1	Large Bypass	0	Containment isolation	1.05E-6
	Large Isolation	0		
	Large Early	5.97E-6		
	Small Early	1.36E-6	Suppression pool bypass	(Insufficiently modeled)
	Late	5.66E-6		
	None	3.51E-6		
River Bend	Large Bypass	0	Containment isolation	1.53E-5
	Large Isolation	4.12E-7		
	Large Early	0		
	Small Early	4.13E-6	Suppression pool bypass	(Insufficiently modeled)
	Late	2.14E-6		
	None	8.98E-6		
Perry 1	Large Bypass	0	Containment isolation	1.1E-5
	Large Isolation	3.96E-9		
	Large Early	2.14E-6		
	Small Early	9.12E-7	Suppression pool bypass*	(Insufficiently modeled)
	Late	4.76E-6		
	None	5.30E-6		

*At Perry, suppression pool bypass events (other than those that involve drywell failure) have a frequency of 0.

Based on the information summarized in the above tables, it is concluded that performance degradation in the following equipment-related elements could cause significant changes in LERF:

- For Large-Dry PWRs, containment isolation
- For Ice-Condenser PWRs, in addition to containment isolation, the Ice-Condenser function
- For Mark-1 BWRs, suppression pool bypass, drywell spray, and isolation condenser (some Mark-1s)
- For Mark-2 BWRs, suppression pool bypass
- For Mark-3 BWRs, suppression pool bypass and containment isolation

These areas are frequently modeled, but are not reflected in models currently available to this project.

A.3.2 Obtain Performance Data for Risk-Significant, Equipment-Related Elements

Plant-specific performance data for these elements are not currently available to this project.

A.3.3 Identify Indicators Capable of Detecting Performance Changes in a Timely Manner

Although data for the above elements are not available to this project, based on Appendix F and on work presented in Sections A.1 and A.2, it is judged that essentially passive elements or elements that are only infrequently challenged are not amenable to RBPI development. Based on this, the following elements have been identified from the LERF-significant elements listed above as having the potential to be RBPIs. Each possible indicator is applicable to different containment types:

- Reliability / Availability of Drywell Spray (Mark I BWRs)
- Reliability / Availability of Large Containment Isolation Valves (PWRs, Mark III BWRs) (valves isolating paths that connect the containment atmosphere directly to the outside atmosphere).

A.3.4 Identify Performance Thresholds Consistent with a Graded Approach to Performance Evaluation from SECY 99-007

Although the RBPI development process has established the risk significance of the functions identified above in Section A.3.3, models and data available are not sufficient to establish baseline performance values and to quantify thresholds. LERF models exist for some PWR large dry containments and PWR ice condenser containments, as well as BWR Mark I containments. Therefore, BWR Mark II and Mark III containments, as well as some PWR containments, do not have LERF models developed for establishing threshold values. In addition, the existing models can only link with the older and less complete Revision 2QA SPAR models. Therefore, some accident sequences that could affect LERF cannot be propagated through the LERF models because they are not included in the Revision 2QA SPAR models.

Moreover, drywell spray is closely identified with Type A functionality (low pressure injection and suppression pool cooling). This means that RBPIs and thresholds for certain mitigating systems and certain containment-related systems need to be evaluated together within an integrated CDF/LERF perspective. Similarly, although containment heat removal is not generally an important contributor to LERF, in some PWRs it has a role in core damage prevention and in prevention of large early releases. This, too, is a Type A function, and needs to be examined within an integrated CDF/LERF perspective.

When applicable models and data are obtained, RBPI development will be completed for these potential RBPIs. In addition, RBPIs previously analyzed under the initiating events and mitigating systems cornerstones will also be re-examined to determine whether LERF considerations alter the findings of Sections A.1 and A.2.

A.3.5 Inspection Areas Covered by New RBPIs

These RBPIs are not among the performance indicators in the ROP. The inspection areas that could be impacted by these RBPIs were determined. The results are summarized in Table A.3.5-1.

Table A.3.5-1 Summary of Inspection Areas Impacted by Potential RBPIs for Containment Portion of Barrier Integrity Cornerstone

RBPI	Attribute	Inspection Area
CIV (UR&UA) and Drywell Spray (UR&UA)	Design Control	71111.02, Evaluation of Changes, Tests, or Experiments 71111.17, Permanent Plant Modifications 71111.23, Temporary Plant Modifications 71152, Identification and Resolution of Problems
	Barrier Performance	71111.12, Maintenance Rule Implementation 71111.15, Operability Evaluations 71111.20, Refueling and Outage Activities 71111.22, Surveillance Testing

A.3.6 LERF as the Figure of Merit for Containment Barrier Performance

A.3.6.1 The Definition of LERF

Regulatory Guide 1.174 defines LERF as follows:

"In this context, LERF is being used as a surrogate for the early fatality QHO. It is defined as the frequency of those accidents leading to significant, unmitigated releases from containment in a time frame prior to effective evacuation of the close-in population such that there is a potential for early health effects. Such accidents generally include unscrubbed releases associated with early [**containment failure at or shortly after vessel breach, containment bypass events, and loss of containment**] isolation. This definition is consistent with accident analyses used in the safety goal screening criteria discussed in the Commission's regulatory analysis guidelines. An NRC contractor's report (Ref. 23) describes a simple screening approach for calculating LERF."

Definition used in the RBPI Program:

A number of requirements and constraints peculiar to the RBPI Program contribute to a (slight) reformulation of the definition of LERF from that in Regulatory Guide 1.174. These are:

- Since quantitative determinations will be made as part of the RBPI process, it is necessary to assume a quantitative value for "large." The large release threshold is defined by volatile/semi-volatile fission product releases greater than 2.5% (i.e., the release of iodine, cesium, or tellurium greater than 2.5% is considered large). The reason for this choice is three-fold: (1) releases at or above this level have been shown to result in early fatalities (Ref. 24), thus maintaining consistency with the qualitative definition in Regulatory Guide 1.174; (2) this definition is one of three considered (Ref. 23) (the other two are "... greater than 10%" and "all releases, regardless of release magnitude); and (3) this definition allows for effective use of the IPE database to determine large-early release sequences and LERF. This large release threshold, of course, can be changed if warranted.

- The definition of "early" in the IPEs and the IPE Database is generally consistent with the definition of "early" in Regulatory Guide 1.174, that is, "... in a time frame prior to effective evacuation of the close-in population such that there is a potential for early health effects." In the absence of health effect and evacuation analysis in the IPEs, this definition has been translated into a containment failure definition, based on the occurrence of the first radiological release from the containment (containment failure) relative to time of failure of the reactor vessel. "Early Release," then, is any release before, at, or shortly after (usually a few hours) vessel failure. Although the IPEs vary in the demarcation from early to late, that is, the specific number of hours after vessel failure, they are sufficiently consistent for the purposes here. "Early" as used here is no different from "early" in the IPE Database.

A.3.6.2 The Justification for Using LERF as a Containment Barrier Metric

The issue arises as to why LERF is used alone, rather than (or in combination with) a metric that includes "late" large releases. In this report, LERF has been used based on its role in risk-informed regulation as described in Regulatory Guide 1.174. It has been shown (Ref. 25) that the E-4/yr core damage frequency (CDF) objective is more limiting than the late release frequency criterion that one would derive from the latent fatality QHO, and this argument has been used to justify a focus on LERF.

However, focusing exclusively on LERF as a metric for the containment barrier does not assign risk significance to those elements of containment barrier performance discussed in SECY 99-007 that do not affect either CDF or LERF significantly, although they affect late release frequency or other post-accident considerations such as worker dose. Moreover, if performance bands for large late release frequency were derived from the latent fatality QHO in the same way that performance bands for LERF are derived from the early fatality QHO, then performance thresholds for many of these significant elements would be implied, where currently they are not.

The possibility of considering late releases in near-term RBPI development will be discussed with stakeholders.

A.4 References

1. SECY-99-007, "Recommendations for Reactor Oversight Process Improvements," U.S. Nuclear Regulatory Commission, January 8, 1999.
2. Poloski, J. P., et al., *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 – 1995*, NUREG/CR-5750, Idaho National Engineering and Environmental Laboratory, February 1999.
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Appendix B
RBPI Determination for Shutdown Modes

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Preface

The following conditions make RBPI determination for shutdown significantly different from RBPI determination for full power operation.

- At shutdown, the risk is strongly dependent on the RCS condition and on the operability of mitigating systems. Risk metrics plotted as a function of time exhibit pronounced increases and decreases as RCS conditions change and accident mitigating systems are removed from service and returned to service.
- Human-induced initiating events are relatively more frequent during shutdown than during power operations.
- The risk is strongly dependent on operator response to initiating events.
- Configuration management is a more significant factor in shutdown safety than in full power safety.
- Shutdown occupies a much smaller fraction of the year than does full power operation, so shutdown-specific reliability, availability, and frequency metrics would accumulate failure data much more slowly than do comparable metrics for full power.
- Relatively few models for shutdown CDF and LERF are available compared to model availability for full power.

Model Availability

Because of lack of plant-specific shutdown PRA models, the RBPI determination process has to rely on risk insights gained from the representative models available to this project. Only two quantifiable shutdown PRA models were available to this project.

- A draft version of the Sequoyah SPAR model (which is based on the Surry LPSD PRA model) (Ref. 1)
- A generic Westinghouse 4-loop shutdown model developed for use in the Safety Monitor Version 2.0 software. (Ref. 2)

The Grand Gulf LPSD PRA model (Ref. 3) was selected as the reference model for BWR plants. The results of this PRA were used to develop thresholds for PIs. This project did not have access to a working version of the Grand Gulf PRA model.

Shutdown PRA Model Insights

Based on the results of the shutdown PRAs for Surry and Grand Gulf, the following factors dominate the risk of shutdown.

Early phase of cold shutdown at PWRs:
- High decay heat
- Overpressurization of RHR causing a rupture

Mid-loop at PWRs
- High decay heat

- RCS loops isolated (no steam generator cooling capability)
- High maintenance unavailabilities and human error probabilities (e.g., over-draining)

Cold shutdown at PWRs
- RCS loops isolated
- High maintenance unavailabilities and human error probabilities
- Failure of thimble tube seals

Startup at PWRs
- Rapid boron dilution (French reactivity scenario)

Cold shutdown at BWRs
- LOCA/diversions
- Unavailability of safety relief valves (alternative means of core cooling) when the vessel head is on
- High maintenance unavailabilities
- High human error probabilities when decay heat is high
- Failure of makeup from the suppression pool for LOCAs

Difficulties Associated with Defining a Baseline CDF

Baseline values are a special problem at shutdown compared to full power. At full power, the overall configuration is constrained by technical specifications, and with a few typical PRA assumptions (technical specifications are not violated, all legal configurations occur with probabilities determined by the products of the unavailability of individual elements, decay heat is always computed as if the reactor were at the end of a cycle, ...), baseline performance can be characterized in a straightforward manner. At shutdown, the plant configuration is much more discretionary, and determining baseline risk is therefore less straightforward than at full power. Shutdowns vary widely in risk, according to what kinds of operating states are entered, the respective dwell times, and what configurations within those states are realized. Early PRAs (e.g., Surry and Grand Gulf LPSD studies), in generating average risk values, effectively averaged over a broad range of configurational possibilities consistent with operating practices that were current at that time. In principle, these studies could be used to assess baseline performance, but operating practices have changed significantly since those studies were performed, and adopting those risk values as baselines in the current program would not serve the aim of maintaining risk at current levels.

Modern shutdown PRAs (on-line risk monitors) essentially require the input of a specific outage schedule (configurations and dwell times), so that outage-specific risk figures of merit can be obtained. Determining baseline values from such a model logically requires that either a particular outage schedule be designated as "baseline," or a set of outage schedules be taken in the aggregate to define "baseline." In this report, a representative outage schedule and a representative annual frequency of outage have been assumed (it is assumed that the baseline annual risk predicted by the reference PRA model approximates the risk of shutdown for plants belonging to the class).

Baseline Annual CDF for PWRs at Shutdown

The core damage frequency during a typical outage can vary by several orders of magnitude. The cumulative risk caused by the entry into risk-significant configurations (those with relatively high conditional CDF or conditional LERF) represents a significant portion of the total average risk. The entry into certain RCS vulnerable conditions (e.g., mid-loop operation in PWRs) is unavoidable due to the nature of the outage. Also, many equipment maintenance and testing activities are scheduled during shutdown conditions. Because the threshold values can only be developed after a realistic baseline yearly CDF is established, an attempt was made to arrive at a baseline CDF by surveying shutdown PRAs. The results for PWR plants are shown in Table B-1 and in Figure B-1. The CDF values reported for PWRs are generally between 1.0E-5 and 1.0E-4. The following clarifications are noted:

In items 1-10, the reported CDFs

- are predicted using IPE-like PRA models,
- reflect past shutdown practices (pre-NUMARC initiative, Ref. 10), and
- are underestimated in some cases because of the scope of the models.

The CDF reported in items 11-13

- is either the actual cumulative risk or target risk associated with a recent outage in a PWR plant, and
- reflects present shutdown practices (post-NUMARC initiatives).

Table B-1 Summary of PRA Results for PWRs

	PRA Study (PWR)	CDF (per calendar year)
1	NSAC-84 (1981) (Quoted in Ref. 4)	1.8E-05
2	NUREG/CR-5015 (Quoted in Ref. 4)	5.2E-05
3	Seabrook (Quoted in Ref. 4)	4.5E-05
4	Sequoyah (upper bound for LOCAs only) (Quoted in Ref. 4)	7.5E-05
5	Safety Monitor™ model for a generic Westinghouse plant (zero maintenance assumption) (Ref. 2) (Assuming two outages every 18 months and 30 days per outage)	3.1E-05
6	NUREG/CR-6144 (midloop only) (Ref. 5)	5.0E-06
7	NUREG/CR-6616 (zero maintenance assumption) (Ref. 6) (Assuming two outages every 18 months and 30 days per outage)	1.2E-05
8	Sequoyah SPAR model (Ref. 1) (Assuming two outages every 18 months and 30 days per outage)	1.0E-04
9	Surry (RES study; cold shutdown only; zero maintenance) (Ref. 7)	3.2E-06
10	Surry (RES study; cold shutdown only; with maintenance) (Ref. 7)	4.4E-05

Table B-1 (Continued)

	PRA Study (PWR)	CDF (per calendar year)
11	STP (1RE08; projected) (Ref. 8) (Assuming two outages every 18 months)	5.6E-05
12	STP (2RE06) (Ref. 8) (Assuming two outages every 18 months)	5.3E-05
13	STP (1RE07) (Ref. 8) (Assuming two outages every 18 months)	5.3E-05
14	IN 2000-13, Review of Refueling Outage Risk (Table 1, Ref. 9) (Assuming two outages every 18 months)	1.7E-4 range: [2.8E-6, 8.9E-4]

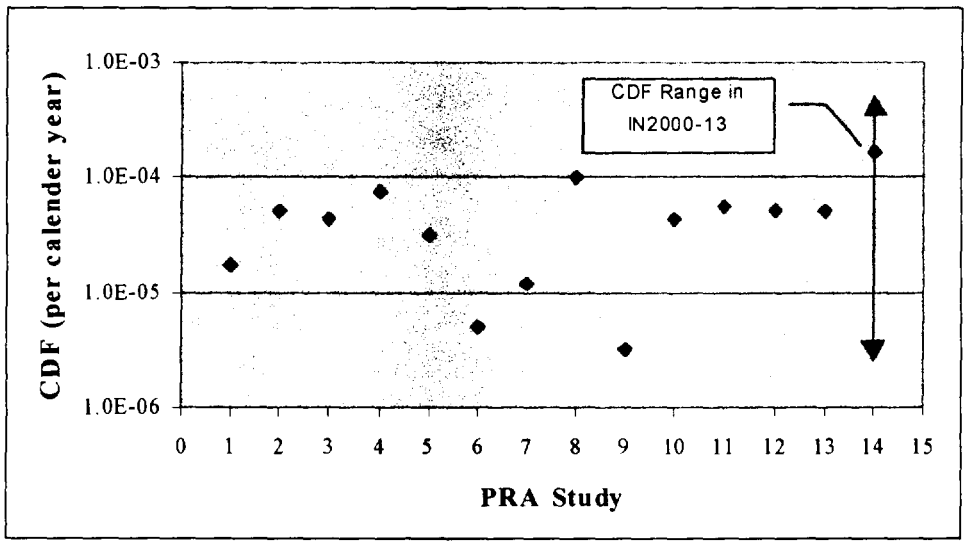

Figure B-1 Summary of PRA Results for PWRs

Item 14, derived from IN 2000-13 (Ref. 9), represents a more recent survey of outage risk experience. The following PWR shutdown risk information is provided in IN 2000-13:

> With respect to the cumulative risk data, (both predicted and actual) an extremely wide range of values were observed with respect to the outage risk. When pooled, the data (associated with the actual risk) for the PWRs showed a cumulative mean core damage probability (CDP) of approximately 1.2E-04 for the outage. However, the values ranged from a low of 1.5E-06 to a high of 6.6E-04 with a standard deviation of 2.0E-04. (Twelve data points were used in the analysis.) These same wide ranges of values were observed with respect to the data associated with the predicted cumulative risk. The mean value for the PWR peak risk (in units of cdp/hr) was 1.6E-06/hr. As with the cumulative risk data, a wide range of values were observed with a high of 5.0E-06/hr, a low of 2.0E-08/hr and a standard deviation of 2.1E-06/hr.

Elsewhere in IN 2000-13, it is noted that some of the reported variation in the numbers is due to differences in assumptions and methods used in different evaluations. However, it is further stated that another major source of variation in the risk numbers is variation in the outages themselves. A significant factor in PWR outage risk is reduced-inventory operation. According to IN 2000-13:

> The majority of the PWR outages which were assessed employed an early "hot" midloop or reduced inventory configuration. This was almost exclusively an economic consideration in that the early midloop allowed for earlier entry into the steam generators to perform the required inspection activities. In order to eliminate the midloop, licensees would have been required to delay the steam generator entry until after the reactor vessel was defueled. This would have had the net effect of making the steam generator inspections "critical path" (i.e., the driving factor for the outage duration) in many instances thereby increasing the overall length of the outage. Even with the implementation of the early midloop, the steam generator inspection activities constituted the critical path for many of the refueling outages which were assessed. For the vast majority of the PWR outages, either the steam generator inspections or the actual refueling activities themselves constituted the critical path for the outage.

Midloop configurations contribute significantly to the total CDF, especially those occurring before 5 days after reactor shutdown. RBPI development needs to reflect this.

Baseline Annual CDF for BWRs at Shutdown:

Relatively little published information is available for BWR shutdown risk. The following results are provided in IN 2000-13.

> The data for the BWR plants included only three observations. Additionally, one of the BWR units experienced unexpected complications due to fuel integrity issues which significantly extended the duration of the outage. Similar to the PWR data, a wide range of values existed in the cumulative and peak risk estimates associated with the BWR outage observations. Notwithstanding these issues related to data quality, the mean actual risk was estimated to be approximately 8.6E-07 with a high and low of 1.7E-06 and 2.0E-08 respectively. The peak risk was estimated at about 1.2E-08/hr with a range of 3.3E-10/hr to 3.1E-08/hr.

Among the few published studies for BWR shutdown risk is the Grand Gulf study (Ref. 3). The annualized CDF indicated by that study is 4E-6 per calendar year. This is approximately a factor of two higher than the "high" value quoted above from IN 2000-13. This difference could be due to the difference in average CDF as a result of dwell times rather than differences in CCDF. The risk information from Ref. 3 will be used to define the BWR baseline for this development.

B.1 Initiating Events Cornerstone

B.1.1 Assess the Potential Risk Impact of Degraded Performance

Many events have the potential to challenge the shutdown cooling function. Examples of undesirable and potentially risk-significant events include:

- any unintentional, uncontrolled, undesired, and unexpected reduction of water level[1] in the reactor vessel of greater than 1 foot (a few inches during mid-loop operation in PWRs)

- flow diversions from the reactor vessel,
- inadvertent drain downs,
- uncontrolled level perturbations in the reactor vessel.

The more significant events are those that drain water down to a level close to or below the top of the core. But any undesired, uncontrolled, or unexpected draindown is an instance of poor performance. The same is true of violations of mode temperature or reactivity parameters. Reactor Mode is defined by the technical specifications in terms of temperature and reactivity bounds. Mode 6, for example, is k_{eff} less than .95 and RCS temperature less than 140°F. Mode 5 is k_{eff} less than .99 and RCS temperature less than 200°F. If flow diversions, reactivity changes, or other events occur causing a heat production/heat removal mismatch, exceeding one of these mode parameters may be the first indication of performance problems.

However, many such events do not qualify as IEs in PRA space because they do not actually lead to the loss of RHR. Shutdown PRAs typically do not develop these events logically below the level of the initiating event itself. RBPI development is therefore limited to consideration of the initiating events for RBPI potential. The statistics that are used to quantify these high level nodes may contain information on the causal factors that led to an initiating event, but, in general, these lower level factors are not modeled. Therefore, RBPIs cannot be based on events of this kind.

The following are modeled initiating events that lead to the actual loss of the shutdown cooling function and are therefore potentially risk-significant:

- Loss of the decay heat removal (LDH) system (loss of RHR or a critical support system)
- Loss or diversion of inventory (LDI) sufficient to cause loss of RHR
- Loss of level control (LLC) when going to mid-loop (PWRs only) sufficient to cause loss of RHR
- Loss of offsite power (LOP) causing at least momentary loss of RHR

Based on the representative studies cited above, the risk significance of these events has been assessed as described below. The risk significance of these events with respect to the CDF metric is determined by their frequencies and their conditional core damage probabilities (CCDPs). For the above initiating events, the CCDPs were assessed as follows. Results presented below establish that all of these initiating events are risk-significant in at least some configurations.

---

[1]Excluding normal water level fluctuations.

Assessment of Initiating Event CCDPs

- A 35-day refueling outage each 18 months of operation was assumed. It was further assumed that analyzing the time during which the decay heat is removed by the RHR system (during mode 4, 5, and 6) could capture the more risk-significant portions of a refueling outage. This corresponds to approximately 85% of the assumed outage time (29-30 days).
- Non-refueling outages consist of both scheduled outages and unscheduled outages. These outages share one characteristic - they vary widely from a few hours in hot standby to many days of cold shutdown. The latter may or may not include extended periods with the containment and the RCS open, and may sometimes include extended mid-loop operation in PWRs. For purposes of the PI analysis, it was judged that the risk of non-refueling outage operation could be estimated by assuming that the refueling outage results could be applied to non-refueling outages. An additional 35 days every 18 months is assumed for non-refueling outages.
- The assumed refueling outage and maintenance outage times of 35 days every 18 months, yields a power operation fraction of 87%.
- The shutdown SPAR model for Sequoyah (the reference model for PWR plants) uses the concept of POS groups/time windows to account for the variability in RCS conditions and decay heat level. The approximate correspondence between POS groups and operating modes of a typical PWR are as follows:
  - Pressurized cooldown -- Mode 4: hot shutdown (cooldown with RHR to 200°F); Mode 5: cold shutdown (cooldown to ambient temperature); Mode 4: hot shutdown (RCS heat-up)
  - Depressurized RHR cooling with normal inventory -- Mode 5: cold shutdown (reactor inventory is at normal level and RCS is depressurized); Mode 6: refueling (draining RCS to midloop before and after refueling)
  - Depressurized RHR cooling with reduced inventory -- Mode 5: (mid-loop operation and reduced inventory)
  - Depressurized RHR cooling with refueling cavity filled -- Mode 6: (refueling)

- The Grand Gulf shutdown PRA model (the reference model for BWR plants) also uses the concept of POS groups/time windows to account for the variability in RCS conditions and decay heat level. This model is however limited to the analysis of cold shutdown only.
- The differences in decay heat level are accommodated by introducing the time windows shown below in Table B.1-1.

Table B.1-1 Time Window Definitions

	Time Window 1	Time Window 2	Time Window 3	Time Window 4
Time After Shutdown (TAS) in hours	<75	75<TAS<240	240<TAS<768	>768

- In Phase 2 of the Grand Gulf study, the annual CDF associated POS 5 (consisting mainly of cold shutdown operating condition) is estimated to be 2.1E-6 per reactor year. Based on the Phase 1 study, approximately 60% of the CDF occurs in POS 5. To account for the risk of the unanalyzed portion of the outage, the CDF of POS 5 was extrapolated linearly.

This provided an estimate of a total baseline aggregate CDF of 3.5E-6 (2.1E-6/0.6). To obtain average conditional core damage probabilities (CCDPs), the hourly rate of each class of initiating events was converted to a calendar base rate (using the outage schedule defined above). The results are shown in Table B.1-2.

Table B.1-2 Calculation of Weighted CCDPs for BWR Shutdown Initiators

IE	POS 5 CDF (Based on Grand Gulf Study)	Approximate Aggregate Yearly CDF (adjusted to account for unanalyzed POSs)	IE Frequency (per hour)	IE Frequency (per year)	Average Baseline CCDP
LDH	9.9E-08	1.65E-07	6.16E-05	5.72E-02	2.88E-06
LDI	1.3E-06	2.17E-06	8.74E-06	8.11E-03	2.67E-04
LOP	7.0E-07	1.17E-06	1.50E-05	1.39E-02	8.38E-05
Total	2.10E-06	3.50E-06	8.54E-05	7.92E-02	4.41E-05

- The PWR SPAR model provided the estimates of the initiating event frequencies on a per hour basis (see Table B.1-3), and the conditional core damage probability (CCDP) for various combinations of IEs and time windows (see Table B.1-4). The data in Table B.1-4 along with the assumed refueling outage schedule are used to generate a weighted baseline CCDP for each initiator (Table B.1-5 below). The third and fourth columns of Table B.1-5 provide the timing of entry into a POS group in terms of days after shutdown (DAS) and the residence time (RT) in the POS group.

Table B.1-3 Generic Initiating Event Frequency Estimates for PWRs

	Frequency	
IE	**Per Reactor Hour**	**Per Calendar Year**[2]
LDH	8.38E-05	7.78E-02
LDI	7.20E-05	6.68E-02
LOP	1.63E-05	1.51E-02
Total (Time- Related Initiating Events)	1.72E-04	1.60E-01
	Per Demand	**Per Calendar Year** (assuming 2 drain downs per year)
LLC	1.81E-02	2.41E-02

[2]The frequency value accounts for the average amount of time that a plant is in the shutdown condition during a typical calendar year.

Table B.1-4 Estimates of CCDPs for Various POS Groups and Time Windows (SPAR Generated data; Applicable to PWRs)

General Mode Characteristic				Time Window	Baseline CCDP			
Mode	POS Group	Reactor Inventory	RCS Boundary		LDH	LDI	LLC	LOP
Mode 4/5	Pressurized RHR cooldown	Normal	Intact	window 1	1.24E-03	1.63E-03	NA	5.17E-03
				window 2	1.04E-03	1.52E-03		5.00E-03
				window 3	1.01E-03	1.13E-03		4.92E-03
				window 4	1.04E-04	2.20E-04		2.78E-04
Mode 5	Depressurized RHR cooling with normal inventory	Normal	Intact or vented	window 1	5.21E-04	7.55E-04	NA	2.43E-03
				window 2	3.34E-04	6.52E-04		1.24E-03
				window 3	4.62E-05	2.10E-04		1.12E-03
				window 4	4.90E-05	1.92E-04		4.31E-04
Mode 5	Depressurized RHR cooling with reduced inventory	Reduced	Intact or vented	window 1	9.92E-04	7.64E-04	7.64E-04	2.12E-03
				window 2	9.69E-04	6.63E-04	6.63E-04	1.26E-03
				window 3	3.32E-05	1.26E-04	1.26E-04	6.12E-04
				window 4	2.23E-05	1.08E-04	1.08E-04	1.99E-04
Mode 6	Refueling cavity filled	Gravity full	Vessel head off	window 1	cannot realistically reach this state			
				window 2				
				window 3	time to core uncovery > 48 hours	5.60E-04[3]	NA	time to core uncovery > 48 hours
				window 4		5.60E-04		

[3]The reference SPAR model does not handle this POS group. The value for the CCDP is obtained from a generic Westinghouse 4-loop shutdown model developed for use in the Safety Monitor Version 2.0 software.

Table B.1-5 Calculation of Weighted CCDP for PWR Shutdown Initiators [Weighted by Residence Time (RT) in Each POS Group] – Applicable to PWR Plants

Mode	POS Group	DAS	RT Day	Fraction of Time in State	LDH		LDI		LLC	LOP	
					CCDP	Duration Weighted CCDP	CCDP	Duration Weighted CCDP	CCDP	CCDP	Duration Weighted CCDP
Mode 2/3	Low power cooldown with SGs	0-1	Not analyzed								
Mode 4 hot/cold shutdown	Pressurized RHR cooldown	1-2	1	0.03	1.24E-03	4.28E-05	1.63E-03	5.62E-05		5.17E-03	1.78E-04
Mode 5 cold shutdown	Pressurized RHR cooldown	2-3	1	0.03	1.24E-03	4.28E-05	1.63E-03	5.62E-05		5.17E-03	1.78E-04
Mode 5 cold shutdown	Depressurized RHR cooling with normal inventory	3-5	2	0.07	3.34E-04	2.30E-05	6.52E-04	4.50E-05		1.24E-03	8.55E-05
Mode 5 cold shutdown	Depressurized RHR cooling with reduced inventory	5-7	2	0.07	9.69E-04	6.68E-05	6.63E-04	4.57E-05	6.63E-04	1.26E-03	8.69E-05
Mode 6 refueling	Depressurized RHR cooling with normal inventory	7-9	2	0.07	3.34E-04	2.30E-05	6.52E-04	4.50E-05		1.24E-03	8.55E-05
Mode 6 refueling	Refueling cavity filled	9-19	10	0.34	0.00E+00	0.00E+00	5.60E-04	1.93E-04		0.00E+00	0.00E+00
Mode 6 refueling	Depressurized RHR cooling with normal inventory	19-20	1	0.03	4.62E-05	1.59E-06	2.10E-04	7.24E-06		1.12E-03	3.86E-05
Mode 5 cold shutdown	Depressurized RHR cooling with reduced inventory	20-22	2	0.07	3.32E-05	2.29E-06	1.26E-04	8.69E-06	1.26E-04	6.12E-04	4.22E-05
Mode 5 cold shutdown	Depressurized RHR cooling with normal inventory	22-27	5	0.17	4.62E-05	7.97E-06	2.10E-04	3.62E-05		1.12E-03	1.93E-04
Mode 4 hot shutdown	RCS heat-up (similar to pressurized RHR cooldown)	27-30	3	0.10	1.01E-03	1.04E-04	1.13E-03	1.17E-04		4.92E-03	5.09E-04
Mode 3/2	RCS heat-up	30-35	Not analyzed								
Σ			**29**	**1.00**		**3.15E-04**		**6.10E-04**	**7.89E-04**		**1.40E-03**

B.1.2 Obtain Performance Data for Risk-Significant, Equipment-Related Elements

Previous work has led to the values of initiating event frequency tabulated above. Data for these initiating events are forthcoming because their associated reporting requirements are governed by the LER rule.

B.1.3 Identify Indicators Capable of Detecting Performance Changes in a Timely Manner

The initiating event frequencies tabulated above are too low to indicate plant-specific performance changes in a timely manner. Therefore, there are no shutdown-related RBPIs for the initiating events cornerstone.

However, these events occur at an observable rate in the operating fleet. Therefore, these initiating events are referred for industry trending.

B.1.4 Identify Performance Thresholds Consistent with a Graded Approach Outlined in SECY 99-007

No RBPIs were identified, so no performance thresholds were determined.

B.2 Mitigating Systems Cornerstone

B.2.1 Assess the Potential Risk Impact of Degraded Performance

Some equipment that is important at shutdown is also used at full power and is covered by RBPIs developed to cover full power operation. In principle, performance thresholds for these items should be determined based on change in total CDF resulting from performance degradation, and not just the change in full-power, internal-events CDF resulting from performance degradation.

The following discussion focuses on licensee management of plant configuration during shutdown. Most licensees manage shutdown risk in accordance with Generic Letter 88-17 and the NUMARC-91-06 (Ref. 10) directives. These directives are designed to give the licensee guidance in maintaining adequate defense in depth during shutdown operations for controlling risk. From a risk point of view, defense in depth is maintained if, through configuration control, the licensee maintains an adequate mitigating capability consistent with the risk significance of the POS. Because technical specifications are relaxed at shutdown, there is a potential for entering into vulnerable RCS conditions (e.g., mid-loop in PWRs) without adequate mitigating capability. The shutdown PRA models surveyed have identified the unavailability of equipment due to maintenance as the dominant cause of loss of mitigation capability. If the duration and frequency of risk-significant configurations (configurations in which CCDF is relatively high; defined more explicitly below) are not controlled, the accumulated risk (core damage probability) can be significant.

Maintenance unavailabilities of mitigating systems and human performance responding to the initiating event are especially risk-significant elements that are modeled. Accident sequences

include contributions from conjunctions of train unavailabilities. These conjunctions of unavailabilities are the elements of risk-significant configurations. There are many risk-significant configurations that are not covered by TS in Modes 5 and 6. It is possible for a plant to be in a risk-significant configuration for significant portions of an outage.

Equipment performance is also important, but as noted above, most of the equipment involved in the mitigation of accidents during shutdown falls within the scope of the RBPIs developed for full power operation. Moreover, the reliability characteristics of the mitigating systems are not likely to change significantly during shutdown, because the duration of a shutdown is typically much shorter than the duration of full power operations. Much of the equipment used only at shutdown is not modeled in typical PRAs. Shutdown-specific system-level RBPIs therefore have limited potential.

B.2.2 Obtain Performance Data for Risk-Significant, Equipment-Related Elements

Performance data for the configuration element consists of a statement of plant configuration (availability of mitigating system trains) as a function of time. For a given shutdown, an outage plan is a statement of the licensee's intent. The actual configurational data will reflect not only equipment trains being taken out for maintenance deliberately, but also trains being unavailable due to failure, error, or unplanned over-running of allotted maintenance time. Calculations presented below were based on outage schedules considered representative.

Routine characterization of actual plant configuration would require information collection beyond current reporting requirements.

B.2.3 Identify Indicators Capable of Detecting Performance Changes in a Timely Manner

A key element of configuration control than can be monitored is the accumulated time spent in risk-significant configurations during the observation period. Performance indicators are proposed below based on this metric. The proposed performance indicators directly measure the time the plant spent in risk-significant configurations (combinations of unavailabilities and plant conditions with respect to decay heat and RCS inventory).

<u>Characterization of Risk-Significant Configurations</u>

In order to quantify PWR CDF conditional on plant configuration (i.e., CCDF), a generic Westinghouse safety monitor model was quantified under different configurations that have the potential to occur during a typical refueling outage. The results of the evaluation of the risk impact of the different preventive maintenance schedules (NUREG/CR-6166, Ref. 11) contain the estimates of CCDFs for various shutdown configurations at BWRs. The results are as shown in Table B.2-1 for PWRs and Table B.2-2 for BWRs. The "zero-maintenance CDF" values shown in each table represent the core damage frequency per day assuming all mitigating systems are available. The following observations are made:

PWRs:

- The most vulnerable RCS condition is when RCS water level is low and secondary cooling is unavailable within the first two weeks following shutdown. The daily CCDF for this configuration (with zero maintenance assumption) is on the order of 1E-4 per day up to 4½ days after shutdown, and 1E-5 per day 5 or more days after shutdown. Several days of residence in this state can incur significant core damage probability.

BWRs:

- The baseline CDF is highest in POS 5 when the decay heat is still high and the vessel head is on.
- The highest daily CCDF calculated was about 5E-5/day. This is about 2E-6/hr. This corresponds to two conditions:

    - When the suppression pool is drained in POS 4 or 5. The suppression pool provides the suction source for ECCS pumps and acts as a heat sink for the removal of decay heat from the core. This condition should definitely be captured as a risk-significant configuration.
    - When all safety relief valves are removed from service in POS 4 or 5. The SRVs are required for water solid closed loop core cooling following the loss of shutdown cooling.

Definition of the RBPI

The proposed RBPIs reflect excess time spent in risk-significant configurations during the observation period. Four categories of configurations are defined in terms of conditional core damage frequency (CCDF) and, in the case of "Early Reduced-Inventory," operational conditions. The baseline for each category (the typical time spent in configurations associated with that category) has been determined by examination of representative outage profiles, as discussed in the Preface to this appendix. Spending time over and above the baseline duration in configurations having relatively high CCDF results in core damage probability above the baseline value.

The configuration category definitions are as follows:

Negligible	CCDF << 1E-6/day
Low	CCDF ~ 1E-6/day
Medium	CCDF ~ 1E-5/day
Early Reduced-Inventory	CCDF ~ 1E-4/day
High	CCDF ~ 1E-4/day

Based on these definitions, realizable configurations can be assigned to these categories based on the CCDF and operational conditions associated with the configuration. This is done in Table B.2-3 and Table B.2-4 for PWRs and BWRs respectively.

The BWR results (Tables B.2-2 and B.2-4) are extracted from published results, and details of the assumptions underlying those results are not available. For the PWR case, the results presented were performed using a generic Westinghouse 4-loop shutdown model acquired by the USNRC from SCIENTECH, Inc. This model was developed for use in Safety Monitor Version 2.0 software. The assumptions used in calculating CCDF for PWR configurations are presented below.

Detailed Assumptions Underlying Calculation of CCDF for PWR Configurations

Pressurized Cooldown (Mode 4)

- This mode is hot shutdown.
- The RCS temperature is below 275° F, and the RCS is pressurized.
- There is a bubble in the pressurizer. The Safety Monitor model assumes that the reactor is normally cooled by SG heat removal in this POS, with SG's supplied by AFW or condensate. Although RHR shutdown cooling is possible in this POS, the model does not have a Loss of RHR initiating event for this POS.
- All SGs are supplied with secondary makeup and removing decay heat.
- RHR shutdown cooling is available if SG heat removal fails, but may not be the preferred option for the operators. If the accident goes too long without restoration of DHR, the primary will heat up and pressurize beyond the point at which RHR shutdown cooling can be established.
- Both RHR loops are operable.
- Both DG's are operable.
- Both PORV's are operable with block valves open.
- 3 AFW pumps are operable, with one MD pump operating.
- All SI signals are disabled.
- The SI pump breakers are racked out.
- One charging pump is providing charging flow. The other two charging pumps are racked out, but available.
- All operator errors are set to nominal probabilities.

Depressurized RHR Cooling with Normal Inventory (Mode 5)

- The RCS temperature is less than 200° F, and the RCS is at atmospheric pressure.
- The RCS is not vented.
- There is a bubble in the pressurizer.
- RHR shutdown cooling is operating.

Table B.2-1 Conditional CDF (Daily) Under Various Shutdown Configurations of a PWR

Representative Configurations Occurring in a Typical Outage																				
POS				Zero maintenance daily CDF	Backup RHR Train	Emergency AC			Support Cooling		Secondary Cooling			Emergency Injection			Other			
Group	Mode	RCS Boundary	Days After Shutdown		RHR	DG	2DG	AC	ESW	CCW	AFW	All AFW	All SGs	RWST	SI(2)	2 Sumps	PORV(2)	SG PORV	SG RWST	SG Sump
Pressurized Cooldown	Mode 4 Hot shutdown	Intact	4	7.7E-08	1.5E-07	8.5E-07	2.4E-05	1.2E-06	7.4E-07	2.7E-07	1.2E-07			7.7E-06	7.9E-08	1.3E-06	3.0E-07			
Depressurized RHR Cooldown with Normal Inventory	Mode 5 Cold shutdown	Intact	8	1.9E-08	2.3E-08	4.1E-08	6.8E-07	7.1E-07	3.8E-07	3.8E-07	1.2E-06	1.2E-06	1.2E-06	8.8E-07	1.9E-08	1.4E-06	1.6E-07	1.1E-04	1.1E-04	1.1E-04
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	Intact or isolatable	12	3.8E-07	6.8E-07	4.1E-07	1.2E-06	1.9E-06	1.3E-06	1.3E-06	1.2E-05	1.2E-05	1.2E-05	1.7E-06	3.8E-07	2.2E-06	1.9E-06	1.1E-04	1.1E-04	1.1E-04
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	13	1.0E-05	1.5E-05	1.1E-05	1.7E-05	5.8E-05	1.6E-05	1.6E-05				1.1E-04	1.0E-05	1.7E-05				
Refueling Cavity Filled	Mode 6	vented	14	3.3E-08	2.2E-07	3.8E-08	3.3E-08	2.7E-07	2.2E-07	2.2E-07				3.8E-08	3.3E-08	1.2E-05				
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	24	3.0E-07	4.7E-07	6.3E-07	9.6E-06	1.1E-06	6.3E-07	7.1E-07					3.0E-07	4.1E-06				

Low Inventory Configurations Occurring Early in a Typical Outage																				
Group	Mode	RCS Boundary	Days After Shutdown	Zero maintenance daily CDF	RHR	DG	2DG	AC	ESW	CCW	AFW	All AFW	All SGs	RWST	SI(2)	2 Sumps	PORV(2)	SG PORV	SG RWST	SG Sump
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	Intact or isolatable	2	3.0E-06	5.1E-06	3.0E-06	3.6E-06	3.6E-06	3.0E-06	5.0E-06	1.1E-04	1.1E-04	1.1E-04	3.0E-06	3.0E-06	1.3E-04	3.0E-06	1.1E-04	1.1E-04	1.3E-04
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	2.5	1.1E-04	1.6E-04	1.1E-04	1.2E-04	1.6E-04	1.1E-04	1.6E-04				1.1E-04	1.1E-04	1.3E-04				
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	7	2.4E-05	3.5E-05	2.4E-05	3.3E-05	6.9E-05	2.4E-05	3.5E-05				1.1E-04	2.4E-05	3.6E-05				

Table B.2-2 Conditional CDF (Daily) Under Various Shutdown Configurations of a BWR

Description	POS 4 Hot Shutdown	POS 5 Cold Shutdown (vessel head is on)	POS 6 Refueling (with vessel head off and level raised to steam lines)	POS 7 Refueling (with vessel head off and upper pool filled)
Zero Maintenance, Baseline	1.3E-07	3.4E-07	~1E-8	~1E-8
Emergency Diesel Generator III (dedicated to HPCS)	2.6E-07	4.8E-07	~1E-8	~1E-8
Condensate System (CDS)	1.1E-07	3.4E-07	~1E-8	~1E-8
Control Rod Drive Train B	1.2E-07	3.5E-07	~1E-8	~1E-8
Emergency Diesel Generator (EDG) I	4.6E-07	8.5E-07	~1E-8	~1E-8
Emergency Diesel Generator II	4.6E-07	8.5E-07	~1E-8	~1E-8
Standby Service Water Train C (dedicated support system to HPCS)	9.6E-07	1.3E-06	~1E-7	~1E-8
Suppression Pool (empty)	2.3E-05	5.5E-05	5.8E-06	1.3E-06
Residual Heat Removal System Train (RHR) A	1.2E-07	3.5E-07	~1E-7	~1E-8
Residual Heat Removal System Train C	1.2E-07	3.5E-07	~1E-8	~1E-8
Standby Service Water (SSW) Train A	4.9E-07	1.1E-06	1.2E-07	~1E-7
All Safety Relief Valves (SRV)	4.5E-05	5.1E-05	N/A	N/A
Division I Battery	4.6E-07	8.5E-07	~1E-8	~1E-8
Division II Battery	4.6E-07	8.5E-07	~1E-8	~1E-8
Division III Battery	2.6E-07	4.8E-07	~1E-8	~1E-8
High Pressure Core Spray (HPCS)	9.3E-07	1.2E-06	~1E-7	~1E-8
Low Pressure Core Spray (LPCS)	1.1E-07	3.7E-07	~1E-8	~1E-8
SSW Train A and HPCS	6.3E-06	9.7E-06	1.2E-07	1.1E-06
SSW Train A and CDS	4.9E-07	1.1E-06	1.3E-07	~1E-7
Firewater System (all three pump trains)	1.1E-07	3.6E-07	2.9E-07	~1E-7
Firewater Diesel-Driven Pumps	1.1E-07	3.4E-07	~1E-8	~1E-8
EDGs I and II	6.0E-06	9.1E-06	~1E-7	~1E-8
EDGs I and III	1.9E-06	2.1E-06	~1E-7	~1E-8
RHR System Train A and all SRVs	6.8E-05	7.4E-05	N/A	N/A
Divisions I and II Batteries	6.8E-05	6.9E-05	~1E-7	~1E-8
Shutdown Cooling Train A and the Suppression Pool	2.4E-05	5.8E-05	6.4E-06	1.3E-06
LPCS and HPCS	1.2E-06	1.6E-06	~1E-8	1.2E-07
LPCS and RHR Train A	1.7E-07	7.3E-07	~1E-7	~1E-7
SSW Train A and SSW Train C	6.3E-06	9.7E-06	1.4E-07	1.1E-06
RHR Train A and RHR Train C	3.6E-07	3.8E-07	~1E-7	~1E-8

Table B.2-3 PWR Shutdown Configurations Risk Classification (Based on a Generic Westinghouse 4-Loop Shutdown PRA Model)

POS				No Maintenance Unavailability	Backup RHR Train Unavail-able	Emergency AC Trains Unavailable			Support Cooling Trains Unavailable		Secondary Cooling Trains Unavailable			Emergency Injection Trains Unavailable			Other Trains Unavailable			
Group	Mode	RCS Boundary	Days After Shutdown		RHR	EDG	EDG(2)	One Safety-Related AC Bus	One train of ESW	One train of CCW	One train of AFW	All AFW	All SGs	RWST	SI(2)[a]	Both Sumps	PORV(2)	SG/ PORV	SG/ RWST	SG/ and Both Sumps
Low Inventory Configurations Occurring Very Early (within the first 5 days) in an Outage																				
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	Intact or isolatable	2	Low	Med	Low	Low	Low	Low	Med	High	High	High	Low	Low	High	Low	High	High	High
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	< 5	ERI-V[b]	ERI-V[b]									ERI-V[b]						
Representative Configurations Occurring in a Typical Outage																				
Pressurized Cooldown	Mode 4 Hot shutdown	Intact	4			Low	Med	Low	Low					Med		Low				
Depressurized RHR Cooldown with Normal Inventory	Mode 5 Cold shutdown	Intact	8				Low	Low			Low	Low	Low	Low		Low		High	High	High
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	Intact or isolatable	12		Low		Low	Low	Low	Low	Med	Med	Med	Low		Low	Low	High	High	High
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	7	Med	Med	Med	Med	High	Med	Med				High	Med	Med				
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	13	Med	Med	Med	Med	High	Med	Med				High	Med	Med				
Refueling Cavity Filled	Mode 6	vented	14													Med				
Low Inventory Configurations Occurring Late in a Typical Outage																				
Depressurized RHR Cooling with Reduced Inventory	Mode 5 Cold shutdown	vented	24			Low	Med	Low	Low	Low				Med	Low	Low				

Notes:

a. In this configuration it is assumed that a makeup pump is available.

b. This configuration category assumes that measures are taken to compensate for the risk associated with early reduced-inventory operations. If compensatory measures are not taken, these configurations are assigned to the "High" configuration category.

- Shaded cells correspond to combinations of POS and configuration that are not analyzed, either because the configuration violates the POS definition, or because the systems involved play no role in the POS. They include:

- Mode 4 configurations related to complete unavailability of the secondary cooling systems. This is because it is assumed that in Mode 4 (hot shutdown) the heat removal function is performed by the SGs.
- Mode 5 configurations related to complete/partial unavailability of the secondary cooling systems when the RCS is vented. This is because under vented RCS condition, secondary cooling is not possible.
- Mode 6 configurations related to complete/partial unavailability of the secondary cooling systems. In this mode, secondary cooling is not possible.
- Mode 5/6 configurations related to unavailability of PORVs when the RCS is vented. PORV operability is inconsequential when the RCS is vented.

• Blank cells represent configurations whose CCDF < 1.0E-6 per day. The low CCDF for specific cells is explained below.

- Cell <one RHR train is OOS in Mode 4 >: the decay heat removal function is performed by AFW. Cooling by the operable RHR train and feed and bleed are credited.
- Cell <one RHR train is OOS in Mode 5 and RCS is intact or isolatable>: SG heat removal is credited as recovery after RCS heats up. Feed and bleed is also credited.
- Cell <one EDG is OOS in Mode 5 and RCS is intact or isolatable>: SG heat removal is credited as recovery after RCS heats up.
- Cell <one ESW/CCW train is OOS in Mode 5 and RCS is intact or isolatable>: The equipment OOS affects RHR. SG heat removal, which is unaffected by the CCW/ESW outage, is credited as recovery after RCS heats up.
- Cell <specified equipment OOS in Mode 6 and refueling cavity is flooded>: Continual boiling with water addition to vessel is credited.
- Cell <2 sumps OOS in Mode 6 and refueling cavity is flooded>: This is a risk-significant configuration (medium ranking) because the long term inventory control function is lost following a LOCA.
- Cell <two SI trains are OOS in Mode 4/5 and RCS is intact or isolatable>: Credit is taken for the isolation of the leak, initial injection by the make-up pumps, and secondary cooling via SGs. When the RCS is vented, secondary cooling cannot be established.
- Cell <PORVs are OOS in Mode 5 and RCS is intact or isolatable and RCS inventory low>: a bleed path cannot be established to support cooling by a "feed and spill" method. The worth of the "feed and spill" success path is greater under reduced inventory conditions than under normal-inventory conditions.

Key:

Low	Low Risk Configuration
Med	Medium Risk Configuration
High	High Risk Configuration
ERI-V	Early Reduced-Inventory (vented)
AC	Alternating Current power division
AFW	Auxiliary feed water
CCW	Component cooling water
DC	Direct Current power division
EDG	Emergency diesel generator
ESW	Emergency service water
RHR	Residual heat removal
SG	Steam generator
RWST	Refueling water storage tank
SI	Safety injection
PORV	Power-operated relief valve

Table B.2-4 BWR Shutdown Configurations Risk Classification (Based on NUREG/CR-6166 Results)

POS			No Maintenance Unavailability	Emergency AC/DC Trains Unavailable					Support Cooling Trains Unavailable			Emergency Cooling Trains Unavailable				Other Trains Unavailable			
Group	Mode	RCS Boundary		EDG I or II	4 EDG I and II	EDG I and III	One. BAT division	Two BAT divisions	SSW A	SSW C	SSW A and C	HPCS	LPCS and HPCS	SP empty	SRVs all	SSW A and HPCS	SSW A and CDS	RHR A and all SRVs	SDC A and SP
POS 4	Hot shutdown	Intact		Low	Med	Low		High		Low	Med	Low	Low	Med	Med	Med		High	Med
POS 5	Cold shutdown	Vessel head on		Low	Med	Low	Low	High	Low	Med	Med	Low	Low	High	High	Med	Low	High	High
POS 6	Refueling	Vessel head off (level raised to steam line)												Med					Med
POS 7	Refueling	Upper pool filled									Low			Low		Low			Low

Note: Blank cells represent configurations whose CCDF < 1.0E-6 per day.

Key:

Low	Low Risk Configuration
Med	Medium Risk Configuration
High	High Risk Configuration
EDG	Emergency diesel generator
BAT	Battery
SSW	Standby service water
HPCS	High pressure core spray
LPCS	Low pressure core spray
SP	Suppression pool
SRV	Safety relief valve
CDS	Condensate system
SDC	Shutdown cooling

- If RHR fails, SG heat removal, using AFW / condensate, is available. The SG secondary sides contain normal inventory.
- Both RHR loops are operable.
- Both DG's are operable.
- Both PORV's are operable with block valves open.
- Two motor driven AFW pumps are operable.
- All SI signals are disabled.
- The SI pump breakers and 1 charging pump breaker are racked out.
- One charging pump breaker is racked in, but the charging pump is in standby.
- SI and charging are "available" with operator action if required.
- No RCP cooling is required.
- All operator errors are set to nominal probabilities.
- Two trains of AC are operable.
- The RCS is at atmospheric pressure.
- Pipe break LOCA frequencies are reduced from those that pertain to power operation.
- SG tube rupture and steam line break are not postulated.
- Inventory diversion from the RCS (in containment) is postulated.
- Interfacing LOCA (due to human error) is postulated.

Depressurized RHR cooling with Reduced inventory (Non-vented RCS in Mode 5)

- The RCS temperature is less than 200° F, and the RCS is at atmospheric pressure.
- The RCS is not vented.
- The pressurizer is drained. The water level is at midloop of the cold leg. RHR shutdown cooling is operating.
- If RHR fails, SG heat removal is available through reflux cooling
- Both RHR loops are operable.
- Both DGs are operable.
- Both PORVs are operable with block valves open.
- All ESF signals are disabled.
- The SI pump breakers and one charging pump breaker are racked out.
- One Charging pump breaker is racked in, but the charging pump is in standby.
- SI and charging are "available" with operator action if required.
- No RCP cooling is required.
- Two trains of AC are operable.
- Pipe break LOCA frequencies are reduced from those that pertain to power operation.
- Inventory diversion from the RCS (in containment) is postulated.
- Interfacing LOCA (due to human error) is postulated.

Depressurized RHR cooling with Reduced inventory (Vented RCS in Mode 5)

- The RCS temperature is less than 200° F, and the RCS is at atmospheric pressure.
- The RCS is vented.
- The pressurizer is drained. The water level in the RCS is at midloop.
- RHR shutdown cooling is operating.
- If RHR fails, SG heat removal is not available because the RCS is vented.
- Both RHR loops are operable.
- Both DG's are operable.
- The PORV status is inconsequential because the RCS is vented.
- Gravity feed from the RWST is available.
- All SI signals are disabled.
- SI pump and charging pump breakers are racked out.
- SI and charging pumps are "available" with operator action if required.
- All operator errors are set to nominal probabilities.
- Two trains of AC are operable.
- The RCS pressure is atmospheric.
- Pipe break LOCA frequencies are reduced from those that pertain to power operation.
- Inventory diversion from the RCS (in containment) is postulated.
- Interfacing LOCA (due to human error) is postulated.

Refueling (Mode 6)

- The RCS temperature is less than 140° F, and the RCS is at atmospheric pressure.
- The head is off.
- The refueling cavity is full.
- RHR shutdown cooling is operating.
- One RHR loop is operable and operating.
- Both DG's are operable.
- Gravity feed from the RWST is available.
- All SI signals are disabled.
- SI pump and charging pump breakers are racked out.
- SI and charging pumps are "available" with operator action if required.
- All operator errors are set to nominal
- 2 trains of AC are operable.
- Loss of RHR cooling in this state can not lead to core damage within 24 hrs. Time to boiling after loss of RHR is about 15 hours. Time to core damage is greater than 48 hrs.
- The RCS pressure is atmospheric.
- Pipe break LOCA frequencies are reduced from those that pertain to power operation.
- Inventory diversion from the RCS (in containment) is postulated.
- Interfacing LOCA (due to human error) is postulated.

Interpretation of the Risk Significance of Shutdown Configurations

The POS group in which the accident is postulated to occur determines what systems can be credited for mitigation. The potential success paths are determined by the operability of mitigating systems at the time of an accident, and by whether the challenge to the RHR function is caused by a LOCA or a non-LOCA condition. The following success paths are potentially available:

If the RHR function is lost as a result of a LOCA or a flow diversion:

1. Leak termination prior to loss of RHR cooling
2. (Makeup to RCS) *AND* (Spill if needed) *AND* (Long term re-circulation)

If the RHR function is lost as a result of a non-LOCA condition:

1. RHR restoration – either by repair of the lost train or alignment of the standby train
2. Secondary cooling
3. (Forced feed to RCS) *AND* (Spill) *AND* (Long term re-circulation)
4. Gravity feed of the RWST through the RCS if conditions allow.

The key characteristics of the POS group are the following:

Water Level

The water level in the vessel is one of the key attributes of a POS definition. In a Westinghouse PWR, the water level can range from mid-loop to 23' above the vessel flange. In mid-loop, the time to boil after a loss of RHR cooling can be as short as 10 to 30 minutes. Time to core uncovery can be as short as 2 hours. In this configuration, the loss of RHR is a significant safety challenge. During refueling, when the refueling cavity is flooded, the time to boil can be 15 to 30 hours. The time to core uncovery after a loss of RHR is 2 to 3 days. In this configuration, the loss of RHR is a less significant safety challenge.

RCS Pressure Boundary

The status of the RCS pressure boundary affects the methods available for decay heat removal. During Modes 4, 5, and 6 the RCS can be intact (with operable relief valves), vented, or have the head removed. Heat removal through the steam generators and reflux cooling is only available when the RCS is isolatable or intact. RHR shutdown cooling is available in all modes. Gravity feed of the RWST (through the RHR lines) is only available under certain conditions when a large vent exists. Feed and bleed is available when the RCS is intact or when sufficient vent area exists. Avoidance of Low Temperature Overpressure (LTOP) is required when the RCS boundary is intact and the

RCS temperature is less than 275° F. Charging pumps and SI pumps are usually racked out in Mode 4 and 5 if the RCS is not vented. This complicates operator response to lowering water level in response to a LOCA, and operator initiation of feed and bleed cooling in response to a loss of RHR.

Decay Heat Level

Decay heat level is important to accident sequence modeling during shutdown, because it determines the time available for mitigation, prior to inventory boil-off. This time affects the probability of successful operator action. The decay heat varies as a function of time from shutdown, and it depends on whether the reactor contains old fuel waiting to be off-loaded, or new fuel waiting for start-up. Over a complete refueling operation, decay heat levels vary by a factor of 6 from 2 days after shutdown to 30 days after shutdown with new fuel. Decay heat levels determine the success criteria, and the time for operator action. Thus the time at which an accident occurs impacts the effectiveness of mitigating functions.

Based on the above, the CCDF associated with reduced inventory operations soon after shutdown is potentially high (> 1E-4 per day). These configurations are nevertheless entered, but typically with compensatory measures in place that serve to reduce the CCDF. This is explained in IN 2000-13:

With respect to the time of entry into the midloop configurations, data were collected relative to the scheduled as well as the actual time after shutdown before midloop conditions were achieved. Additionally, information associated with the estimated time-to-boil while at midloop was collected. As shown in Table 1 [of the IN], the average scheduled time after shutdown before entering midloop was about 84 hours with the actual value being closer to 93 hours. (The most aggressive schedule planned a midloop configuration 68 hours after shutdown.) The average estimated time-to-boil for the reduced inventory/midloop configurations was about 15 minutes (assuming a loss of shutdown cooling or inventory control) with a high and low estimate of 24 minutes and 9 minutes respectively.

...

Of the PWR outages employing a midloop or reduced inventory configuration, 9 of the 15 outages did so with a concurrent unavailability of either an emergency diesel generator or the performance of significant switchyard maintenance. At least one outage employed a midloop configuration with concurrent switchyard and emergency diesel maintenance. However, each of the outages prescribed a number of contingencies and other strict controls during midloop activities. These controls generally followed the NUMARC guidance with respect to protecting trains of equipment, comprehensive pre-evolution briefings, establishment of diverse means of level indications, and in some cases, the addition of temporary emergency power supplies.

The calculations presented in Table B.2-3 are based on a model that reflects the impact of decay heat, reduced inventory, and most aspects of equipment configuration, but not the compensatory measures described above.

B.2.4 Identify Performance Thresholds Consistent with a Graded Approach Outlined in SECY 99-007

The thresholds for time spent in risk-significant configurations can be developed once the baseline risk values are established. The baseline values need to reflect typical times spent in risk-significant configurations. As stated in the Preface to this appendix, the baseline at shutdown is a strong function of the outage plan, and assignment of a baseline for purposes of this indicator requires the characterization of a characteristic shutdown risk profile. Accordingly, based on available risk insights, the following assumptions are made:

PWRs:

- A baseline of 20 days is assigned to "Low" risk configurations. This accounts for a total contribution from this category on the order of 2E-5.
- A baseline of 2 days is assigned to "Medium" risk configurations. This corresponds to a contribution from this category of approximately 2E-5. An important sub-set of this category is mid-loop operations that take place early in the shutdown, but 5 or more days after reactor shutdown occurs.
- A baseline of 1 day is assigned to "ERI-V" configurations. These are reduced-inventory configurations with the RCS vented, taking place less than 5 days after reactor shutdown occurs when decay heat is still relatively high. This baseline corresponds to a contribution from this category that could be as high as 1E-4, if compensatory measures are not in place.
- A baseline of 0 is assigned to "High" risk configurations. A PWR plant will not deliberately enter into any "High" risk configurations, although it may enter ERI-V configurations if compensatory measures are in place.

BWRs:

- A BWR plant does not enter into any high risk category configurations (daily CCDF 1E-4).
- On average, 50% of the annual CDF of 4E-6 is incurred while in medium risk category configurations (CCDF of 1E-5) that typically last less than 6 hours.
- The remaining CDF (2E-6) is incurred while operating in low risk category configurations (daily CCDF of 1E-6). This corresponds to 2 days of stay in low risk category configurations.

Using the assumptions listed above, the threshold values for time spent in each risk category configuration are calculated. The results are shown in Table B.2-5 and Table B.2-6.

The thresholds calculated for "ERI-V" configurations are quantified as if the associated CCDF were on the order of 1E-4 per day. These thresholds may be somewhat conservative if the compensatory measures taken upon entry into ERI-V are highly effective. However, no quantitative model available to this project takes credit for those compensatory measures. The possible conservatism in the thresholds has been offset to some extent by the choice of 1 day as a baseline for ERI-V configurations.

Table B.2-5 Baseline and Thresholds for Time in Risk-Significant Configurations Indicators - PWRs

Configuration Category	Baseline	G/W Threshold	W/Y Threshold	Y/R Threshold
Low	20 days	21 days	30 days	120 days
Medium	2 days	2 days + .08 day (2 hrs)	3 days	12 days
Early Reduced-Inventory (vented)[a]	1 day	1 day	1.08 days (1 day + 2 hrs)	2 days
High	0	0	.08 day (2 hrs)	1 day

a. This configuration category assumes that measures are taken to compensate for the risk associated with early reduced-inventory operations. If compensatory measures are not taken, these configurations are assigned to the "High" configuration category.

Table B.2-6 Baseline and Thresholds for Time in Risk-Significant Configurations Indicators - BWRs

Configuration Category	Baseline	G/W Threshold	W/Y Threshold	Y/R Threshold
Low	2 days	3 days	12 days	102 days
Medium	0.20 day (5 hrs)	0.29 day (7 hrs)	1 day	10 days
High	0	0	.08 day (2 hrs)	1 day

B.2.5 Inspection Areas Covered by New RBPIs

The potential RBPIs developed above for shutdown are not currently in the ROP. The inspection areas that could be impacted by the new initiating event RBPIs were determined. The results are summarized below in Table B.2.5-1.

Table B.2.5-1 Summary of Inspection Areas Impacted by Potential Shutdown RBPIs for Mitigating Systems Cornerstone

RBPI	Attribute	Inspection Area
Time in High/Medium/Low Risk-Significant Configurations	Configuration Control	71111.04, Equipment Alignment 71111.13, Maintenance Risk Assessments and Emergent Work Evaluation 71111.20, Refueling and Outage Activities 71111.23, Temporary Plant Modifications

B.3 Barrier Integrity Cornerstone

No quantifiable models of LERF at shutdown were available to this project to support application of the full flowchart process presented in Section 2 of the main report. The following discussion is based on risk insights summarized below.

Containment performance at shutdown is affected by one issue that does not enter into consideration of full-power RBPIs, namely, that containment may be open during shutdown, and needs to be reclosed expeditiously under certain conditions. The situation for specific plant types is as follows:

PWRs:

Analysis performed in NUREG-1449 shows that timely closure of PWR containment prevents large early release in core damage scenarios initiated at shutdown.

BWRs with Mark-I and Mark-II Containments:

Analysis performed in NUREG-1449 shows that BWR secondary containment alone is not expected to prevent large early release in core damage scenarios. This means that a change in BWR Mark-I and -II shutdown CDF equates to a change in LERF if primary containment is open. This circumstance is offset by generally lower shutdown CDFs for BWRs.

BWRs with Mark-III Containments:

Analysis performed in NUREG/CR-6143 shows that timely closure of these BWR containments prevents large early release in core damage scenarios initiated at shutdown.

This suggests possible containment RBPIs analogous to the possible time-in-risk-significant-configurations RBPIs defined above in Section B.2.2. These would be defined for the risk-significant configuration categories introduced for the RBPIs defined for mitigating systems as follows.

Potential RBPI for PWRs and Mark-III BWRs:

Time spent in risk-significant configurations with containment not closed and preparations for timely closure not complete (timely: before boiling, if RCS is vented)

Potential RBPI for Mark-I and Mark-II BWRs:

Time spent in risk-significant configurations with primary containment not closed and not capable of timely closure.

An increase in time spent in a particular configuration with containment not capable of timely closure implies an increase in LERF equal to the CDF associated with that configuration. Configurations with negligible conditional CDF are therefore associated with negligible changes in LERF (except for changes in CDF that exceed 1.0E-7, which would not be considered negligible changes in LERF). However, risk-significant configurations contribute directly and significantly to LERF if containment is open and timely closure is not provided for. Configurations in which only a short time is available to respond to initiating events are also generally those in which only a short time is available to effect containment closure.

Data and models are not presently available to quantify these indicators. Therefore, neither baselines nor thresholds can be quantified. Quantification of these indicators would require the following:

- the time spent in risk-significant configurations defined in Section B.2.3,
- the time spent with containment in the indicated state during those risk-significant configurations, and
- extension of the treatment in Section B.2.3 to assessment of configurations in which the CDF change exceeds 1.0E-7.

B.4 References

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2. A Generic Westinghouse 4-Loop Shutdown Model Developed for Use in the Safety Monitor Version 2.0 Software, acquired by USNRC from SCIENTECH, Inc.

3. "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Grand Gulf, Unit 1," NUREG/CR-6143, SAND93-2440, Vol. 1, U.S. NRC, July 1995.

4. "Shutdown and Low-Power Operation at Commercial Nuclear Power Plants in the United States," NUREG-1449, U.S. NRC, 1993.

5. "Evaluation of Potential Severe Accidents during Low Power and Shutdown Operations at Surry Unit-1," NUREG/CR-6144, U.S. NRC, October 1994.

6. "Risk Comparison of Scheduling Preventive Maintenance During Shutdown vs. During Power Operation for PWRs," NUREG/CR-6616, BNL-NUREG-52549, U.S. NRC, December 1998.

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Appendix C
RBPI Determination for External Events Accident Risk

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Appendix C: RBPI Determination for External Events Accident Risk

This appendix provides preliminary RBPI results for fire. Other external events, such as seismic and flood, are not included in the scope of Phase 1 RBPI development.

The results from the Individual Plant Examinations for External Events (IPEEE's) were used to assess the risk-significant performance attributes in accordance with the RBPI development process shown in Figure 2.1. The IPEEE results are not collated in as comprehensive a way as was done for the IPE program. These studies indicate that fire CDF varies significantly among plants. However, fire CDF is generally high enough that some elements of fire scenarios are risk-significant compared to risks associated with full power internal events or shutdown risk.

The following IPEEE reports were reviewed:

Browns Ferry 2	Fort Calhoun	Prairie Island
Clinton	H.B. Robinson 2	Quad Cities 1&2
Davis-Besse	Millstone 2	Sequoyah 1&2
Dresden 2&3	Monticello	Waterford 3
Duane Arnold	North Anna 1&2	Washington Nuclear 2

Table C-1 below shows a comparison of fire CDF to internal events CDF for the above plants.

Table C-1 Significance of Fire CDF Relative to Internal Events CDF

Plant	Fire CDF	Internal Events CDF	Fire/Internal Events Ratio
Browns Ferry 2	6.73E-06	4.80E-05	14%
Clinton	3.26E-06	2.66E-05	12%
Davis-Besse	1.72E-05	6.60E-05	26%
Dresden 2	2.04E-04	1.85E-05	1103%
Dresden 3	2.53E-04	1.85E-05	1368%
Duane Arnold	1.05E-05	7.84E-06	128%
Fort Calhoun	2.78E-05	1.36E-05	204%
H.B. Robinson 2	2.23E-04	3.20E-04	70%
Millstone 2	6.30E-06	3.42E-05	18%
Monticello	8.37E-06	2.60E-05	32%
North Anna 1&2	3.99E-06	7.16E-05	6%
Prairie Island	6.32E-05	5.00E-05	126%
Quad Cities 1	6.60E-05	1.20E-06	5500%
Quad Cities 2	7.13E-05	1.20E-06	5942%
Sequoyah 1&2	1.56E-06	1.70E-04	9%
Waterford 3	7.04E-06	1.70E-05	41%
Washington Nuclear 2	1.76E-05	1.75E-05	100%

C.1 Initiating Events Cornerstone

For the purposes of this analysis, a fire initiating event is defined as the occurrence of a potentially significant fire, regardless of its duration or significance, and regardless of whether a given event actually causes a plant trip. (By definition, a potentially significant fire has the potential to cause a plant trip, if not suppressed.) Detection and suppression are addressed as part of the mitigating systems cornerstone.

C.1.1 Assess the Potential Risk Impact of Degraded Performance

"Elements" correspond to items that appear in accident sequence descriptions. Under the initiating events cornerstone, the only elements appearing in typical models are the initiating events themselves. Fire accident sequences are defined by fire areas. In fact, then, "fire" is not the initiating event definition: rather, fire *in a specific area* is the initiating event of a fire CDF sequence. Because different areas are associated with different degrees of vulnerability to fire, associating thresholds with generic fires would be a poor approximation.

The risk-significant fire areas vary from plant to plant. However, the following fire areas are the most common among the list of risk-significant fire areas based on the accident sequences identified in the IPEEE for each plant:

- Switchgear Room
- Control Room
- Cable Spreading Room
- Auxiliary Building (PWR)/Reactor Building (BWR)
- Turbine Building
- Battery Room

The complete list of risk-significant fire areas was created for each IPEEE reviewed and is provided in the tables below. A fire area was considered risk-significant if the contribution to the total fire CDF was two percent or greater.

Table C.1.1-1 Significant Fire Areas for Browns Ferry

Fire Area	CDF	Percent of Total
Unit 2 Reactor Building, 621' and North Side of 639'	1.07E-06	15.9%
Turbine Building	7.30E-07	10.8%
Unit 2 Battery and Battery Board Room	5.53E-07	8.2%
4kV Shutdown Board Room B	4.97E-07	7.4%
Control Bay - 593' Elev	4.73E-07	7.0%
Intake Pump Station	4.72E-07	7.0%
4kV Shutdown Board Room C and 250V Battery Room	4.51E-07	6.7%
Cable Spreading Room	4.48E-07	6.7%
4kV Shutdown Board Room D	4.15E-07	6.2%
4kV Bus Tie Board Room	3.08E-07	4.6%

Table C.1.1-1 (Continued)

Fire Area	CDF	Percent of Total
Unit 1 and 2 Diesel Generator Building	2.84E-07	4.2%
Unit 2 Reactor Building, South 593' Elev. And RHR Hx Rooms	2.78E-07	4.1%
4kV Shutdown Board Room A and 250V Battery Room	2.54E-07	3.8%
Total	6.73E-06	

Table C.1.1-2 Significant Fire Areas for Clinton

Fire Area	CDF	Percent of Total
Div 1, Div 2, & Div 3 Switchgear Rooms	1.45E-06	44.5%
Main Control Room	1.20E-06	36.8%
Screenhouse, General Access and Pipe Tunnel Areas	3.39E-07	10.4%
Total	3.26E-06	

Table C.1.1-3 Significant Fire Areas for Davis-Besse

Fire Area	CDF	Percent of Total
No. 1 Low Voltage Switchgear Rooms	5.90E-06	34.4%
High Voltage Switchgear Room B	5.18E-06	30.2%
Control Room	4.31E-06	25.1%
High Voltage Switchgear Room A	1.38E-06	8.0%
Total	1.72E-05	

Table C.1.1-4 Significant Fire Areas for Dresden 2

Fire Area	CDF	Percent of Total
Units 2 & 3 Control Room Backup HVAC	6.16E-05	30.2%
Units 2 & 3 SBGT & TBCCW Hx	5.87E-05	28.8%
Unit 2 Reactor Building Open Area 545 Elev.	2.34E-05	11.5%
Unit 2 North Trackway/Switchgear Area	1.57E-05	7.7%
Units 2 & 3 Turbine Corridor	1.32E-05	6.5%
Unit 2 Battery Room	1.04E-05	5.1%
Unit 2 Reactor Building Switchgear Area	9.11E-06	4.5%
Unit 2 Reactor Building Elev. 545	8.76E-06	4.3%
Total	2.04E-04	

Table C.1.1-5 Significant Fire Areas for Dresden 3

Fire Area	CDF	Percent of Total
Units 2 & 3 SBGT & TBCCW Hx	5.89E-05	23.3%
Unit 3 West Corridor and Trackway	5.27E-05	20.8%
Unit 3 Second Floor Reactor Building	5.06E-05	20.0%

Table C.1.1-5 (Continued)

Fire Area	CDF	Percent of Total
Units 2 & 3 Turbine Corridor	2.15E-05	8.5%
Unit 3 Reactor Building Switchgear Area	1.78E-05	7.0%
Units 2 & 3 Cable Tunnel	1.38E-05	5.5%
Units 2 & 3 Aux. Electric Equipment Room	1.12E-05	4.4%
Unit 3 Reactor Building Ground Floor	7.39E-06	2.9%
Units 2 & 3 Mezzanine Floor	7.27E-06	2.9%
Units 2 & 3 Control Room Backup HVAC	5.54E-06	2.2%
Total	2.53E-04	

Table C.1.1-6 Significant Fire Areas for Duane Arnold

Fire Area	CDF	Percent of Total
Division I Switchgear Room	5.61E-06	53.3%
Division II Switchgear Room	4.92E-06	46.7%
Total	1.05E-05	

Table C.1.1-7 Significant Fire Areas for Fort Calhoun

Fire Area	CDF	Percent of Total
Control Room	7.90E-06	28.4%
Compressor Area	6.01E-06	21.6%
Turbine Building	3.97E-06	14.3%
Upper Electrical Penetration	3.26E-06	11.7%
Basement Level General Area	2.05E-06	7.4%
East Switchgear Area	7.84E-07	2.8%
Transformer Yard Area	6.18E-07	2.2%
Intake Structure	5.96E-07	2.1%
Group 1 MCC Area	5.66E-07	2.0%
Total	2.78E-05	

Table C.1.1-8 Significant Fire Areas for H.B. Robinson 2

Fire Area	CDF	Percent of Total
Battery Room	7.76E-05	34.7%
Control Room	4.47E-05	20.0%
Transformer Yard	3.70E-05	16.6%
Electric Switchgear/Electrical Equipment Room	2.38E-05	10.7%
Unit 2 Cable Spreading Room	1.50E-05	6.7%
Aux. Bldg Hallway	1.24E-05	5.5%
SW Pump Area	4.38E-06	2.0%
Total	2.23E-04	

Table C.1.1-9 Significant Fire Areas for Millstone 2

Fire Area	CDF	Percent of Total
Auxiliary Building - Area A-1G	1.69E-06	26.8%
Turbine Building	1.63E-06	25.9%
Intake Structure - Area I-1A	9.66E-07	15.3%
Control Room - Main Control Board/ESAS Cabinets	6.57E-07	10.4%
Auxiliary Building - Area A-12A	5.50E-07	8.7%
Auxiliary Building - Area A-1B	5.21E-07	8.3%
Cable Vault - Area A-24	2.83E-07	4.5%
Total	6.30E-06	

Table C.1.1-10 Significant Fire Areas for Monticello

Fire Area	CDF	Percent of Total
Admin Building (Cable Spreading Room)	1.45E-06	17.3%
Admin Building (Control Room)	1.45E-06	17.3%
Turbine Building (MCC 142/143 TB Fire Area XII)	1.27E-06	15.2%
Turbine Building (MCC 133/Feedwater Pump Area)	1.20E-06	14.3%
Reactor Building (West Side)	5.56E-07	6.6%
Turbine Building (Lower 4KV Area)	5.03E-07	6.0%
Emergency Filtration Building (Div. II)	4.05E-07	4.8%
Admin Building (Battery Rooms 7A & 7B)	3.21E-07	3.8%
Turbine Building (Upper 4 KV Area)	2.47E-07	2.9%
Reactor Building (NE Corner)	2.18E-07	2.6%
Total	8.37E-06	

Table C.1.1-11 Significant Fire Areas for North Anna 1&2

Fire Area	CDF	Percent of Total
Emergency Switch Gear Room - Instrument Rack Room	2.43E-06	60.8%
Cable and Vault Tunnel - Control Rod Drive Room	4.39E-07	11.0%
Emergency Switch Gear Room -1H Room	3.79E-07	9.5%
Emergency Switch Gear Room -1J Room	3.45E-07	8.6%
Auxiliary Building B Component Cooling Pumps	1.78E-07	4.5%
Total	3.99E-06	

Table C.1.1-12 Significant Fire Areas for Prairie Island

Fire Area	CDF	Percent of Total
Auxiliary Building Ground Floor Unit 1	2.78E-05	44.0%
408V Safeguards Switchgear Room (Bus 121)	8.90E-06	14.1%
Turbine Building Ground and Mezzanine Floor Unit 1	6.44E-06	10.2%
Relay and Cable Spreading Room Units 1 and 2	3.94E-06	6.2%

Table C.1.1-12 (Continued)

Fire Area	CDF	Percent of Total
4KV Safeguards Switchgear Room (Bus 15)	3.67E-06	5.8%
480V Safeguards Switchgear Room (Bus 111)	2.93E-06	4.6%
"B" Train Hot Shutdown Panel & Air Comp/AFW Room	2.25E-06	3.6%
Control Room	1.97E-06	3.1%
"A" Train Hot Shutdown Panel & Air Comp/AFW Room	1.82E-06	2.9%
Total	6.32E-05	

Table C.1.1-13 Significant Fire Areas for Quad Cities 1

Fire Area	CDF	Percent of Total
Unit 1 Turbine Building Ground Floor (South)	1.66E-05	25.2%
Main Control Room	9.51E-06	14.4%
Unit 1 Mezzanine Floor (South)	3.72E-06	5.6%
Auxiliary Transformer 11	3.32E-06	5.0%
Reserve Auxiliary Transformer 12	3.32E-06	5.0%
Unit 1 Switchgear Area (North)	2.91E-06	4.4%
Unit 2 Turbine Building Ground Floor	2.64E-06	4.0%
Unit 1 Cable Tunnel	2.19E-06	3.3%
Unit 1/2 Mezzanine Floor (Central)	2.04E-06	3.1%
Unit 2 Cable Tunnel	1.82E-06	2.8%
Auxiliary Electric Tunnel	1.78E-06	2.7%
Cable Spreading Room	1.52E-06	2.3%
Unit 1 DC Panel Room	1.45E-06	2.2%
Total	6.60E-05	

Table C.1.1-14 Significant Fire Areas for Sequoyah 1&2

Fire Area	CDF	Percent of Total
Aux Building	1.17E-05	74.8%
ERCW Pump Station	3.26E-06	20.8%
Turbine Building	6.78E-07	4.3%
Total	1.56E-05	

Table C.1.1-15 Significant Fire Areas for Waterford 3

Fire Area	CDF	Percent of Total
H&V Mechanical Room	1.95E-06	27.7%
Control Room	1.94E-06	27.6%
Switchgear Room	1.48E-06	21.0%
Emergency Diesel Generator B	5.90E-07	8.4%
Electrical Penetration Area A	4.30E-07	6.1%

Table C.1.1-15 (Continued)

Fire Area	CDF	Percent of Total
Turbine Generator Building	3.17E-07	4.5%
Total	7.04E-06	

Table C.1.1-16 Significant Fire Areas for Washington Nuclear 2

Fire Area	CDF	Percent of Total
Control Room	8.40E-06	47.8%
Turbine Generator Corridor	2.91E-06	16.6%
Div 2 Battery Room	1.48E-06	8.4%
Div 1/Div 2 Elec/Battery Room Corridor	1.06E-06	6.0%
NW Reactor Building	7.77E-07	4.4%
Turbine Generator Building West	5.91E-07	3.4%
Div 1 Electrical Equipment Room	5.54E-07	3.2%
Div 2 Electrical Equipment Room	4.06E-07	2.3%
Equipment Hatch	3.77E-07	2.1%
Total	1.76E-05	

C.1.2 Obtain Performance Data for Risk-Significant, Equipment-Related Elements

Since fire initiating events are modeled at the event level, performance data are obtained for the initiating events themselves for indicator development. Much of the information on fire initiating events comes from an NRC study in 1997 of all fire events from 1986-1994, AEOD/S97-03 (Ref. 16).

C.1.3 Identify Indicators Capable of Detecting Performance Changes in a Timely Manner

Based on these data, the fire initiating event frequencies for these areas range from 6.9E-2 to 8.5E-4. These frequencies (once every 14 years or more on a plant-specific basis) do not allow for timely quantification of changes to the frequencies. Therefore, there were no fire frequency RBPIs. For transient combustible fires, lower-lying elements were considered, such as transient combustible control. However, modeling at this level is not typically detailed enough to support RBPI development. Moreover, data are not currently available to support quantification of indicators at this level.

Fire in a risk-significant area is considered an industry trending indicator.

C.1.4 Identify Performance Thresholds Consistent with a Graded Approach to Performance Evaluation from SECY 99-007

No RBPIs were identified, so no performance thresholds were identified.

C.1.5 Outputs of RBPI Development Process

The frequencies of occurrence of fires in the most commonly risk-significant fire areas listed above will be used for industry trending. There is no impact on inspection areas.

C.2 Mitigating Systems Cornerstone

Key performance areas for fire include fire detection and suppression systems, installed fire barriers, human response, and post-fire safe shutdown systems.

A review of available information indicates that the role of physical fire barriers is significant. Although barriers are identified in the IPEEE models, failure of barriers is not explicitly modeled by the IPEEE's. Physical failure of fire barriers may allow propagation of a fire beyond the initial fire area, but the risk significance of this potential, or of leaving fire doors open, is not practical to establish from IPEEE's.

As defined in the Appendix R Analysis, fire areas are bounded by fire barriers that will withstand the fire hazards within the fire area and protect the equipment within the fire area from a fire outside the area.

C.2.1 Assess the Potential Risk Impact of Degraded Performance

Elements of fire-initiated core damage sequences include the following:

- Occurrence of Fire in Specific Fire Area
- Failure of Detection/Suppression (automatic and/or manual)
- Fire Damage to Plant Systems
- Failure of Post-Fire Safe Shutdown Systems (typically normal mitigation systems that are not affected by the fire scenario, covered in Section 3.1.2)

As identified in the initiating events cornerstone for fire, the risk-significant accident sequences are defined by fire areas. For the mitigating systems cornerstone, the typical risk-significant fire areas are the same as those identified for the initiating events cornerstone, with the same high degree of variability from plant to plant.

The equipment-related elements are the following:

- Detection (automatic)
- Suppression (automatic)
- Safe shutdown systems (including human action)

It is important to note that the IPEEE's have included detection probabilities in the automatic suppression "system" unavailability when automatic suppression is credited in a fire area. Thus, it is not possible to separate detection and automatic suppression contributions to fire CDF, as modeled, in the IPEEE's.

C.2.2 Obtain Performance Data for Risk-Significant, Equipment-Related Elements

Very few data are available for detection and suppression. Generic values are typically used in the IPEEE's for these functions, and are the basis for the calculations below.

Data for post-fire safe shutdown systems are the same as the data used to evaluate those systems' performance in non-fire scenarios.

C.2.3 Identify Indicators Capable of Detecting Performance Changes in a Timely Manner

For generically significant post-fire safe shutdown systems, RBPIs are already developed to the extent practical, as a result of those systems' importance in non-fire scenarios. For detection and suppression equipment, the widely used generic data are "unavailability" data, and do not furnish the kind of event frequency information needed to establish the practicality of detecting performance changes in a timely manner. For purposes of this step, it is tentatively assumed that monitoring at the train or channel level (depending on the system) will turn out to be appropriate.

C.2.4 Identify Performance Thresholds Consistent with a Graded Approach to Performance Evaluation from SECY 99-007

Thresholds for the RBPIs for safe shutdown systems should be quantified in light of the impact of performance declines on fire CDF as well as internal events CDF. This is addressed as part of the development of internal events RBPIs.

For automatic suppression systems, performance data are not currently reported. Thus, development of an indicator for automatic suppression systems is not currently feasible. However, in the event that performance data for automatic suppression systems do become available, typical RBPI thresholds were calculated for several plants based on the available information from the IPEEE's.

Due to the high degree of variability in the IPEEE's, it is very difficult to identify any type of grouping for automatic suppression system thresholds. Thus, each type of automatic fire suppression system credited by a plant IPEEE is assigned a class-type indicator corresponding to the PRA-style "unavailability" applied to quantify core damage frequency in the IPEEE. That is, the unavailability of the automatic suppression system is averaged over the fire areas it is credited in to determine whether the threshold is exceeded. For automatic suppression systems, the "unavailability" accounts for failure of the system to operate on demand as well as systems being out of service at the time of a fire demand.

Table C.2.4-1 Potential Automatic Suppression System Thresholds for Mitigating Systems Cornerstone - External Events (Fire)

Plant	Automatic Suppression System	Baseline	Thresholds		
			White	Yellow	Red
Browns Ferry 2	N/A	N/A	No automatic suppression credited in significant sequences		
Davis-Besse	wet pipe	2.0E-02	7.88E-02	6.08E-01	-
Duane Arnold	N/A	N/A	No automatic suppression credited		
Fort Calhoun	halon	5.0E-02	5.90E-2	1.40E-1	9.47E-1
	wet pipe	2.0E-02	1.27E-1	8.20E-1	-
Millstone 2	halon	5.0E-02	8.05E-02	3.55E-01	-
	wet pipe	2.0E-02	9.06E-02	7.26E-01	-
Monticello	halon	5.0E-02	8.45E-02	3.95E-01	-
	wet pipe	2.0E-02	3.67E-02	1.87E-01	-
North Anna 1&2	N/A	N/A	No automatic suppression credited		
Prairie Island	CO_2	2.02E-02	5.02E-02	1.42E-01	-
	wet pipe	5.0E-02	2.52E-02	6.98E-02	5.17E-01
Quad Cities 1	wet pipe	2.0E-02	6.85E-02	5.05E-01	None
Quad Cities 2	wet pipe	2.0E-02	2.35E-02	5.46E-02	3.66E-01
Sequoyah 1&2	preaction	5.0E-02	5.65E-02	1.15E-01	6.98E-01
Waterford	preaction	5.0E-02	6.96E-02	2.46E-01	-
	wet pipe	2.0E-02	9.29E-01	-	-
Washington Nuclear 2	wet pipe	2.5E-02	1.79E-01	-	-

Notes: A "-" indicates that the threshold is greater than 1.0. Also, the Clinton, Dresden 2&3 and H.B. Robinson 2 IPEEE's were reviewed and determine to credit automatic suppression systems, but insufficient information was contained in the IPEEE to calculate thresholds.

Systems credited by each IPEEE in prevention of core damage, given a fire, were identified for each risk-significant fire area whenever possible. Based on the information available in the IPEEEs, it was not possible to determine the exact contribution to the CCDP due to a given system. In fact, some IPEEEs did not even provide enough information to characterize the roles played by any post-fire safe shutdown systems. Many, however, did identify the "major" contributors to CCDP for each risk significant fire area. For some IPEEEs, enough information is presented to allow the use of an IPE or SPAR model, with appropriate fire-damaged equipment "removed," to determine the assumed contribution to CCDP of a given system. Currently, the information contained in the IPEEEs was only extracted to identify "significant" safe shutdown systems and compare these systems to the systems identified during the development of risk-based performance indicators for internal events. Table C.2.4-2 below lists the safe shutdown systems identified by each IPEEE. The systems are abbreviated using the IPE database

standardized abbreviations. Table C.2.4-2 shows that the significant mitigating systems identified for post-fire scenarios that are not captured in the internal events indicators are systems that do not meet the criteria for development into RBPI's.

Table C.2.4-2 Significant Post-Fire Safe Shutdown Systems by for Mitigating Systems Cornerstone - External Events (Fire)

Plant	Firs safe shutdown systems that ARE internal events indicators	Fire safe shutdown system that ARE NOT internal events indicators
Davis-Besse	HPI	MFW, RPS
Dresden 2&3	ICS	
H.B. Robinson 2	CCW, MDAFW, PPORV, SDAFW, SW2	ACBU1, BI, DC, EDC
Millstone 2	MDAFW, SDAFW	RCPS, RPS
Monticello	EAC, HPCI/HPCS, RCIC, SPC	CRDS*, CS*, CTS, LPCI*, MFW, SRVS*, VENT (HPV)*
North Anna 1&2	CCW, CHPI, EAC, ESW, HPI, HPR, MDAFW, PPORV, SDAFW	ACC, AR1, CSI*, HVAC1*, LPI, LPR, MFW, PSRV, SGA
Waterford 3	MDAFW, SDAFW	DC
WNP 2	SPC	

* Indicates systems that have significant potential as an indicator for internal events, but it is currently uncertain whether this will be an indicator for the particular plant in question.

C.2.5 Outputs of RBPI Development Process

No RBPIs were identified. Many of the systems relied upon to mitigate the effects of a fire are already addressed under internal events. In the event that performance data for automatic suppression systems do become available, development of an appropriate RBPI will be pursued. The inspection areas that could be impacted by this potential RBPI were determined. The results are in Table C.2.5-1.

Table C.2.5-1 Summary of Inspection Areas Impacted by Potential External Event (Fire) RBPIs for Mitigating Systems Cornerstone

RBPI	Attribute	Inspection Area
Fire Suppression System (UR&UA)	Protection Against External Factors	71111.05, Fire Protection

C.3 Barrier Integrity Cornerstone: Containment Performance

The IPEEE's typically only provide a qualitative analysis of barrier integrity, with the general conclusion that the results of the IPE analysis are unchanged as a result of the fire scenarios. Consideration of fire does not lead to any risk-significant LERF scenarios whose containment barrier attributes are not already being addressed under the internal events treatment of the containment barrier.

C.4 References

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6. "Individual Plant Examination of External Events for Fort Calhoun Station," June 1995.

7. "Individual Plant Examination of External Events for H.B. Robinson 2."

8. "Millstone Unit 2 Individual Plant Examination of External Events," Northeast Utilities Services Co., December 1995.

9. "Monticello Individual Plant Examination of External Events (IPEEE)."

10. "North Anna Units 1 and 2 Individual Plant Examination of External Events," April 1994.

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13. "Sequoyah Nuclear Plant (SQNP) Individual Plant Examination of External Events (IPEEE)," Tennessee Valley Authority, June 1995.

14. "Waterford Individual Plant Examination of External Events."

15. "Individual Plant Examination of External Events, Washington Nuclear Plant 2," Washington Public Power Supply System, June 1995.

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ABBREVIATIONS AND ACRONYMS

A	Large Loss of Coolant Accident
AC	Vital AC Buses
ACBU1	Other Onsite Backup 1
ACC	Accumulators
ADS	Automatic Depressurization System
AFW	Auxiliary Feedwater
AM1	Alternate Makeup 1
AM2	Alternate Makeup 2
AOV	Air-Operated Valve
ARI	Alternate Rod Insertion
ASP	Accident Sequence Precursor
ASPC	Alternate Suppression Pool Cooling
AUXC1	Auxiliary Cooling 1
AUXC2	Auxiliary Cooling 2
BI	Borated Injection
BWR	Boiling Water Reactor
CCDP	Conditional Core Damage Probability
CCDF	Conditional Core Damage Frequency
CCF	Common Cause Failure
CCW	Component Cooling Water
CD	Core Damage
CDF	Core Damage Frequency
CHPI	Normally Running Makeup (Injection)
CHPR	Normally Running Makeup (During Recirculation)
CIV	Containment Isolation Valve
CONDA	Condenser Available
CRDS	Control Rod Drive Pumps
CS	Core Spray
CSR	Containment Spray Recirculation

CTS	Condensate Pumps
DBI	Design Basis Issue
DWS	Drywell Spray
EAC	Emergency AC Power (usually EDGs)
EDC	Battery-backed DC Buses
EDG	Emergency Diesel Generator
EPIX	Equipment Performance and Information Exchange System
EPS	Emergency Power System
ESAS1	Engineered Safety Actuation System 1
ESW	Emergency Service Water
GT	General Transients
HP1	High-Pressure 1
HPCI	High-Pressure Coolant Injection
HPCS	High-Pressure Core Spray
HPI	High-Pressure Injection System
HPR	High Head Safety Injection (During Recirculation)
HUM	Operator Action
HVAC	Heating, Ventilation, Air Conditioning
HVAC1	Heating, Ventilation, Air Conditioning 1
HVAC2	Heating, Ventilation, Air Conditioning 2
HVAC3	Heating, Ventilation, Air Conditioning 3
IA	Instrument Air Compressors
IC	Isolation Condenser
INEEL	Idaho National Engineering and Environmental Laboratory
IPE	Individual Plant Examination
IPEEE	Individual Plant Examinations for External Events
ISLOCA	Interfacing Systems LOCA
LER	Licensee Event Report
LERF	Large Early Release Frequency
LLOCA	Large Loss of Coolant Accident
LOCA	Loss of Coolant Accident

LOFW	Loss of Feedwater
LOHS	Loss of Heat Sink
LONHR	Loss of Normal Heat Removal
LOOP	Loss of Offsite Power Event
LOSP	Loss of Offsite Power
LP1	Low-Pressure 1
LP2	Low-Pressure 2
LP3	Low-Pressure 3
LPCI	Low-Pressure Coolant Injection
LPCS	Low-Pressure Core Spray
LPI	Low Pressure Injection
LPR	Low Pressure Injection
MDAFW	Motor-Driven Auxiliary Feedwater Pumps
MDPs	Motor Driven Pumps
MFW	Main Feedwater Pumps
MLOCA	Medium Loss of Coolant Accident
MOR	Monthly Operating Report
MOV	Motor-Operated Valve
MSIV	Main Steam Isolation Valve
NISP	Non-1E Startup Pumps
NRC	U.S. Nuclear Regulatory Commission
NRR	Nuclear Reactor Regulation
OA3	Alternate Air System 3
PORV	Power Operated Relief Valve
PPORV	Pressurizer Power Operated Relief Valves
PRA	Probabilistic Risk Assessment
PSRV	Pressurizer Safety Relief Valves
PWR	Pressurized Water Reactor
QHO	Quantitative Health Objective
RADS	Reliability and Availability Database System
RAW	Risk Achievement Worth

RBCLCW	Reactor Building Closed Loop Cooling Water
RBPI	Risk-Based Performance Indicator
RCIC	Reactor Core Isolation Cooling
RCPS	Reactor Coolant Pump Seals
RCS	Reactor Coolant System
RECIRC	Recirculation Pumps
RHR	Residual Heat Removal
ROP	Reactor Oversight Process
RPS	Reactor Protection System
RWST	Refueling Water Storage Tank
SCSS	Sequence Coding and Search System
SDC	Shutdown Cooling
SDP	Significance Determination Process
SG	Steam Generator
SGTR	Steam Generator Tube Rupture
S1	Medium Loss of Coolant Accident
S2	Small Loss of Coolant Accident
S3	Small-small Loss of Coolant Accident
SDAWF	Steam-Driven Auxiliary Feedwater Pumps
SGA	Steam Generator Atmospheric Dump Valves
SGS	Steam Generator Safety Valves
SI	Safety Injection
SLC	Standby Liquid Control
SLOCA	Small Loss of Coolant Accident
SPAR	Standardized Plant Analysis Risk
SPC	Suppression Pool Cooling
SRV	Safety Relief Valve
SRVS	Safety Relief Valves Steam
SSCs	Systems, Structures, and Components
SSW	Standby Service Water
SW2	Alternate Service Water 2

SW3	Alternate Service Water 3
SWS	Service Water System
T-AC	Transient - Initiated by Loss of Vital AC Buses
T-ATWS	Transient - Anticipated Transient without Scram
T-AUXC2	Transient - Initiated by Loss of Auxiliary Cooling 2
T-CCW	Transient - Initiated by Loss of Component Cooling Water
T-DC	Transient - Initiated by Loss of DC Buses
T-ESW	Transient - Initiated by Loss of Essential Service Water Pumps
T-EXFW	Transient - Excessive Feedwater Addition
T-HVAC1	Transient - Initiated by Loss of Heating, Ventilation, and Air Conditioning 1
T-HVAC2	Transient - Initiated by Loss of Heating, Ventilation, and Air Conditioning 2
T-IA	Transient - Initiated by Loss of Instrument Air Compressors
T-IFL	Transient - Internal Flood
T-IORV	Transient - Intermittent Open Relief Valve
T-IORV/ SORV	Transient - Intermittent or Stuck Open Relief Valve
T-LMFW	Transient - Loss of Main Feedwater
T-LOOP	Transient - Loss of Offsite Power
T-MSIV	Transient - Initiated by Loss of Main Steam Isolation Valve
T-NSW	Transient - Initiated by Loss of Normal Service Water Pumps
T-RX	Transient - Reactor Trip
T-SGTR	Transient - Steam Generator Tube Rupture
T-SLBIC	Transient - Steam Line Break Inside Containment
T-SLBOC	Transient - Steam Line Break Outside Containment
T-SW2	Transient - Initiated by Loss of Alternate Service Water 2
T-TBCLCW	Transient - Initiated by Loss of Turbine Building Closed Loop Cooling Water
T-TT	Transient - Turbine Trip
T-UHS	Transient - Loss of Ultimate Heat Sink
T-VAC	Transient - Initiated by Loss of Vital Instrument AC
TB	Turbine Bypass Valves
UA	Unavailability

UR	Unreliability
V	Interfacing System Loss of Coolant Accident
V&V	Validation and Verification
V-AR1	Interfacing System Loss of Coolant Accident in Alternate Recirculation 1
V-CCW	Interfacing System Loss of Coolant Accident in Component Cooling Water
V-CHPI	Interfacing System Loss of Coolant Accident in Normally Running Makeup (Injection)
V-HPI	Interfacing System Loss of Coolant Accident in High Head Safety Injection
V-LPI	Interfacing System Loss of Coolant Accident in Low Pressure Injection
V-RHR	Interfacing System Loss of Coolant Accident in Residual Heat Removal
VAC	Vital Instrument AC
VENT	Venting System

Appendix D: Assessment of RBPI Coverage

The purpose of this appendix is to show the extent of risk coverage by RBPIs associated with core damage sequences, to show which risk-significant contributors are not covered by RBPIs, and to indicate briefly why these elements are not covered by RBPIs.

How Coverage Is Assessed

Two approaches to assessment of the extent of RBPI coverage of core damage frequency have been applied.

One approach is based on element Risk Achievement Worth (RAW), which measures how quickly CDF increases if element performance degrades. Given the baseline CDF and the RAW associated with a given element, the magnitude of the CDF increment that could be caused by degradation of the element can be determined. For each plant examined here, this is done for all basic events appearing in its SPAR model (Ref. 1), and the extent of RBPI coverage is then assessed for each basic event whose failure could cause a CDF increment greater than 1.0E-6. This assessment is closely related to the method for selecting candidate RBPIs in the first place (see Section 3 of the main report, and Appendix A).

In addition, an assessment of RBPI coverage of dominant accident sequences (sequences whose frequency contributes most to overall CDF) was performed, based on results in the IPE Database (Ref. 2). Dominant accident sequences are examined to determine which contributors to risk are covered by an RBPI. This is similar to a Fussell-Vesely importance evaluation.

Results of Coverage Assessment

Table D-1 shows results for the RAW-importance-based assessment of coverage, derived from SPAR models for these plants. For those events whose failure could lead to an increase in CDF > 1.0E-6/y, typically about 40% of the events in the SPAR models are part of the RBPIs (20% of the initiating events, and in many cases over 40% of the mitigating system elements). Industry-trended initiating events typically account for another 20% or more of the initiating events.

Table D-1 Coverage of Risk-Significant Core Damage Elements from SPAR Models

Category	BWR 3/4 Plant 6	WE 4-Lp Plant 1	CE Plant 2	BWR 3/4 Plant 5	BWR 3/4 Plant 8
Total number of SPAR model elements whose failure can result in ΔCDF ≥ 1E-6/yr	248	249	249	188	173
Initiating Events	15	16	12	13	15
Mitigating System Elements	233	233	237	175	158
Elements covered by RBPI's					
Initiating Events	3/15 (20%)	3/16 (19%)	3/12 (25%)	3/13 (23%)	3/15 (20%)
Mitigating System Elements	105/233 (45%)	81/233 (35%)	94/237 (40%)	83/175 (47%)	70/158 (44%)
Elements covered by industry trend indicators					
Initiating Events	3/15 (20%)	4/16 (25%)	4/12 (33%)	3/13 (23%)	3/15 (20%)

Category	CE Plant 4	BWR 5/6 Plant 2	BWR 3/4 Plant 11	CE Plant 5	B&W Plant 4
Total number of SPAR model elements whose failure can result in ΔCDF ≥ 1E-6/yr	147	176	220	243	175
Initiating Events	13	12	19	13	13
Mitigating System Elements	134	164	201	230	162
Elements covered by RBPI's					
Initiating Events	3/13 (23%)	3/12 (25%)	3/19 (16%)	3/13 (23%)	3/13 (23%)
Mitigating System Elements	49/134 (37%)	78/164 (48%)	78/201 (39%)	95/230 (41%)	64/162 (40%)
Elements covered by industry trend indicators					
Initiating Events	4/13 (31%)	3/12 (25%)	3/19 (16%)	4/13 (31%)	4/13 (31%)

Category	BWR 3/4 Plant 15	WE 2-Lp Plant 5	BWR 3/4 Plant 18	CE Plant 12	WE 4-Lp Plant 22
Total number of SPAR model elements whose failure can result in ΔCDF ≥ 1E-6/yr	173	244	178	214	203
Initiating Events	15	13	14	13	14
Mitigating System Elements	158	231	164	201	189
Elements covered by RBPI's					
Initiating Events	3/15 (20%)	3/13 (23%)	3/14 (21%)	3/13 (23%)	3/14 (21%)
Mitigating System Elements	69/158 (44%)	96/231 (42%)	70/164 (43%)	88/201 (44%)	72/189 (38%)
Elements covered by industry trend indicators					
Initiating Events	3/15 (20%)	4/13 (31%)	3/14 (21%)	4/13 (31%)	4/14 (29%)

The following is a list of elements not explicitly covered by RBPI's but common to most plants:

- Batteries
- Circuit breakers
- Check valves
- Electrical buses
- Heat exchangers
- Human error
- Reactor protection system
- Safety relief valves
- Strainers
- Tanks

The following is a list of elements not explicitly covered by RBPI's but found in a small number of the plants:

- Atmospheric dump valves
- Automatic bus transfer switches
- Battery chargers
- Butterfly valves
- Chillers
- Dam
- Engine-driven pumps
- Fans
- Filters
- Heat trace
- Overhead/underground feeders
- Pipe segments
- Squibb valves
- Transformers
- Traveling screens

Tables D-2a through o show RBPI coverage of dominant accident sequences at the initiating event / system level for the plants for which SPAR Revision 3 models are available. The tables are derived from the IPE Database results for these plants. Almost all sequences are covered by multiple RBPIs. Most of the elements that are not covered are either not amenable to RBPI treatment, or appear in sequences that contribute a relatively small fraction of core damage frequency. Some are normally-operating systems credited for plant-specific reasons that do not appear in enough plant PRAs to have justified generically applicable RBPIs.

Figures D-1a through o show RBPI coverage of initiating events for the same plants, based on relative contribution to core damage frequency (full power, internal events), derived from the IPE Database for these plants.

Many initiating events occur too infrequently to permit timely quantification of declining performance, and RBPIs based on frequency of occurrence of individual initiating events in this category are therefore not defined. However, as discussed in Section 3.1.1 of the main report, initiating events contributing more than 1% on average to industry-wide CDF and which include one or more occurrences (industry wide) over the past 10 years are included in the industry-wide trends. They are tabulated below and reflected in the coverage assessment presented in Table D-1 and in Figures D-1a through o.

Industry Trend Indicators (Other than Plant-Specific RBPIs)
Loss of Offsite Power
Loss of Vital AC
Loss of Vital DC
Flood
Inadvertent open/stuck open relief valve
Steam generator tube rupture
Loss of instrument/control air
Small/very small LOCA

Elements Not Covered By RBPIs

There were only a few events from the IPE Database information in Tables D-2a through o that were not covered by either RBPIs or industry-wide trending. Tables D-2a through o, prepared using the IPE Database format, display ATWS events as if ATWS were an initiator. "ATWS" as such is not covered by an RBPI, but initiating events potentially leading to ATWS are covered as shown. Steam line break events appear as accident sequence initiators for a few plants. As discussed in Appendix A, steam line break events do not meet the criteria to be identified as risk significant, and are therefore not covered by an RBPI. Medium and large LOCAs are not covered because of their low frequencies. Certain support systems whose loss is an initiating event are monitored under the Mitigating Systems cornerstone (Service Water and Component Cooling Water in PWRs). Although there is no RBPI directly monitoring the frequency of total loss of these systems, the corresponding initiating events are therefore implicitly monitored at a lower level (the train level rather than the system level).

Table D-3 lists mitigating system elements appearing in Tables D-2a through o that are not covered by RBPIs, with an indication of why they are not covered.

Table D-2a RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - WE 4-Lp Plants 1 and 2 (IPE Data Base Results)

IE RBPI
Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
1	8.76E-06	T-LOOP	AC	CHPR	HPR	MDAFW	AM2
2	3.43E-06	T-LOOP	AC	CHPR	HPR	MDAFW	AM2
3	1.77E-06	T-LOOP	EAC	EDC			
4	1.66E-06	T-LOOP	AC	CHPI	MDAFW	AM2	
5	6.41E-07	T-LOOP	AC	CHPI	MDAFW	AM2	
6	6.40E-07	T-DC	CHPR	HPR	MDAFW	AM2	
7	4.46E-07	T-LOOP	AC	CHPI	MDAFW	AM2	
8	4.36E-07	T-LOOP	AC	LPR	MDAFW	AM2	
9	3.76E-07	T-LOOP	AC	EAC	AM2		
10	3.40E-07	T-LOOP	AC	PPORV	MDAFW	AM2	
11	3.40E-07	T-LOOP	AC	ESW	AM2		
12	3.13E-07	T-LOOP	AC	ESW	AM2		
13	3.02E-07	T-LOOP	EAC	EDC			
14	2.66E-07	T-LOOP	AC	EAC	CHPR	HPR	AM2
15	2.40E-07	T-LOOP	AC	EAC	CHPR	HPR	AM2
16	2.27E-07	T-LOOP	ESW	EDC			
17	1.96E-07	T-RX	MDAFW	AM2	HUM		
18	1.75E-07	A	LPR				
19	1.75E-07	T-LOOP	AC	CHPI	MDAFW	AM2	
20	1.74E-07	S2	ESAS1	HUM			
21	1.71E-07	T-LOOP	AC	LPR	MDAFW	AM2	
22	1.69E-07	T-LOOP	AC	CHPR	HPR	MDAFW	AM2
23	1.62E-07	T-LOOP	AC	CHPR	HPR	MDAFW	AM2
24	1.54E-07	T-LOOP	AC	ESW	AM2		
25	1.44E-07	T-LOOP	AC	PPORV	MDAFW	AM2	
26	1.31E-07	T-RX	RPS	MSIV	HUM		

Table D-2a (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES						
27	1.28E-07	T-LOOP	AC	ESW	AM2				
28	1.25E-07	S2	LPR	HUM					
29	1.14E-07	T-LOOP	AC	CHPR	HPR	MDAFW	AM2		
30	1.09E-07	T-LOOP	AC	EAC	CHPR	HPR	MDAFW	AM2	
31	1.09E-07	T-LOOP	AC	ESW	CHPI	AM2			
32	1.00E-07	T-ESW	ESW						
33	9.96E-08	T-LOOP	EAC	EDC					
34	9.84E-08	T-LOOP	AC	EAC	CHPI	AM2			
35	9.42E-08	T-RX	CHPR	HPR	MFW	NISP	MDAFW	AM1	AM2
36	9.29E-08	T-LOOP	EAC	EDC					
37	9.19E-08	T-RX	RPS	MFW	NISP	MDAFW	AM1	AM2	
38	7.91E-08	T-LOOP	AC	ESW	AM2				
39	7.80E-08	S2	ESAS1	HUM					
40	7.35E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2		
41	7.26E-08	T-SLBOC	ESAS1	HUM					
42	7.26E-08	T-SLBOC	ESAS1	HUM					
43	7.26E-08	T-LOOP	AC	EAC	CHPI				
44	7.17E-08	T-SLBIC	ESAS1	HUM					
45	7.17E-08	T-SLBIC	ESAS1	HUM					
46	7.17E-08	T-LOOP	AC	MDAFW	AM2	HUM			
47	7.15E-08	T-LOOP	AC	EAC	AM2				
48	7.00E-08	T-LOOP	EAC	EDC					
49	6.92E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2		
50	6.84E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2		
51	6.36E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2		
52	6.33E-08	T-LOOP	AC	EAC	AM2				
53	5.87E-08	T-LOOP	EAC	EDC					

Table D-2a (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES					
54	5.81E-08	T-LOOP	AC	ESW	EAC	AM2		
55	5.80E-08	T-LOOP	AC	EAC	AM2			
56	5.57E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2	
57	5.48E-08	T-DC	CHPI	MDAFW	AM2			
58	5.36E-08	T-LOOP	AC	CHPI	MDAFW	AM2		
59	5.11E-08	T-LOOP	AC	ESW	AM2			
60	4.88E-08	T-DC	MDAFW	AM2				
61	4.67E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2	
62	4.56E-08	T-LOOP	AC	ESW	AM2	HUM		
63	4.53E-08	A	LPI					
64	4.46E-08	T-LOOP	AC	ESW	CHPI	AM2		
65	4.41E-08	S2	LPR					
66	4.40E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2	
67	4.35E-08	T-LOOP	AC	ESW	AM2			
68	4.12E-08	T-LOOP	AC	EAC	AM2	HUM		
69	4.10E-08	T-LOOP	AC	EAC	CHPR	HPR	AM2	
70	4.08E-08	T-LOOP	AC	EAC				
71	4.07E-08	T-DC	PPORV	MFW	MDAFW	AM1	AM2	
72	3.74E-08	T-RX	CHPR	HPR	MFW	MDAFW	AM1	AM2
73	3.69E-08	T-LOOP	AC	ESW				
74	3.24E-08	T-LOOP	AC	EAC	AM2			
75	3.22E-08	S1	ESAS1	HUM				
76	3.18E-08	T-DC	LPR	MDAFW	AM2			
77	3.01E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2	
78	2.98E-08	T-LOOP	AC	EAC				
79	2.87E-08	T-LOOP	AC	ESW	AM2			
80	2.87E-08	T-LOOP	AC	CHPI	MDAFW	AM2		

Table D-2a (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
81	2.81E-08	T-LOOP	AC	MDAFW	AM2	HUM	
82	2.77E-08	A	ESAS1	HUM			
83	2.68E-08	T-LOOP	AC	MDAFW	AM2	HUM	
84	2.65E-08	A	LPR				
85	2.63E-08	A	LPR				
86	2.43E-08	S1	LPR				
87	2.39E-08	T-LOOP	AC	MDAFW	AM2	HUM	
88	2.38E-08	T-LOOP	AC	ESW	EAC	AM2	
89	2.28E-08	T-LOOP	EAC	EDC			
90	2.28E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2
91	2.10E-08	T-LOOP	AC	CHPI	MDAFW	AM2	
92	2.01E-08	T-LOOP	AC	CHPI	MDAFW	AM2	
93	1.91E-08	T-LOOP	AC	ESW	AM2		
94	1.90E-08	A	LPR				
95	1.88E-08	A	LPR				
96	1.87E-08	T-LOOP	AC	EAC	AM2	HUM	
97	1.83E-08	S2	CHPR	HPR	LPR		
98	1.78E-08	T-LOOP	AC	ESW	AM2		
99	1.77E-08	T-LOOP	AC	CHPI	MDAFW	AM2	
100	1.72E-08	T-LOOP	AC	CHPR	HPR	MDAFW	AM2
101	3.87E-09	T-IFL					
102	1.68E-06	REMAINDER					

Table D-2b RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences -CE Plants 2 and 3 (IPE Data Base Results)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
1	3.55E-06	T-CCW	CCW				
2	1.88E-06	T-LOOP	AC	CCW	ESAS1	HUM	
3	1.59E-06	T-RX	RPS				
4	1.21E-06	A	RPS	BI			
5	1.07E-06	S2	HVAC3	HUM			
6	8.25E-07	S2	HPR				
7	7.50E-07	S1	HPI				
8	7.50E-07	S2	HPI				
9	7.39E-07	S2	CCW				
10	6.97E-07	S2	HVAC3				
11	6.95E-07	S2	HVAC3				
12	6.13E-07	T-HVAC1	HVAC1	ESAS1	HUM		
13	5.81E-07	T-DC	IA	OA3	MDAFW	SDAFW	
14	5.75E-07	S2	HPI				
15	5.63E-07	S2	HPI				
16	5.42E-07	T-LMFW	MDAFW	SDAFW			
17	5.30E-07	T-HVAC1	HVAC1	ESAS1	HUM		
18	5.30E-07	T-HVAC1	HVAC1	ESAS1	HUM		
19	5.29E-07	T-LMFW	RPS				
20	5.17E-07	T-CCW	CCW				
21	5.17E-07	T-CCW	CCW				
22	5.16E-07	T-SW2	SW2		HPI		
23	5.10E-07	T-HVAC1	HVAC1	ESAS1	HUM		
24	5.10E-07	T-HVAC1	HVAC1	ESAS1	HUM		
25	4.85E-07	T-VAC	SW2		HPI		
26	4.80E-07	T-HVAC1	HVAC1	ESAS1	HUM		

Table D-2b (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES			
27	4.80E-07	T-LOOP	AC	EAC		
28	4.61E-07	V				
29	4.50E-07	S3	HPR			
30	4.50E-07	S3	HPR			
31	4.42E-07	T-LMFW	MFW	MDAFW	SDAFW	
32	4.35E-07	T-SW2	SW2	ESW	HPI	
33	4.01E-07	S3	CCW	HPI		
34	4.01E-07	S3	CCW	HPI		
35	3.99E-07	A	ACC			
36	3.96E-07	T-IFL	MDAFW	SDAFW		
37	3.95E-07	T-CCW	CCW			
38	3.77E-07	S3	HPI			
39	3.77E-07	S3	HPI			
40	3.66E-07	S2	HPI			
41	3.62E-07	T-IFL	SW2			
42	3.52E-07	T-LMFW	RPS			
43	3.44E-07	T-HVAC2	HVAC2	CCW	PPORV	HPI
44	3.37E-07	T-IFL	ESW	CCW	HPI	
45	3.22E-07	A	HPI	LPI		
46	3.21E-07	T-LOOP	AC	ESAS1	HUM	
47	3.07E-07	S3	HPI			
48	3.07E-07	S3	HPI			
49	3.07E-07	T-RX	RPS			
50	3.07E-07	T-VAC	VAC	RPS	PPORV	
51	3.04E-07	T-LOOP	AC	SW2	SDAFW	
52	3.02E-07	T-RX	RPS	PPORV		
53	3.01E-07	S3	HPI			

Table D-2b (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES			
54	3.01E-07	S3	HPI			
55	2.98E-07	T-LOOP	AC	PPORV	HPI	
56	2.88E-07	T-SLBOC	MDAFW	SDAFW		
57	2.88E-07	T-IFL	SW2	ESW		
58	2.83E-07	T-IFL	SW2	CCW	HPI	
59	2.83E-07	S2	HPI			
60	2.77E-07	T-CCW	CCW			
61	2.77E-07	S2	SW2	ESW		
62	2.74E-07	T-LOOP	AC	ESAS1	HUM	
63	2.73E-07	S2	ESW	CSR		
64	2.72E-07	T-RX	RPS			
65	2.71E-07	T-EXFW	MFW	MDAFW	SDAFW	
66	2.71E-07	T-LMFW	MFW			
67	2.54E-07	T-LOOP	AC	ESAS1	HUM	
68	2.46E-07	T-IFL	SW2	ESW	MDAFW	SDAFW
69	2.44E-07	T-CCW	CCW			
70	2.41E-07	T-DC	HVAC3			
71	3.35E-07	T-DC	MDAFW	SDAFW		
72	2.33E-07	A	RPS	BI		
73	2.31E-07	T-RX	RPS			
74	2.31E-07	T-RX	RPS			
75	2.26E-07	T-LOOP	AC	HVAC2	ESW	PPORV
76	2.26E-07	T-LOOP	AC	SDAFW		
77	2.24E-07	T-CCW	CCW			
78	2.23E-07	NOINFO				
79	2.21E-07	T-EXFW	MDAFW	SDAFW		
80	2.16E-07	T-CCW	CCW			

Table D-2b (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
81	2.13E-07	T-AC	HVAC2	PPORV	HUM		
82	2.13E-07	T-AC	HVAC2	PPORV	HUM		
83	2.13E-07	T-AC	MDAFW	SDAFW			
84	2.12E-07	S3	HVAC3				
85	2.12E-07	S3	HVAC3				
86	2.10E-07	T-SGTR	CCW	HUM			
87	2.08E-07	S3	HVAC3				
88	2.08E-07	S3	HVAC3				
89	2.07E-07	T-UHS	MDAFW	SDAFW			
90	2.07E-07	S2	HVAC3				
91	2.03E-07	S3	HPI				
92	2.03E-07	S3	HPI				
93	1.98E-07	T-SGTR	HPR	HUM			
94	1.97E-07	T-LOOP	AC	SDAFW			
95	1.96E-07	T-IFL	ESW	CCW	HPI		
96	1.96E-07	T-LOOP	AC	EAC	ESAS1	HUM	
97	1.93E-07	T-IORV	AC	EAC			
98	1.84E-07	T-SGTR	SGS	HUM			
99	1.79E-07	S2	HPI				
100	1.78E-07	S2	HPR				
102	1.85E-04	REMAINDER					
101	1.18E-05	T-IFL					

Table D-2c RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - BWR 3/4 Plant 5 (IPE Data Base Results)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES					
1	1.45E-05	T-LOOP	AC	EAC				
2	1.06E-05	T-LOOP	AC	EAC	RCIC			
3	8.22E-06	T-TT	SRVS	HPCI(HPCS)	HUM			
4	7.82E-06	T-NSW	RBCLCW	TBCLCW				
5	6.57E-06	T-IORV/SORV	SRVS	HPCI(HPCS)	HUM			
6	3.09E-06	T-TT	HP1	CTS	LP1	LP2	SPC	
7	1.87E-06	T-IA	IA	HP1	LP1	LP2	SPC	
8	1.52E-06	T-RX	SRVS	HPCI(HPCS)	RCIC	HUM		
9	1.50E-06	T-RX	SRVS	HPCI(HPCS)	HUM			
10	1.49E-06	T-IA	IA	HPCI(HPCS)	RCIC	LPCI	CS	LP1
11	1.28E-06	T-IA	IA	ADS	HPCI(HPCS)	RCIC		
12	1.19E-06	T-LOOP	AC	EAC	SRVS	HPCI(HPCS)	RCIC	
13	1.16E-06	T-TT	SRVS	ADS	HPCI(HPCS)	HUM		
14	9.25E-07	T-RX	CRDS	HPCI(HPCS)	CONDA	HUM		
15	9.05E-07	T-IORV/SORV	HPCI(HPCS)	LPCI	CS			
16	8.85E-07	T-RX	ADS	HPCI(HPCS)	RCIC	HP1		
17	8.57E-07	T-DC	HPCI(HPCS)	HUM				
18	8.35E-07	T-NSW	RBCLCW	TBCLCW	SRVS			
19	8.24E-07	T-DC	RCIC	HUM				
20	7.40E-07	T-LOOP	AC	EAC	SRVS	HPCI(HPCS)	RCIC	
21	7.02E-07	T-TT	SRVS	ADS	HPCI(HPCS)	RCIC	CONDA	
22	6.80E-07	T-TT	CRDS	RECIRC				
23	6.27E-07	T-TT	SRVS	LPCI	CS			
24	5.62E-07	T-RX	CRDS	CTS	LP1	LP2	SPC	
25	5.12E-07	T-AC	HPCI(HPCS)	RCIC	LPCI	CS	LP1	
26	9.82E-06	REMAINDER						
27		T-IFL						

Table D-2d RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - BWR 3/4 Plant 6 (IPE Data Base Results)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES			
1	1.00E-06	T-DC	DC			
2	7.90E-07	T-UHS	HUM			
3	7.40E-07	T-TT	RPS	ARI	SLC	HUM
4	5.80E-07	T-LOOP	EDC	EAC		
5	3.90E-07	T-LOOP	AC	HPCI(HPCS)	RCIC	
6	3.20E-07	T-NSW	ESW	SW2	CONDA	HUM
7	3.05E-07	T-LMFW	HPCI(HPCS)	RCIC	MFW	HUM
8	2.30E-07	T-LOOP	EAC	AC	HPCI(HPCS)	RCIC
9	2.00E-07	T-LOOP	EAC	EDC		
10	1.80E-07	T-LOOP	EDC	EAC		
11	1.50E-07	T-LOOP	EAC	AC	HPCI(HPCS)	RCIC
12	1.50E-07	T-IORV/SORV	SRVS	SPC	HUM	
13	1.30E-07	T-MSIV	RPS	ARI	CONDA	HUM
14	1.30E-07	T-TT	CONDA	SPC	HUM	
15	1.28E-07	T-LOOP	AC	CONDA	SPC	HUM
16	1.26E-07	T-TT	RPS	ARI	SLC	HUM
17	1.02E-07	T-LOOP	EAC	AC	HPCI(HPCS)	RCIC
18	1.01E-07	T-LOOP	EAC	EDC		
19	1.00E-07	T-LOOP	EAC	EDC	HUM	
20	1.00E-07	T-LOOP	EAC	EDC		
21	1.89E-06	REMAINDER				
22	0.00E+00	T-IFL				

Table D-2e RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - BWR 3/4 Plant 8 (IPE Data Base Results)

		IE RBPI Industry-Wide Trending			System RBPI		
SEQ	CDF	INITIATOR			ACCIDENT SEQUENCE FAILURES		
1	7.15E-07	T-LOOP	EAC	EDC	CONDA		
2	3.64E-07	T-LOOP	EAC	ESW	SRVS	CONDA	
3	3.17E-07	T-LOOP	EAC	EDC	CONDA		
4	7.10E-08	T-LOOP	EAC	EDC	CONDA		
5	5.19E-08	T-LOOP	EAC	EDC	CONDA		
6	3.62E-08	T-RX	EAC	EDC	CONDA		
7	1.77E-08	T-LOOP	EAC	ESW	SRVS	CONDA	
8	1.16E-08	T-LOOP	EAC	ESW	SRVS	CONDA	
9	4.99E-09	T-RX	RPS	ARI	CONDA	HUM	
10	1.00E-09	T-RX	RPS	ARI	HUM		
11	1.00E-09	T-IORV/SORV	RPS	ARI	SRVS		
12	1.00E-09	T-LOOP	RPS	HUM			
13	1.00E-09	T-LMFW	RPS	ARI	MFW	HUM	
14	1.00E-09	T-MSIV	RPS	ARI	MSIV	CONDA	HUM
15	1.00E-09	T-IORV/SORV	RPS	ARI	SRVS		
16	1.00E-09	S1	LPCI	CS			
17	7.40E-09	A	LPCI	CS			
18	8.25E-08	T-LOOP	AC	SRVS			
19	5.56E-09	T-LOOP	AC	SRVS			
20	1.00E-09	T-MSIV	SRVS	LPCI	CS	CONDA	
21	1.00E-09	T-LMFW	SRVS	MFW	LPCI	CS	CONDA
22	1.00E-09	T-RX	LPCI	CS	CONDA	HUM	
23	8.15E-08	T-AC	AC	CONDA	SPC		
24	9.40E-08	T-AC	AC	CONDA	SPC		
25	4.97E-08	REMAINDER					
26		T-IFL					

Table D-2f RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - CE Plant 4 (IPE Data Base Results)

IE RBPI: Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES					
1	9.63E-08	T-RX	MDAFW	SDAFW	AM1	HUM		
2	1.07E-06	T-RX	MDAFW	SDAFW	AM1	HUM		
3	1.60E-08	T-RX	MDAFW	SDAFW	AM1	HUM		
4	2.01E-07	T-RX	MDAFW	SDAFW	AM1	HUM		
5	3.37E-08	T-RX	RCPS	HPI	MDAFW	SDAFW	AM1	HUM
6	2.48E-09	T-RX	RCPS	HPI	MDAFW	SDAFW	AM1	HUM
7	1.28E-08	T-RX	RCPS	HPI	MDAFW	SDAFW	AM1	HUM
8	3.91E-09	T-RX	RCPS	HPI	MDAFW	SDAFW	AM1	HUM
9	2.48E-09	T-RX	RCPS	HPI	MDAFW	SDAFW	AM1	HUM
10	1.27E-08	T-RX	RCPS	HPI				
11	1.32E-06	T-RX	RCPS	HPI				
12	8.23E-07	T-RX	RCPS	HPI				
13	1.85E-09	T-RX	RCPS	HPR				
14	2.25E-07	T-RX	RCPS	HPR				
15	1.88E-08	T-RX	RCPS	HPR				
16	1.50E-06	T-RX	HPR					
17	1.03E-08	T-RX	HPR					
18	6.96E-09	T-RX	HPR					
19	3.03E-08	T-RX	HPR					
20	3.70E-06	T-RX	HPR					
21	3.14E-09	S2	RPS	BI				
22	3.14E-09	S2	RPS	BI				
23	1.12E-09	S2	HPI					
24	2.08E-08	S2	HPI					
25	3.65E-07	S2	HPI					
26	2.97E-07	S2	HPI					
27	1.58E-10	S2	HPR					

Table D-2f (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
28	5.86E-09	S2	HPR				
29	8.06E-08	S2	HPR				
30	5.86E-09	S2	HPR				
31	7.69E-08	S1	HPI				
32	6.30E-09	S1	HPR				
33	9.00E-10	S1	HPR				
34	5.86E-09	S1	HPR				
35	5.38E-08	A	ACC				
36	4.52E-09	A	HPR	LPR			
37	5.10E-08	A	HPR	LPR			
38	6.15E-08	T-SGTR	HPR	MSIV			
39	2.91E-08	T-SGTR	RPS	BI			
40	1.81E-09	T-SGTR	HPI	MDAFW	SDAFW	AM1	
41	2.01E-09	T-SGTR	HPI	MDAFW	SDAFW	AM1	
42	4.01E-09	T-SGTR	HPI	MSIV			
43	1.05E-09	T-SGTR	HPI	MSIV			
44	4.54E-08	T-SGTR	HPI	HPR			
45	6.08E-07	T-SGTR	HPR				
46	5.84E-08	V-LPI					
47	1.00E-13	V-LPI					
48	2.95E-07	V-LPR					
49	7.57E-10	V-CCW	RCPS	MDAFW	SDAFW	AM1	
50	1.84E-07	V-CCW	RCPS				
51	9.40E-08	V-CCW	RCPS				
52	1.82E-08	V-CCW	RCPS	HPR			
53	2.32E-08	V-CHPI	CHPI				
54	1.03E-09	T-ATWS	RPS	BI			

Table D-2f (Continued)

IE RBPI: Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES		
55	2.44E-07	T-ATWS	RPS	PSRV	PPORV
56	1.62E-08	T-ATWS	RPS	PSRV	
57	5.33E-07	T-IFL			
58	1.73E-07	T-IFL			
59	4.04E-07	T-IFL			
60	7.02E-09	T-IFL			
61	1.95E-07	T-IFL			
62	2.84E-07	T-IFL			
63	1.02E-07	T-IFL			
64	5.41E-08	T-IFL			
65	1.11E-07	T-IFL			
66	8.03E-09	T-IFL			
67	8.85E-09	T-IFL			

Table D-2g RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - BWR 5/6 Plant 2 (IPE Data Base Results)

IE RBPI: Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES					
1	4.34E-06	T-LOOP	AC	EAC	RCIC			
2	2.24E-06	T-LOOP	EAC	EDC				
3	1.58E-06	T-LOOP	AC	ADS	HPCI(HPCS)	RCIC	HP1	
4	1.30E-06	T-AC	HPCI(HPCS)	RCIC	LPCI	CS		
5	9.61E-07	T-AC	HVAC2	ESW	CS	LP1	HUM	
6	6.31E-07	T-LOOP	AC	EAC	HPCI(HPCS)	RCIC		
7	4.91E-07	T-AC	HPCI(HPCS)	RCIC	LPCI	LP1		
8	4.77E-07	T-AC	HPCI(HPCS)	CS	LP2	LP3	SPC	DWS

Table D-2g (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES										
9	3.52E-07	T-LOOP	AC	HPCI(HPCS)	RCIC	LPCI	CS	LP1					
10	3.28E-07	T-MSIV	SRVS	ADS	HPCI(HPCS)	RCIC	MFW						
11	3.05E-07	T-AC	ADS	HPCI(HPCS)	RCIC								
12	2.94E-07	T-MSIV	ADS	HPCI(HPCS)	RCIC	HP1							
13	2.88E-07	T-NSW	ADS	HPCI(HPCS)	HP1								
14	2.47E-07	T-AC	ADS	HPCI(HPCS)	RCIC								
15	2.42E-07	T-DC	HPCI(HPCS)	RCIC	LPCI	CS							
16	2.34E-07	T-DC	HPCI(HPCS)	LPCI	LP1								
17	1.73E-07	T-TBCLCW	ADS	HPCI(HPCS)	RCIC	HP1							
18	1.68E-07	T-DC	ADS	HPCI(HPCS)	RCIC								
19	5.33E-08	T-IFL	ADS	HPCI(HPCS)	HP1								
20	1.56E-07	T-LMFW	ADS	HPCI(HPCS)	RCIC	HP1							
21	1.55E-07	S1	HPCI(HPCS)	LPCI	CS	LP1							
22	1.51E-07	T-DC	ADS	HPCI(HPCS)									
23	1.44E-07	T-AC	HPCI(HPCS)	HP1	LPCI	LP1	LP2	LP3	SPC	DWS			
24	1.25E-07	T-RX	HPCI(HPCS)	RCIC	MFW	HP1	LPCI	CS	CTS	LP1			
25	1.18E-07	T-LOOP	AC	EAC	SRVS	RCIC							
26	1.13E-07	T-RX	HPCI(HPCS)	MFW	HP1	LPCI	CS	CTS	LP1	LP2	LP3	SPC	DWS
27	1.07E-07	S1	LP1	ASPC									
28	1.02E-07	T-IA	IA	ADS	HPCI(HPCS)	RCIC							
29	5.44E-08	S3	ADS	HPCI(HPCS)	RCIC	MFW	HP1						
30	5.44E-08	T-AC	HPCI(HPCS)	HP1	LPCI	LP1	LP2	LP3	SPC	DWS			
31	1.02E-07	T-RX	HPCI(HPCS)	MFW	HP1	LPCI	CS	CTS	LP1	LP2	LP3	SPC	DWS
32	5.01E-08	A	HPCI(HPCS)	LPCI	CS	LP1							
33	2.20E-07	T-AC	HPCI(HPCS)	RCIC	LPCI	CS							
34	1.43E-07	T-IFL											
35	7.00E-07	REMAINDER											

Table D-2h RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - BWR 3/4 Plant 11 (IPE Data Base Results)

IE RBPI
Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES					
1	3.27E-05	T-LOOP	EAC	EDC				
2	2.76E-06	T-LMFW	ADS	HPCI(HPCS)	RCIC			
3	1.05E-06	T-MSIV	ADS	HPCI(HPCS)	RCIC			
4	1.04E-06	S1	LPCI	CS	CTS			
5	1.03E-06	T-TT	ADS	HPCI(HPCS)	RCIC	MFW		
6	9.96E-07	S1	ADS	HPCI(HPCS)				
7	9.87E-07	T-HVAC1	HVAC1	EDC	EAC			
8	9.67E-07	T-LOOP	EDC	EAC				
9	5.30E-07	T-LMFW	SPC	DWS	VENT			
10	5.29E-07	T-IORV/SORV	ADS	HPCI(HPCS)	RCIC	MFW		
11	5.07E-07	T-TT	SLC	CRDS				
12	3.97E-07	T-TT	HPCI(HPCS)	RCIC	MFW	LPCI	CS	CTS
13	3.00E-07	S1	ASPC					
14	2.99E-07	T-ESW	HPCI(HPCS)	VENT				
15	2.07E-07	A	LPCI	CS	CTS			
16	1.79E-07	T-TT	SRVS	LPCI	CS	CTS	SPC	DWS
17	1.19E-07	T-MSIV	SLC	CRDS				
18	7.99E-08	S2	RPS					
19	7.80E-08	T-LMFW	ADS	HPCI(HPCS)	RCIC			
20	7.00E-08	A	ASPC					
21	5.85E-08	T-LOOP	EAC	EDC	HPCI(HPCS)	RCIC		
22	5.84E-08	T-LOOP	EAC	EDC	SRVS			
23	5.24E-08	S1	EAC	EDC				
24	5.05E-08	S2	ADS	HPCI(HPCS)	RCIC	MFW		
25	5.01E-08	T-MSIV	ADS	HPCI(HPCS)	RCIC			
26	4.96E-08	T-LOOP	AC	ADS	HPCI(HPCS)	RCIC		
27	4.93E-08	S1	LPCI	CS				

Table D-2h (Continued)

JE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES						
28	4.60E-08	T-TT	SRVS	LPCI	CS				
29	4.55E-08	T-LMFW	HPCI(HPCS)	RCIC	LPCI	CS			
30	4.30E-08	T-AUXC2	AUXC2	HPCI(HPCS)	RCIC	MFW	LPCI	CS	CTS
31	4.27E-08	S2	MFW	LPCI	CS	CTS			
32	4.00E-08	T-TT	RPS	RECIRC	HUM				
33	4.00E-08	T-TT	CRDS	RECIRC					
34	3.55E-08	T-ESW	ESW	CS					
35	3.00E-08	S1	RPS						
36	2.46E-08	S2	RPS						
37	2.18E-08	T-HVAC1	HVAC1	EAC	EDC				
38	2.10E-08	A	RPS						
39	1.97E-08	T-AUXC2	HPCI(HPCS)	RCIC	MFW	LPCI	CS	CTS	
40	1.79E-08	T-MSIV	HPCI(HPCS)	RCIC	LPCI	CS			
41	1.59E-08	T-LMFW	HPCI(HPCS)	RCIC	LPCI	CS	CTS		
42	1.48E-08	T-TT	ADS	HPCI(HPCS)	RCIC	MFW			
43	1.48E-08	A	LPCI	CS	CTS				
44	1.45E-08	T-TT	ADS	HPCI(HPCS)	RCIC	MFW			
45	1.40E-08	T-TT	HPCI(HPCS)	HP1	SPC	DWS	VENT		
46	1.30E-08	S1	HPCI(HPCS)	LPCI	CS				
47	1.20E-08	T-TT	SRVS						
48	1.18E-08	S1	HPCI(HPCS)	LPCI	CS				
49	1.06E-08	T-MSIV	SRVS	LPCI	CS				
50	9.82E-09	T-MSIV	RPS	RECIRC	HUM				
51	9.82E-09	T-MSIV	CRDS	RECIRC					
52	9.21E-09	T-LOOP	EAC	EDC					
53	7.98E-09	S2	ASPC						
54	7.59E-09	S2	ADS	HPCI(HPCS)	RCIC	MFW			
55	7.39E-09	A							
56	4.85E-09	T-IA	IA	HPCI(HPCS)	RCIC	LPCI	CS		

Table D-2h (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES								
57	4.11E-09	T-AUXC2	SRVS	LPCI	CS						
58	3.60E-09	T-IORV/SORV	HPCI(HPCS)	RCIC	MFW	LPCI	CS	CTS			
59	3.14E-09	T-IA	IA	ADS	HPCI(HPCS)	RCIC					
60	2.46E-09	S2	ASPC								
61	2.28E-09	T-TT	SRVS	HPCI(HPCS)	HP1	SPC	DWS	VENT			
62	1.81E-09	T-AUXC2	AUXC2	ADS	HPCI(HPCS)	RCIC	MFW				
63	1.70E-09	T-TT	CRDS	ADS	HPCI(HPCS)	RCIC					
64	1.65E-09	T-LMFW	SRVS								
65	1.64E-09	T-LOOP	AC	ADS	HPCI(HPCS)	RCIC					
66	1.62E-09	S1	LPCI	CS	SPC	DWS	VENT				
67	1.34E-09	T-ESW	ESW	SRVS	CS	VENT					
68	1.21E-09	T-TT	ADS	HPCI(HPCS)	RCIC	HUM					
69	1.09E-09	T-HVAC1	HVAC1	EAC	EDC	SRVS					
70	1.08E-09	T-MSIV	SRVS								
71	1.03E-09	T-IA	IA	HPCI(HPCS)	SPC	DWS	VENT				
72	8.82E-10	A	LPCI	CS	CTS	SPC	DWS	VENT			
73	8.01E-10	T-ESW	ESW	HPCI(HPCS)	RCIC	CS					
74	7.27E-10	T-TT	MFW	HP1	LPCI	CS	CTS	LP1	LP2	SPC	DWS
75	6.01E-10	T-TT	MFW	HP1	LPCI	CS	CTS	LP1	LP2	SPC	DWS
76	5.52E-10	T-MSIV	CRDS	ADS	HPCI(HPCS)	RCIC					
77	4.08E-10	S1	AC	ADS	HPCI(HPCS)						
78	3.00E-10	S1	AC	ASPC							
79	2.77E-10	T-ESW	ESW	ADS	HPCI(HPCS)	RCIC					
80	2.61E-10	T-MSIV	SRVS	SPC	DWS						
81	2.47E-10	T-AUXC2	AUXC2	SRVS	LPCI	CS	CTS				
82	2.30E-09	T-IFL	SRVS	LPCI	CS	CTS	SPC	DWS			
83	1.10E-09	T-IFL	SRVS	LPCI	CS	CTS	SPC	DWS			
84	2.00E-09	T-IFL	HPCI(HPCS)	RCIC	MFW	LPCI	CS	CTS			
85	1.90E-08	T-IFL	ADS	HPCI(HPCS)	RCIC	MFW					

Table D-2h (Continued)

IE RBPI: Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES									
86	3.80E-08	T-IFL	MFW	HP1	LPCI	CS	CTS	LP1	LP2	LP3	SPC	DWS
87	1.50E-09	T-IFL	ADS	HPCI(HPCS)	RCIC	MFW						
88	4.90E-09	T-IFL	SRVS	LPCI	CS	CTS	SPC	DWS				
89	3.60E-10	T-IFL	SRVS	LPCI	CS	CTS						
90	1.70E-08	T-IFL	HPCI(HPCS)	RCIC	MFW	LPCI	CS	CTS				
91	8.00E-09	T-IFL	ADS	HPCI(HPCS)	RCIC	MFW						
92	1.50E-08	T-IFL	SRVS	LPCI	CS	CTS						
93	2.80E-08	T-IFL	HP1	LPCI	CS	CTS	LP1	LP2	LP3	SPC	DWS	
94	7.50E-08	T-IFL	HP1	LPCI	CS	CTS	LP1	LP2	LP3	SPC	DWS	VENT
95	1.50E-08	T-IFL	HPCI(HPCS)	RCIC	LPCI	CS	CTS					
96	1.90E-08	T-IFL	ADS	HPCI(HPCS)	RCIC							
97	3.90E-08	T-IFL	HP1	LPCI	CS	CTS	LP1	LP2	LP3	SPC	DWS	
98	2.20E-09	T-IFL	SRVS	HP1	LPCI	CS	CTS	LP1	LP2	LP3		
99	6.60E-10	T-IFL	ADS	HPCI(HPCS)	RCIC							
100	5.90E-09	T-IFL	SRVS	SPC	DWS							
101	4.80E-10	T-IFL	SRVS	LPCI	CS	CTS						
102	2.16E-07	T-IFL										

Table D-2i RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - CE Plant 5 (IPE Data Base Results)

IE RBPI: Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES		
1	6.59E-07	T-DC	MDAFW	SDAFW	
2	6.22E-07	T-DC	MDAFW	SDAFW	
3	5.91E-07	T-LOOP	AC	MDAFW	SDAFW
4	5.91E-07	T-LOOP	AC	MDAFW	SDAFW

Table D-2i (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
5	5.66E-07	T-DC	RPS				
6	5.34E-07	T-DC	RPS				
7	4.94E-07	S2	HPR	LPR			
8	4.68E-07	T-DC	MDAFW	HUM			
9	4.48E-07	T-SLBIC	MDAFW	SDAFW	HUM		
10	4.42E-07	T-DC	MDAFW	HUM			
11	4.25E-07	T-DC	MDAFW	SDAFW			
12	4.20E-07	T-LOOP	AC	MDAFW	HUM		
13	4.20E-07	T-LOOP	AC	MDAFW	HUM		
14	4.01E-07	T-DC	MDAFW	SDAFW			
15	3.81E-07	T-LOOP	AC	MDAFW	SDAFW		
16	3.81E-07	T-LOOP	AC	MDAFW	SDAFW		
17	3.73E-07	T-DC	MDAFW	SDAFW			
18	3.52E-07	T-DC	MDAFW	SDAFW			
19	3.34E-07	T-LOOP	AC	MDAFW	SDAFW		
20	3.34E-07	T-LOOP	AC	MDAFW	SDAFW		
21	3.33E-07	T-ESW	ESW				
22	3.19E-07	T-SLBIC	HUM				
23	3.00E-07	T-LMFW	MDAFW	SDAFW	HUM		
24	2.89E-07	T-SLBIC	SDAFW	HUM			
25	2.89E-07	T-ESW	ESW	HUM			
26	2.73E-07	T-LOOP	AC	MDAFW	SDAFW	HUM	
27	2.65E-07	T-DC	MDAFW	HUM			
28	2.50E-07	T-DC	MDAFW	HUM			
29	2.48E-07	T-RX	RPS	PSRV			
30	2.37E-07	T-LOOP	AC	MDAFW	HUM		
31	2.37E-07	T-LOOP	AC	MDAFW	HUM		

Table D-2i (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES			
32	2.03E-07	T-RX	PSRV	HPR	LPR	AR1
33	2.03E-07	T-RX	PSRV	HPR	LPR	AR1
34	1.96E-07	T-DC	MDAFW	HUM		
35	1.91E-07	S1	IA	ESW		
36	1.90E-07	S3	HVAC1	HUM		
37	1.84E-07	T-DC	MDAFW	HUM		
38	1.75E-07	T-LOOP	AC	MDAFW	HUM	
39	1.75E-07	T-LOOP	AC	MDAFW	HUM	
40	1.75E-07	T-DC	MDAFW	SDAFW	HUM	
41	1.72E-07	A	IA	ESW	HUM	
42	1.65E-07	T-DC	MDAFW	SDAFW		
43	1.59E-07	T-DC	MDAFW	SDAFW		
44	1.56E-07	S1	HPR			
45	1.52E-07	S1	ESW			
46	1.51E-07	T-RX	RPS	PPORV		
47	1.50E-07	T-DC	MDAFW	SDAFW		
48	1.44E-07	S1	HPI			
49	1.43E-07	T-LOOP	AC	MDAFW	SDAFW	
50	1.43E-07	T-LOOP	AC	MDAFW	SDAFW	
51	1.40E-07	A	HPR	LPR		
52	1.40E-07	A	LPI			
53	1.39E-07	S3	MDAFW	SDAFW		
54	1.37E-07	A	ESW			
55	1.33E-07	T-SLBIC	HUM			
56	1.33E-07	T-ESW	ESW	MDAFW	SDAFW	
57	1.29E-07	S3	ESW	HUM		
58	1.29E-07	S3	CCW	HUM		

Table D-2i (Continued)

IE RBPI
Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES			
59	1.29E-07	S3	CCW	HVAC1	HUM	
60	1.29E-07	A	HPR	LPR		
61	1.25E-07	T-VAC	RPS			
62	1.20E-07	T-LOOP	AC	MDAFW	SDAFW	
63	1.20E-07	T-LOOP	AC	MDAFW	SDAFW	
64	1.17E-07	T-RX	RPS	HUM		
65	1.11E-07	T-DC	MDAFW	HUM		
66	1.04E-07	T-DC	MDAFW	HUM		
67	9.92E-08	T-LOOP	AC	MDAFW	HUM	
68	9.92E-08	T-LOOP	AC	MDAFW	HUM	
69	9.75E-08	T-RX	MDAFW	SDAFW		
70	9.24E-08	T-RX	RPS	PSRV		
71	9.24E-08	T-RX	RPS	PSRV		
72	9.21E-08	S2	HVAC1	HUM		
73	9.21E-08	S3	AR1			
74	8.90E-08	T-SGTR	HPI	HUM		
75	8.49E-08	T-LOOP	AC	MDAFW	HUM	
76	8.49E-08	T-LOOP	AC	MDAFW	HUM	
77	8.48E-08	T-SLBIC	SGA	SDAFW		
78	8.48E-08	T-SLBIC	SGA	SDAFW		
79	8.12E-08	T-VAC	MDAFW	SDAFW		
80	7.71E-08	T-LOOP	AC	MDAFW	SDAFW	
81	7.60E-08	A	HVAC2	VAC	HUM	
82	6.92E-08	T-RX	MDAFW	HUM		
83	6.79E-08	T-DC	MDAFW	HUM		
84	6.76E-08	T-LOOP	AC	MDAFW	SDAFW	
85	6.74E-08	S2	MDAFW	SDAFW		
86	6.28E-08	T-RX	MDAFW	SDAFW		

Table D-2i (Continued)

		IE RBPI	System RBPI			
		Industry-Wide Trending				
SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES			
87	6.27E-08	S2	ESW	HUM		
88	6.27E-08	S2	CCW	HUM		
89	6.27E-08	S2	CCW	HVAC1	HUM	
90	6.12E-08	T-LOOP	AC	MDAFW	SDAFW	
91	6.02E-08	T-SLBIC	SGA	HUM		
92	6.02E-08	T-SLBIC	SGA	HUM		
93	5.86E-08	T-SLBIC	PPORV	SDAFW		
94	5.86E-08	T-SLBIC	PPORV	SDAFW		
95	5.77E-08	T-VAC	MDAFW	HUM		
96	5.67E-08	T-LMFW	SGA	MDAFW	SDAFW	HUM
97	5.67E-08	T-LMFW	SGA	MDAFW	SDAFW	HUM
98	5.59E-08	T-LMFW	RPS	PSRV		
99	5.58E-08	T-RX	ESW	PSRV		
100	5.58E-08	T-RX	ESW	PSRV		
101	5.31E-08	T-IFL	ESW			
102	1.51E-07	T-IFL	IA	AUXC1		
103	1.40E-05	REMAINDER				

Table D-2j RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - B&W Plants 4, 5 and 6 (IPE Data Base Results)

		IE RBPI	System RBPI		
		Industry-Wide Trending			
SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES		
1	1.48E-06	T-IA	IA	HUM	
2	8.00E-07	A			
3	6.11E-07	T-LOOP	EAC	EDC	HUM
4	3.37E-07	T-UHS	HUM		

Table D-2j (Continued)

SEQ	CDF	INITIATOR (IE RBPI / Industry-Wide Trending)	ACCIDENT SEQUENCE FAILURES			(System RBPI)	
5	3.14E-07	T-LOOP	EAC	EDC	HUM		
6	2.19E-07	T-LOOP	AC	HUM			
7	2.14E-07	T-LOOP	EAC	EDC	ACBU1		
8	1.78E-07	T-IA	IA	SDAFW	HUM		
9	1.78E-07	T-LOOP	EAC	EDC	ACBU1		
10	1.65E-07	T-IA	IA	PSRV	HUM		
11	1.48E-07	T-IA	IA	HUM			
12	1.48E-07	T-IA	IA	HUM			
13	1.30E-07	T-LOOP	EAC	EDC	ACBU1		
14	1.24E-07	T-LMFW	MFW	HUM			
15	1.10E-07	T-LOOP	EAC	EDC	ACBU1		
16	1.01E-07	T-LOOP	EAC	EDC	SDAFW	HUM	
17	9.95E-08	T-IA	IA	AM1	HUM		
18	8.38E-08	T-LOOP	EAC	EDC	HUM		
19	7.34E-08	T-LOOP	EAC	EDC			
20	7.22E-08	T-IA	IA	HUM			
21	6.93E-08	T-LOOP	EAC	EDC	SDAFW	HUM	
22	6.75E-08	T-UHS	HUM				
23	6.48E-08	T-LOOP	AC	HUM			
24	6.11E-08	T-LOOP	EAC	EDC	HUM		
25	6.11E-08	T-LOOP	EAC	EDC			
26	5.94E-08	T-IA	IA	AM1	HUM		
27	5.94E-08	T-IA	IA	AM1	HUM		
28	5.78E-08	T-LOOP	EAC	EDC	HUM		
29	5.15E-08	T-LOOP	EAC	EDC			
30	4.98E-08	T-RX	MFW	HUM			
31	7.00E-06	S1	HUM				
32	7.00E-07	A	HUM				

Table D-2j (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR		ACCIDENT SEQUENCE FAILURES		
33	7.00E-07	A	HUM			
34	2.60E-07	S2	HUM			
35	1.90E-07	A	LPR			
36	1.90E-07	S1	LPR			
37	1.40E-07	A	LPI			
38	1.06E-07	S2	HPI			
39	7.00E-08	S1	HUM			
40	6.23E-08	A	SW3			
41	3.98E-08	A	LPI			
42	3.20E-08	T-SGTR	AR1	HUM		
43	3.20E-08	T-SGTR	AR1	HUM		
44	3.20E-08	T-SGTR	AR1	HUM		
45	2.90E-08	T-SGTR	HUM			
46	2.16E-08	T-SGTR	HPI	HUM		
47	2.08E-08	T-SGTR	HPI	HUM		
48	1.60E-08	T-SGTR	TB	HUM		
49	1.39E-08	T-SGTR	HUM			
50	1.28E-08	T-SGTR	HPI	HUM		
51	1.53E-07	T-IFL	ESW	SW2	HUM	
52	1.53E-07	T-IFL	ESW	HUM		
53	1.53E-07	T-IFL	ESW	HUM		
54	1.03E-07	T-IFL	ESW	AM1	HUM	
55	1.03E-07	T-IFL	ESW	SW2	AM1	HUM
56	1.03E-07	T-IFL	ESW	AM1	HUM	
57	1.02E-07	T-IFL	ESW	SW2	HUM	
58	9.18E-08	T-IFL	ESW	HUM		
59	7.44E-08	T-IFL	ESW	AM1	HUM	
60	7.44E-08	T-IFL	ESW	AM1	HUM	

Table D-2j (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES			
61	7.44E-08	T-IFL	ESW	SW2	AM1	HUM
62	7.05E-08	T-IFL	AC	EAC	HUM	
63	6.80E-08	T-IFL	ESW	SW2	HUM	
64	6.80E-08	T-IFL	ESW	SW2	HUM	
65	6.80E-08	T-IFL	ESW	HUM		
66	6.80E-08	T-IFL	ESW	HUM		
67	6.80E-08	T-IFL	ESW	HUM		
68	6.80E-08	T-IFL	ESW	SW2	HUM	
69	6.80E-08	T-IFL	ESW	HUM		
70	6.80E-08	T-IFL	ESW	HUM		
71	6.80E-08	T-IFL	ESW	SW2	HUM	
72	6.12E-08	T-IFL	ESW	AM1	HUM	
73	6.12E-08	T-IFL	ESW	AM1	HUM	
74	6.12E-08	T-IFL	ESW	AM1	HUM	
75	6.12E-08	T-IFL	ESW	SW2	AM1	HUM
76	6.12E-08	T-IFL	ESW	SW2	AM1	HUM
77	6.12E-08	T-IFL	ESW	AM1	HUM	
78	5.58E-08	T-IFL	HUM			
79	5.53E-08	T-IFL	AC	EAC	HUM	
80	5.44E-08	T-IFL	ESW	SW2	HUM	
81	5.10E-08	T-IFL	ESW	HUM		
82	5.10E-08	T-IFL	ESW	SW2	HUM	
83	5.10E-08	T-IFL	ESW	HUM		
84	5.05E-08	T-IFL	ESW	EAC	HUM	
85	4.90E-08	T-IFL	ESW	SW2	HUM	
86	4.75E-08	T-IFL	ESW	SW2	HUM	
87	4.65E-08	T-IFL	AC	EAC	HUM	
88	4.59E-08	T-IFL	ESW	AM1	HUM	
89	4.59E-08	T-IFL	ESW	AM1	HUM	

Table D-2j (Continued)

IE RBPI
Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES			
90	4.59E-08	T-IFL	ESW	SW2	AM1	HUM
91	4.76E-08	T-LOOP	EAC	EDC	HUM	
92	4.45E-08	T-IA	IA	AM1	HUM	
93	4.37E-08	T-LOOP	AC	HUM		
94	3.77E-08	T-LOOP	EAC	EDC	ACBU1	
95	3.76E-08	T-IFL	ESW	SW2	HUM	
96	3.76E-08	T-IFL	ESW	HUM		
97	3.76E-08	T-IFL	ESW	HUM		
98	3.76E-08	T-IFL	ESW	HUM		
99	3.76E-08	T-IFL	ESW	HUM		
100	3.76E-08	T-IFL	ESW	SW2	HUM	
101	3.75E-08	T-UHS	PSRV	HUM		
102	3.74E-08	T-IFL	AM1	HUM		
103	3.70E-08	T-LOOP	EAC	EDC		
104	3.67E-08	T-IFL	ESW	SW2	HUM	
105	3.67E-08	T-IFL	ESW	HUM		
106	3.67E-08	T-IFL	ESW	HUM		
107	3.67E-08	T-IFL	ESW	SW2	HUM	
108	3.67E-08	T-IFL	ESW	HUM		
109	3.67E-08	T-IFL	ESW	HUM		
110	3.66E-08	T-LOOP	EAC	EDC	SDAFW	HUM
111	3.65E-08	T-RX	AC	EAC	HUM	
112	3.56E-08	T-IA	HUM			
113	3.56E-08	T-IA	HUM			
114	3.52E-08	T-LOOP	EAC	EDC	ACBU1	SDAFW
115	3.51E-08	T-LMFW	PSRV	MFW		
116	2.15E-06	T-IFL				
117	1.16E-06	REMAINDER				

Table D-2k RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - BWR 3/4 Plants 15 and 16 (IPE Data Base Results)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
1	6.47E-07	T-LOOP	AC	EDC	HUM		
2	3.61E-07	T-TT	HPCI(HPCS)	RCIC	MFW	HUM	
3	3.55E-07	T-LMFW	HPCI(HPCS)	RCIC	HUM		
4	3.38E-07	T-MSIV	RPS	ARI	HUM		
5	3.35E-07	T-LOOP	AC	HPCI(HPCS)	RCIC	HUM	
6	3.23E-07	T-LOOP	EAC	EDC			
7	2.59E-07	T-MSIV	HPCI(HPCS)	RCIC	HUM		
8	2.59E-07	A	LPCI	CS	CTS		
9	2.49E-07	T-UHS	HPCI(HPCS)	RCIC	HUM		
10	1.92E-07	T-TT	RPS	ARI	SRVS	HUM	
11	1.74E-07	T-LMFW	CRDS	HPCI(HPCS)			
12	1.56E-07	T-LOOP	AC	EDC	HUM		
13	1.32E-07	T-LOOP	EAC	EDC			
14	1.28E-07	S1	ADS	HPCI(HPCS)			
15	1.09E-07	T-TT	RPS	ARI	HUM		
16	1.05E-07	T-IORV/SORV	SPC	HUM			
17	1.00E-07	T-TT	RPS	ARI	SRVS	HPCI(HPCS)	
18	9.00E-08	A					
19	8.35E-08	T-TT	RPS	ARI	HUM		
20	6.65E-08	T-IFL	AC	EAC	HPCI(HPCS)	RCIC	HUM
21	6.26E-08	T-LOOP	AC	HPCI(HPCS)	RCIC	HUM	
22	5.61E-08	T-TT	RPS	ARI	HUM		
23	5.35E-08	T-TT	RPS	ARI	SPC	HUM	
24	1.93E-09	V-LPI	LPCI				
25	1.50E-09	V-HPI	LPCI				
26	8.05E-08	T-IFL					
27	8.12E-07	REMAINDER					

Table D-21 RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - WE 2-Lp Plants 5 and 6 (IPE Data Base Results)

IE RBPI: Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES			
1	1.00E-05	T-IFL	IA			
2	4.40E-07	T-IA				
3	5.00E-06	T-LOOP	AC	MDAFW	SDAFW	HUM
4	3.00E-06	T-IA	IA			
5	1.56E-06	T-RX	MFW	MDAFW	SDAFW	HUM
6	2.50E-06	A	HUM			
7	2.20E-06	S1	HUM			
8	1.20E-06	A	LPR			
9	2.40E-06	S1	LPR			
10	6.30E-07	T-ESW	CCW	HVAC1		
11	2.43E-06	T-RX	RCPS	CHPI	HPI	
12	2.05E-06	T-LOOP	AC	HVAC1		
13	1.39E-06	T-DC	DC	ESW		
14	1.70E-06	S2	HPI			
15	1.10E-06	T-SGTR	SGS	HUM		
16	3.90E-06	T-SGTR	SGS	HUM		
17	8.00E-07	T-SGTR	PPORV	AR1		
18	2.00E-07	T-SGTR	PPORV	SGA		
19	2.30E-07	T-LOOP	EAC	EDC	HUM	
20	2.39E-06	T-LOOP	EAC	EDC	HUM	
21	1.80E-07	T-LOOP	EAC	EDC	SDAFW	
22	3.50E-07	S2	HPR	AR1		
23	1.13E-06	S2	HVAC1	HPR		
24	9.23E-07	S2	HPR	AR1		
25	2.40E-08	T-LOOP	AC	CCW		
26	7.76E-07	T-LOOP	AC	HPR	LPR	

Table D-2l (Continued)

SEQ	CDF	INITIATOR (IE RBPI / Industry-Wide Trending)	ACCIDENT SEQUENCE FAILURES				
					System RBPI		
27	3.50E-08	T-SGTR		HPI	HUM		
28	5.65E-07	T-SGTR		NISP	MDAFW	HUM	
29	2.60E-08	T-LOOP	EAC	EDC	RCPS		
30	2.34E-07	T-LOOP	RCPS				
31	5.50E-08	V-RHR	LPR				
32	1.75E-07	V-RHR	LPR				
33	8.30E-08	T-RX	RPS	HUM			
34	7.70E-08	T-RX	RPS	HUM			
35	2.80E-08	T-LMFW	RPS	PSRV	PPORV		
36	1.32E-07	T-RX	RPS	PSRV	PPORV		
37	2.10E-08	A	LPI				
38	5.50E-08	S1	HPI	LPI			
39	1.50E-10	T-IFL	MDAFW	SDAFW	HUM		
40	5.70E-10	T-IFL	MDAFW	SDAFW			

Table D-2m RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - BWR 3/4 Plants 18 and 19 (IPE Data Base Results)

SEQ	CDF	INITIATOR (IE RBPI / Indudstry-Wide Trending)	ACCIDENT SEQUENCE FAILURES				
					System RBPI		
1	5.28E-07	T-LOOP	AC	EAC			
2	1.60E-07	S1	HUM				
3	2.70E-08	T-LOOP	HPI	HUM	AC		
4	2.21E-08	T-LOOP	AC	EAC			
5	2.05E-08	T-ATWS	RPS	CONDA	HUM		
6	1.80E-08	T-LOOP	HPCI(HPCS)	RCIC	AC	EAC	
7	1.34E-08	T-LOOP	HPI	HUM	AC		
8	1.16E-08	T-RX	ADS	DC			

Table D-2m (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
9	1.10E-08	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
10	8.96E-09	T-LOOP	HP1	LPCI	SPC	AC	
11	8.12E-09	T-RX	DC				
12	7.76E-09	T-ATWS	RPS	LPCI	CS	CONDA	HUM
13	7.59E-09	T-LOOP	SPC	HUM	AC		
14	7.00E-09	T-LOOP	HP1	SPC	HUM	AC	
15	6.90E-09	T-LOOP	HP1	SPC	HUM	AC	
16	6.72E-09	T-LOOP	HP1	HUM	AC		
17	6.13E-09	T-ATWS	RPS	CONDA	HUM		
18	5.83E-09	T-ATWS	RPS	CONDA	HUM		
19	5.77E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
20	5.66E-09	A	LPCI	CS			
21	5.53E-09	T-LOOP	HPCI(HPCS)	RCIC	HUM	AC	
22	5.43E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
23	5.10E-09	T-RX	HPCI(HPCS)	RCIC	HP1	HUM	
24	5.02E-09	S2	HPCI(HPCS)	HUM			
25	4.60E-09	A	SPC	AC			
26	4.46E-09	T-LOOP	HP1	LPCI	SPC	AC	
27	4.44E-09	T-LOOP	LPCI	SPC	HUM	AC	
28	3.88E-09	T-ATWS	RPS	HP1	CONDA	HUM	
29	3.83E-09	S1	HPCI(HPCS)	HUM			
30	3.78E-09	T-LOOP	SPC	HUM	AC		
31	3.62E-09	T-ATWS	RPS	HPCI(HPCS)	CONDA	HUM	
32	3.46E-09	T-LOOP	HP1	HUM	AC		
33	3.42E-09	T-LOOP	SPC	HUM	AC		
34	3.38E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HP1	HUM
35	3.33E-09	T-LOOP	LPCI	SPC	HUM	AC	
36	3.33E-09	T-LOOP	HP1	HUM	AC		
37	2.86E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
38	2.77E-09	T-LOOP	LPCI	SPC	HUM	AC	
39	2.63E-09	T-LOOP	HPCI(HPCS)	RCIC	HUM	AC	
40	2.57E-09	T-RX	HPCI(HPCS)	RCIC	HUM		
41	2.57E-09	A	SPC				

Table D-2m (Continued)

		IE RBPI Industry-Wide Trending			System RBPI		
SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
42	2.42E-09	T-LOOP	HP1	LPCI	SPC	HUM	AC
43	2.40E-09	T-LOOP	HUM	AC			
44	2.26E-09	T-LOOP	HP1	HUM	AC		
45	2.21E-09	T-ATWS	RPS	CONDA	HUM		
46	2.16E-09	S2	HPCI(HPCS)	MFW	HUM		
47	2.15E-09	T-LOOP	HPCI(HPCS)	HP1	AC	EAC	
48	2.10E-09	A	HUM				
49	2.08E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HP1	HUM
50	2.05E-09	T-LOOP	HP1	HUM	AC		
51	1.97E-09	T-LOOP	HP1	LPCI	SPC	AC	
52	1.96E-09	T-LOOP	HP1	LPCI	SPC	AC	
53	1.90E-09	T-LOOP	HUM	AC			
54	1.89E-09	T-LOOP	HP1	SPC	HUM	AC	
55	1.82E-09	T-ATWS	RPS	SLC	CONDA		
56	1.79E-09	T-LOOP	HP1	SPC	AC		
57	1.74E-09	T-ATWS	RPS	MFW	CONDA	HUM	
58	1.72E-09	T-LOOP	HP1	SPC	HUM	AC	
59	1.70E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HUM	
60	1.66E-09	T-LOOP	HP1	LPCI	SPC	HUM	AC
61	1.62E-09	T-ATWS	RPS	RECIRC	CONDA		
62	1.50E-09	T-LOOP	HP1	SPC	HUM	AC	
63	1.43E-09	T-ATWS	RPS	MFW	HUM		
64	1.39E-09	A	HUM				
65	1.38E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HP1	HUM
66	1.33E-09	T-LOOP	HP1	HUM	AC		
67	1.19E-09	T-ATWS	RPS	HUM			
68	1.15E-09	T-LOOP	HP1	LPCI	SPC	VENT	AC
69	1.14E-09	T-LOOP	HUM	AC			
70	1.13E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
71	1.13E-09	A	LPCI	CS	DC		
72	1.13E-09	T-LOOP	HP1	HUM	AC		
73	1.12E-09	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
74	1.10E-09	T-LOOP	HP1	SPC	HUM	AC	

Table D-2m (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
75	1.10E-09	T-ATWS	RPS	MFW	HP1	CONDA	HUM
76	1.09E-09	T-LOOP	HP1	HUM	AC		
77	1.05E-09	T-RX	HPCI(HPCS)	RCIC	MFW	HUM	
78	1.03E-09	T-LOOP	HP1	SPC	HUM	AC	
79	1.03E-09	T-ATWS	RPS	HPCI(HPCS)	MFW	CONDA	HUM
80	1.03E-09	T-LOOP	HP1	HUM	AC	NSW	
81	1.02E-09	T-LOOP	HP1	HUM	AC		
82	1.01E-09	T-LOOP	HP1	AC			
83	9.90E-10	T-LOOP	HP1	LPCI	SPC	AC	
84	9.80E-10	T-LOOP	HP1	SPC	AC		
85	9.75E-10	T-LOOP	HP1	LPCI	SPC	AC	
86	9.53E-10	S2	HPCI(HPCS)	MFW	HUM		
87	9.41E-10	T-LOOP	HP1	SPC	DWS	HUM	AC
88	9.41E-10	T-LOOP	HP1	HUM	AC		
89	9.18E-10	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
90	9.15E-10	A	SPC	AC			
91	9.03E-10	T-LOOP	HUM	AC			
92	8.85E-10	T-LOOP	HP1	SPC	DWS	AC	
93	8.62E-10	T-ATWS	RPS	CONDA	HUM		
94	8.50E-10	T-LOOP	HP1	SPC	HUM	AC	
95	8.16E-10	T-LOOP	HP1	LPCI	CS	AC	
96	8.00E-10	T-LOOP	AC	EAC			
97	7.93E-10	T-LOOP	LPCI	CS	HUM	AC	
98	7.88E-10	T-LOOP	HPCI(HPCS)	RCIC	HP1	HUM	AC
99	7.55E-10	A	SPC				
100	7.28E-10	T-LOOP	HP1	HUM	AC		
101	1.52E-07	REMAINDER					
102		T-IFL					

Table D-2n RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences WE 4-Lp Plants 22 and 23 (IPE Data Base Results)

IE RBPI: Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES		
1	2.14E-05	T-CCW	HUM	CCW	
2	1.27E-05	S2	HUM		
3	5.99E-06	T-CCW	HUM	CCW	
4	3.98E-06	T-AC	SDAFW	HVAC1	
5	3.26E-06	S2	HUM		
6	2.88E-06	T-SGTR	SGS	HUM	
7	2.56E-06	T-CCW	HUM		
8	2.38E-06	T-AC	ESW		
9	2.12E-06	T-CCW	HUM	CCW	
10	1.90E-06	T-AC	HUM	HVAC1	
11	1.80E-06	T-AC	ESW		
12	1.77E-06	T-AC	HUM	CCW	
13	1.69E-06	T-CCW	HUM	CCW	
14	1.30E-06	S1	HUM		
15	1.29E-06	T-CCW	HUM	CCW	
16	1.22E-06	T-DC	MDAFW	SDAFW	HUM
17	1.16E-06	T-AC	AC	EAC	
18	1.14E-06	T-CCW	HUM	CCW	
19	1.07E-06	T-IFL	ESW		
20	1.06E-06	T-IFL	ESW		
21	9.84E-07	T-CCW	HUM	CCW	
22	9.59E-07	T-LOOP	AC	ESW	
23	9.51E-07	T-ESW	ESW		
24	8.94E-07	T-AC	AC	EAC	
25	8.61E-07	T-RX	ESW		
26	8.50E-07	S2			
27	8.46E-07	S2			
28	7.78E-07	T-TT	ESW		
29	7.70E-07	S2	HUM		
30	7.37E-07	T-DC	MDAFW	SDAFW	HUM
31	7.19E-07	T-CCW	HUM	CCW	
32	5.96E-07	T-AC	HVAC1		
33	5.95E-07	T-CCW	HUM	CCW	

Table D-2n (Continued)

		IE RBPI	System RBPI				
		Indusstry-Wide Trending					
SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES				
34	5.93E-07	T-LMFW	ESW				
35	5.56E-07	T-AC	CCW				
36	5.42E-07	T-AC	ESW				
37	5.39E-07	T-LOOP	AC	EAC			
38	5.34E-07	T-AC	HUM	CCW			
39	5.13E-07	T-LOOP	AC	EAC			
40	5.10E-07	A	ACC				
41	4.99E-07	T-LOOP	SDAFW	HVAC1			
42	4.85E-07	T-SGTR	LPR	HUM			
43	4.84E-07	T-TT	RPS	PPORV	MDAFW	SDAFW	HUM
44	4.77E-07	T-IFL	HVAC1				
45	4.75E-07	T-CCW	HUM	CCW			
46	4.75E-07	T-CCW	HUM	CCW			
47	4.73E-07	T-CCW	HUM	CCW			
48	4.52E-07	T-IFL	CCW				
49	4.32E-07	S2					
50	4.27E-07	T-RX	HVAC1				
51	4.25E-07	T-LOOP	AC	EAC			
52	4.05E-07	A					
53	3.86E-07	T-TT	CCW				
54	3.66E-07	S1	HUM				
55	3.64E-07	T-LOOP	SDAFW	HVAC1			
56	3.62E-07	T-CCW	HUM	CCW			
57	3.58E-07	T-IFL	CCW				
58	3.53E-07	T-MSIV	SDAFW	HVAC1			
59	3.47E-07	T-AC	HUM				
60	3.44E-07	T-RX	HUM	HVAC1			
61	3.42E-07	T-RX	HUM	HVAC1			
62	3.41E-07	T-SGTR	LPR	HUM			
63	3.39E-07	T-CCW	HUM	CCW			
64	3.23E-07	T-SGTR	LPR	HUM			
65	3.21E-07	T-IFL	SDAFW	HVAC1			
66	3.14E-07	T-SGTR	HUM				
67	3.13E-07	T-RX	CCW				

Table D-2n (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES		
68	3.12E-07	T-LMFW	RPS	PPORV	HUM
69	3.11E-07	T-TT	HUM	HVAC1	
70	3.09E-07	T-TT	HUM	HVAC1	
71	3.08E-07	T-TT	HUM	CCW	
72	3.06E-07	T-CCW	HUM	CCW	
73	2.94E-07	T-LMFW	ESW		
74	2.85E-07	T-CCW	HUM	CCW	
75	2.83E-07	T-TT	ESW		
76	2.79E-07	T-TT	HUM	CCW	
77	2.76E-07	T-CCW	HUM	CCW	
78	2.73E-07	T-LOOP	ESW		
79	2.68E-07	T-CCW	HUM	CCW	
80	2.63E-07	T-CCW	HUM	CCW	
81	2.63E-07	T-CCW	HUM	CCW	
82	2.56E-07	T-VAC	MDAFW	HUM	
83	2.52E-07	T-DC	MDAFW	SDAFW	HUM
84	2.40E-07	T-MSIV	HUM	HVAC1	
85	2.39E-07	T-AC	AC	EAC	
86	2.37E-07	T-LMFW	RPS	PPORV	
87	2.37E-07	T-LMFW	HUM	HVAC1	
88	2.35E-07	T-LMFW	HUM	HVAC1	
89	2.35E-07	T-CCW	HUM	CCW	
90	2.33E-07	T-SGTR	HUM		
91	2.31E-07	S2	HUM		
92	2.31E-07	S2	HUM		
93	2.31E-07	T-CCW	HUM	CCW	
94	2.31E-07	T-CCW	HUM	CCW	
95	2.28E-07	T-TT	RPS	PPORV	HUM
96	2.27E-07	T-LOOP	ESW		
97	2.25E-07	T-LOOP	ESW		
98	2.24E-07	S2	HUM		
99	2.24E-07	T-CCW	HUM	CCW	
100	2.23E-07	S2	HUM		

Table D-2n (Continued)

SEQ	CDF	INITIATOR (IE RBPI: Industry-Wide Trending)	ACCIDENT SEQUENCE FAILURES (System RBPI)
102	6.08E-05	REMAINDER	
101	3.06E-06	T-IFL	

Table D-2o RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences - CE Plant 12 (IPE Data Base Results)

SEQ	CDF	INITIATOR (IE RBPI: Industry-Wide Trending)	ACCIDENT SEQUENCE FAILURES (System RBPI)	
1	9.98E-07	T-LOOP	EAC	EDC
2	7.73E-07	S3	CCW	
3	7.00E-07	S3	HPI	
4	7.00E-07	S3	HPR	AR1
5	5.95E-07	S3	HPI	
6	5.15E-07	T-LOOP	EAC	EDC
7	4.35E-07	S3	HPI	
8	4.26E-07	S3	ESAS1	
9	2.82E-07	T-CCW	CCW	HUM
10	2.73E-07	S3	ESW	
11	2.21E-07	S2	CCW	
12	2.00E-07	S2	HPI	
13	2.00E-07	S2	HPR	
14	1.99E-07	S3	HPI	
15	1.99E-07	S3	HPR	
16	1.97E-07	T-SLBOC	HPI	
17	1.45E-07	A	CCW	
18	1.31E-07	A	LPI	
19	1.31E-07	A	HPR	

Table D-2o (Continued)

SEQ	CDF	INITIATOR (IE RBPI / Industry-Wide Trending)	System RBPI	ACCIDENT SEQUENCE FAILURES	
20	1.31E-07	A	HPR		
21	1.28E-07	T-DC	DC	EDC	
22	1.28E-07	T-DC	DC	EDC	
23	1.24E-07	S2	HPI		
24	1.22E-07	T-SLBOC	HPI		
25	1.22E-07	S2	ESAS1		
26	1.14E-07	S2	HPI		
27	1.12E-07	T-SLBOC	HPI		
28	9.68E-08	A	ACC		
29	9.68E-08	A	ACC		
30	9.68E-08	A	ACC		
31	9.68E-08	A	ACC		
32	9.68E-08	A	ACC		
33	9.68E-08	A	ACC		
34	9.68E-08	A	ACC		
35	9.68E-08	A	ACC		
36	9.68E-08	A	ACC		
37	9.68E-08	A	ACC		
38	9.68E-08	A	ACC		
39	9.68E-08	A	ACC		
40	9.38E-08	T-LOOP	EAC	EDC	HUM
41	9.35E-08	T-LOOP	EAC	EDC	
42	8.14E-08	A	HPR		
43	8.04E-08	T-ESW	ESW	HUM	
44	7.98E-08	A	ACC		
45	7.98E-08	A	ACC		
46	7.80E-08	S2	ESW		

Table D-2o (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES		
47	7.47E-08	A	HPR		
48	7.34E-08	T-LOOP	EAC	EDC	HUM
49	7.32E-08	T-LOOP	EAC	EDC	
50	7.07E-08	S3	HPR		
51	7.07E-08	S3	HPR		
52	7.03E-08	S3	CCW		
53	7.03E-08	S3	ESW		
54	6.66E-08	T-DC	DC	EDC	
55	6.66E-08	T-DC	DC	EDC	
56	6.54E-08	S3			
57	6.54E-08	S3			
58	6.48E-08	T-SGTR	CHPI	HPI	
59	6.48E-08	T-SGTR	CHPI	HPI	
60	6.35E-08	A	LPI		
61	5.78E-08	S3	HPR	AR1	
62	5.68E-08	T-LOOP	EAC	EDC	HUM
63	5.68E-08	T-LOOP	EAC	EDC	HUM
64	5.66E-08	T-LOOP	EAC	EDC	
65	5.66E-08	T-LOOP	EAC	EDC	
66	5.27E-08	A	LPI		
67	5.22E-08	S3	HPI		
68	5.22E-08	S3	HPI		
69	5.11E-08	A	ESW		
70	4.89E-08	T-DC	MDAFW	SDAFW	
71	4.89E-08	T-DC	MDAFW	SDAFW	
72	4.84E-08	T-LOOP	EAC	EDC	HUM
73	4.83E-08	A	LPI		

Table D-2o (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES		
74	4.83E-08	S3	HPR		
75	4.83E-08	S3	HPR		
76	4.82E-08	T-LOOP	EAC	EDC	
77	4.69E-08	T-DC	MDAFW	SDAFW	
78	4.69E-08	T-DC	MDAFW	SDAFW	
79	4.37E-08	T-DC	DC	EDC	HUM
80	4.27E-08	S3	HPR		
81	4.27E-08	S3	HPR		
82	4.13E-08	T-LMFW	RPS		
83	4.13E-08	T-LMFW	RPS		
84	3.64E-08	S3	HPI		
85	3.64E-08	S3	HPI		
86	3.40E-08	T-DC	MDAFW	SDAFW	
87	3.40E-08	T-DC	MDAFW	SDAFW	
88	3.37E-08	S3	HPR		
89	3.37E-08	S3	HPR		
90	3.32E-08	S3	HUM		
91	3.32E-08	S3	HUM		
92	3.29E-08	T-LOOP	EAC	EDC	HUM
93	3.29E-08	T-LOOP	EAC	EDC	HUM
94	3.28E-08	T-LOOP	EAC	EDC	
95	3.28E-08	T-LOOP	EAC	EDC	
96	3.18E-08	T-DC	MDAFW	SDAFW	
97	3.18E-08	T-DC	MDAFW	SDAFW	
98	3.15E-08	S3	HPI		
99	3.11E-08	T-DC	MDAFW	SDAFW	
100	3.11E-08	T-DC	MDAFW	SDAFW	

Table D-2o (Continued)

IE RBPI

Industry-Wide Trending

System RBPI

SEQ	CDF	INITIATOR	ACCIDENT SEQUENCE FAILURES
101	3.10E-08	T-RX	RPS
102	3.10E-08	T-RX	RPS
103	3.08E-08	S3	HUM
104	3.08E-08	S3	HUM
105	3.01E-08	A	LPI
106	1.62E-06	V-AR1	AR1
107	1.21E-07	V-HPI	HPI
109	7.90E-06	REMAINDER	
108	5.00E-07	T-IFL	

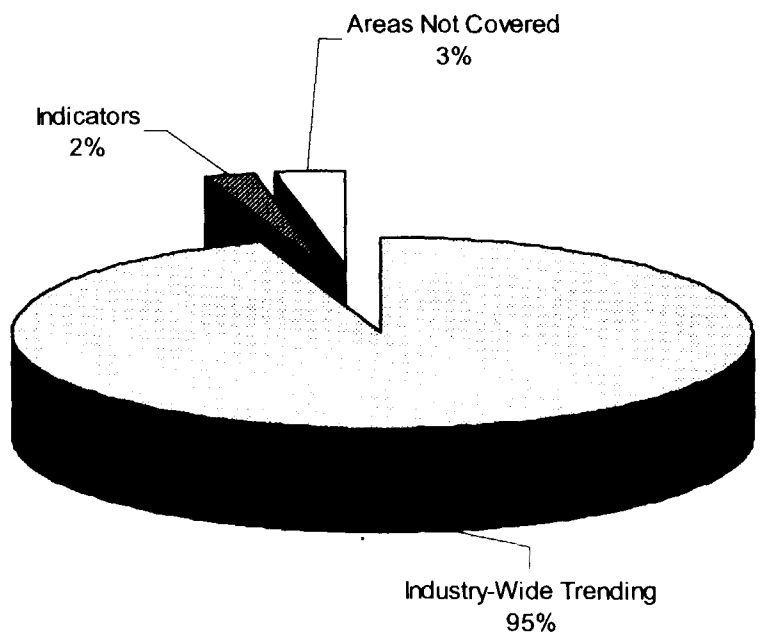

Figure D-1a RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for WE 4-Lp Plants 1&2

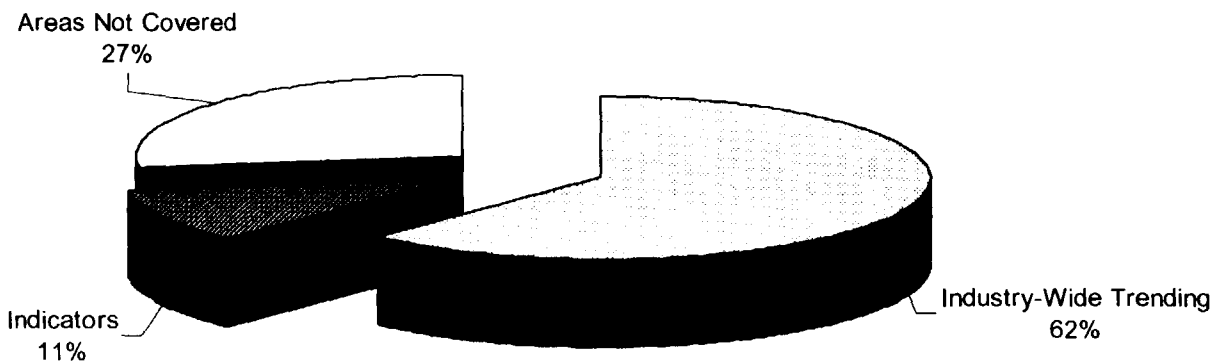

Figure D-1b RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for CE Plants 2&3

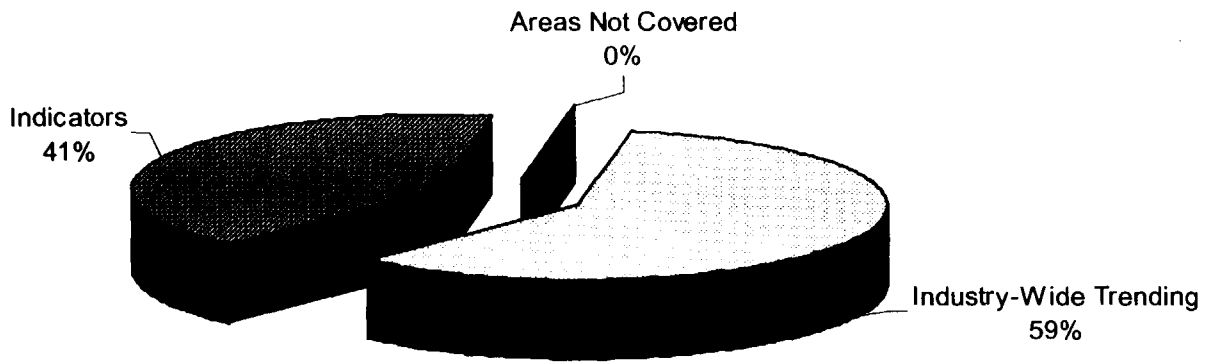

Figure D-1c RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for BWR 3/4 Plant 5

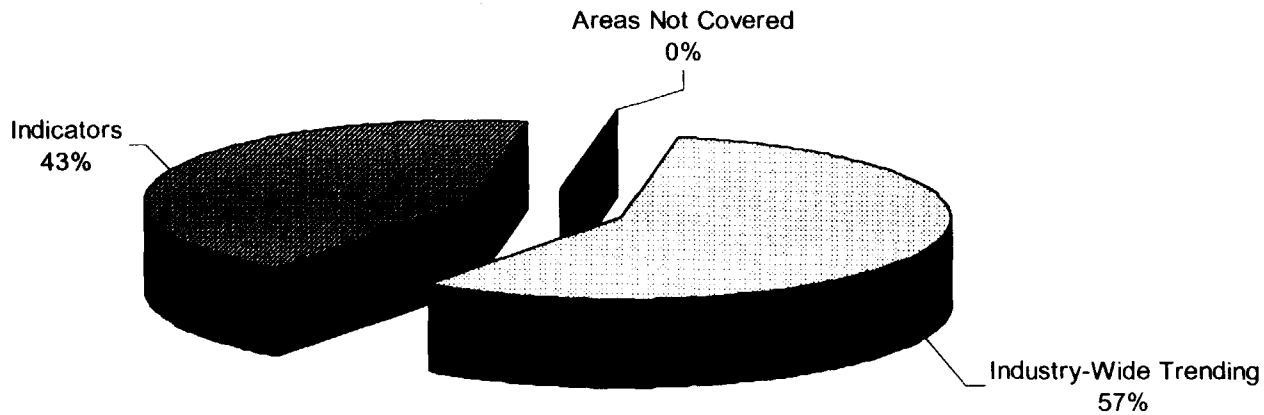

Figure D-1d RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for BWR 3/4 Plant 6

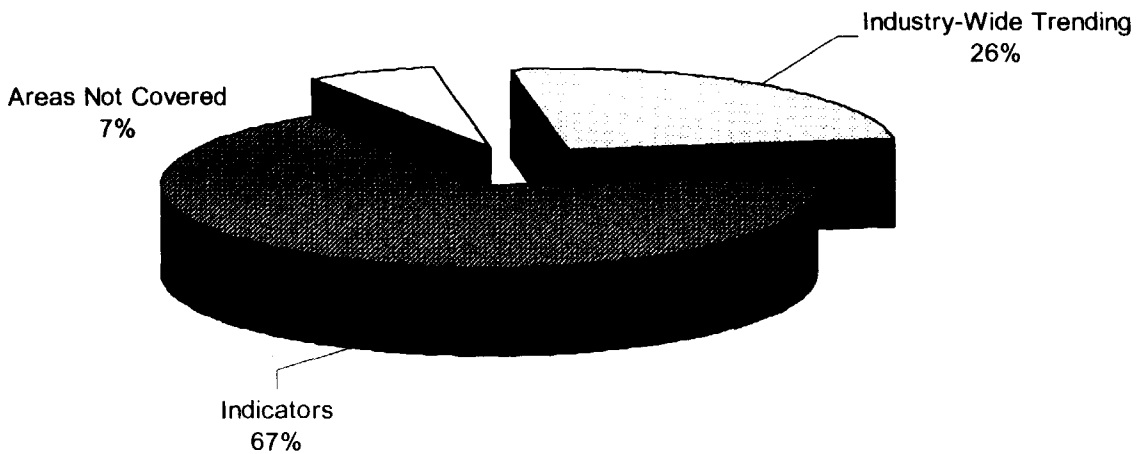

Figure D-1e RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for CE Plant 4

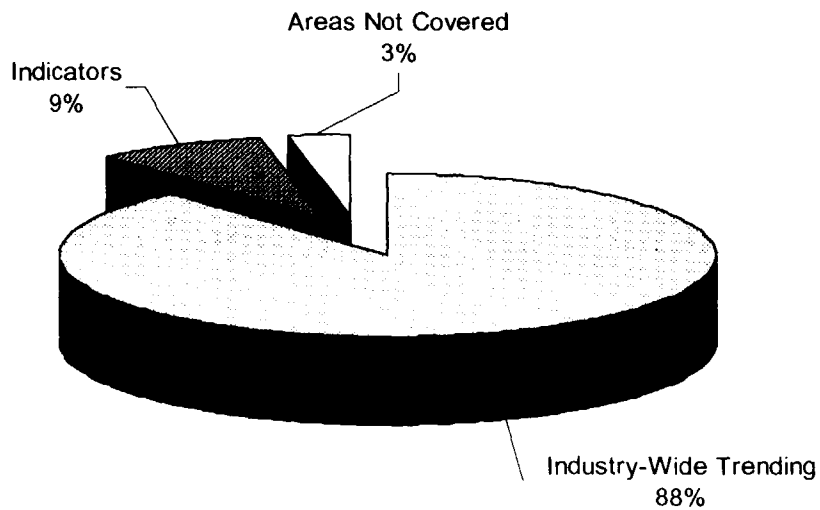

Figure D-1f RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for BWR 5/6 Plant 2

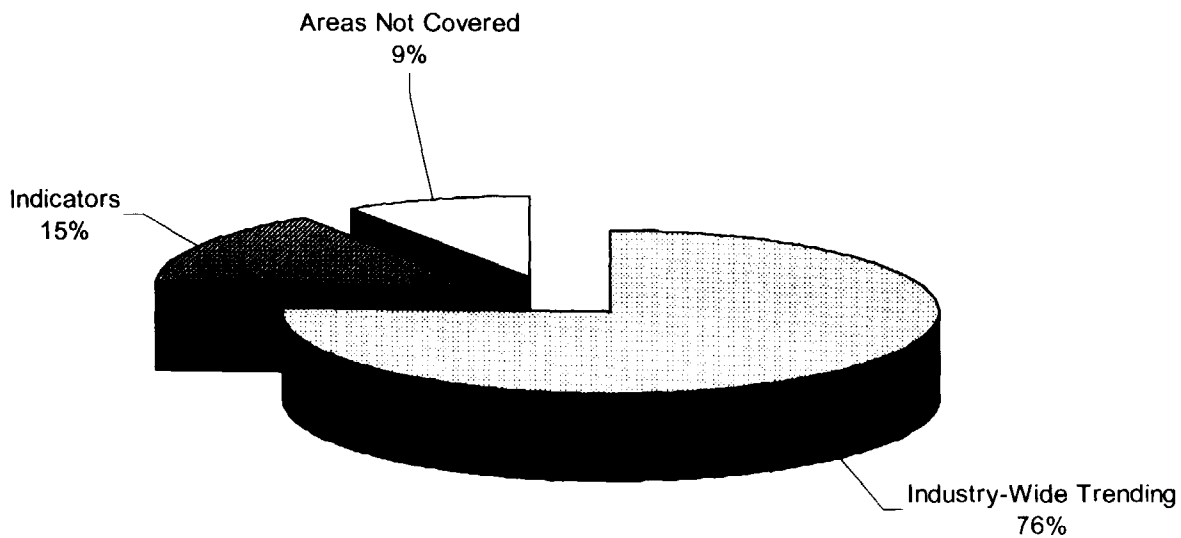

Figure D-1g RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for BWR 3/4 Plant 11

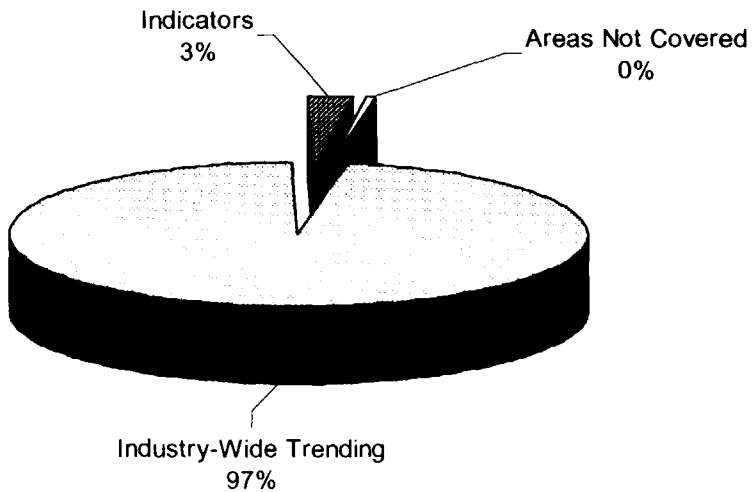

Figure D-1h RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for BWR 3/4 Plant 8

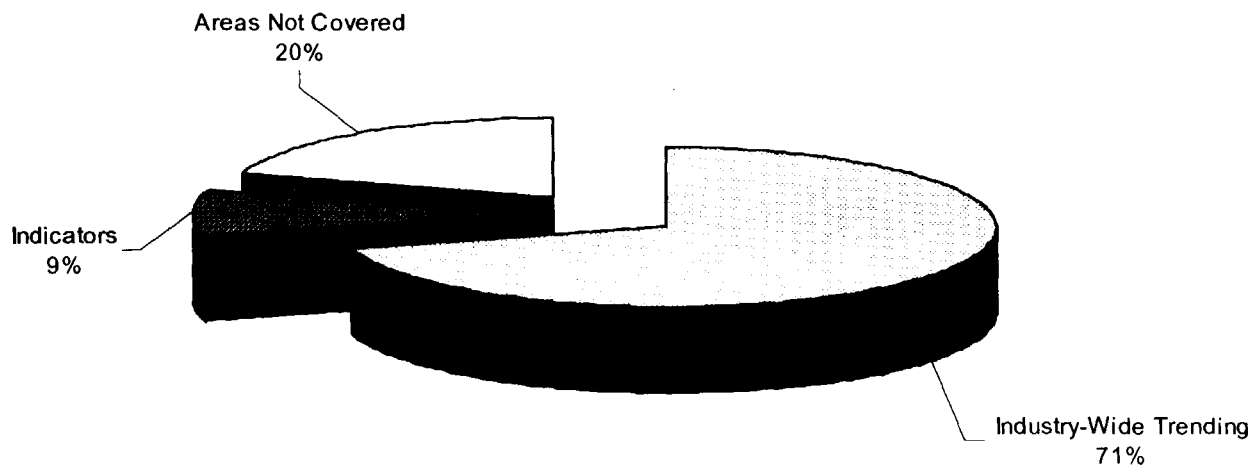

Figure D-1i RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for CE Plant 5

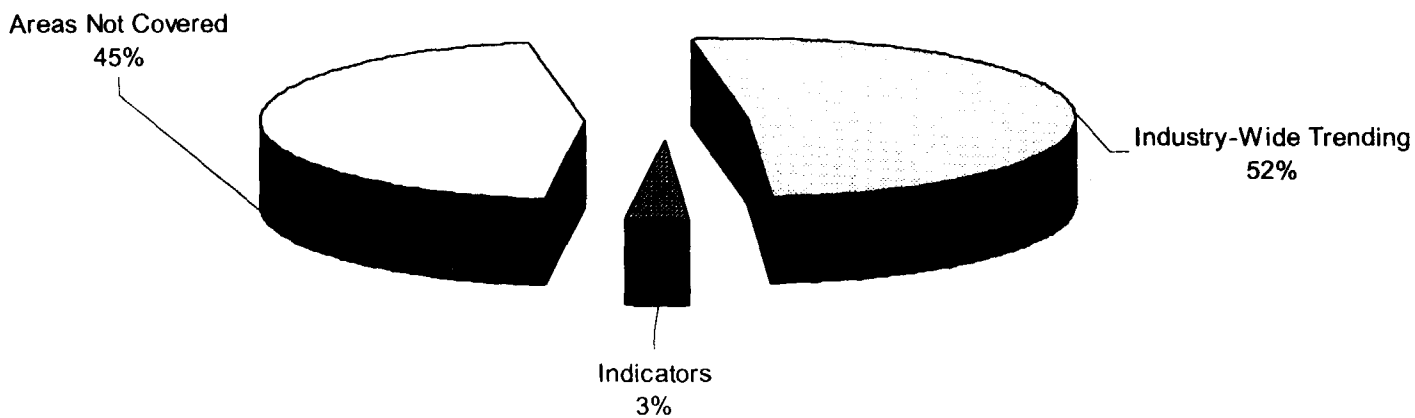

Figure D-1j RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for B&W Plants 4,5&6

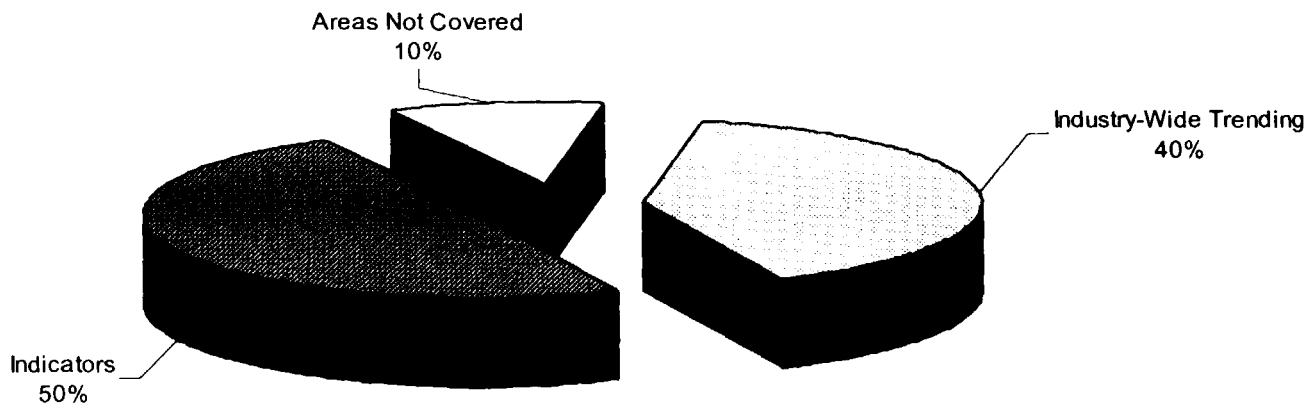

Figure D-1k RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for BWR 3/4 Plants 15&16

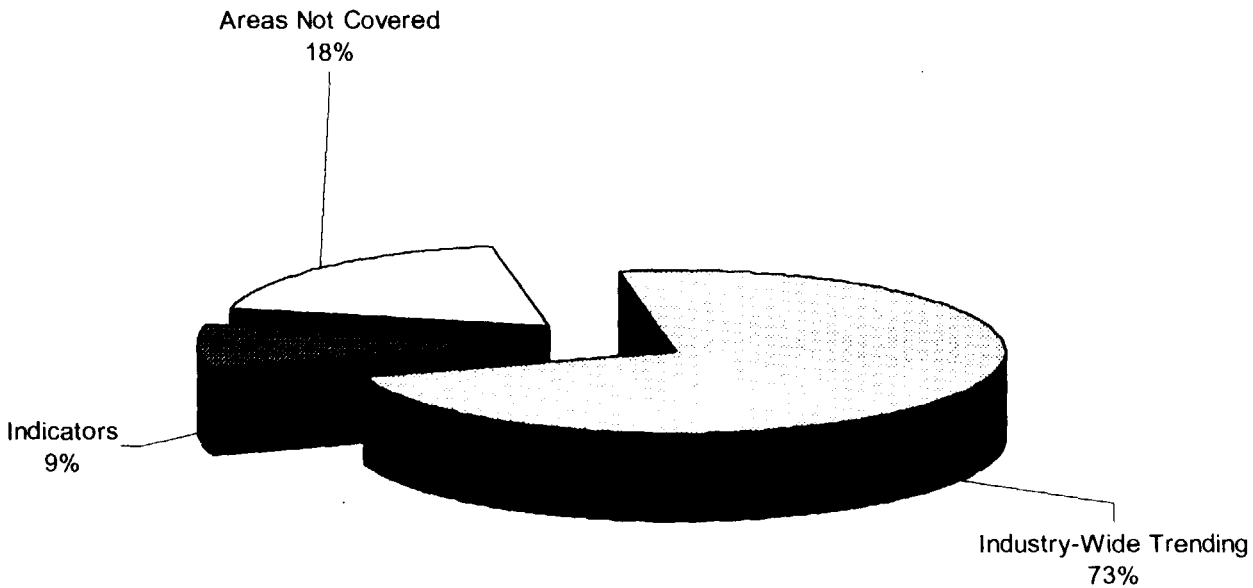

Figure D-11 RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for WE 2-Lp Plants 5&6

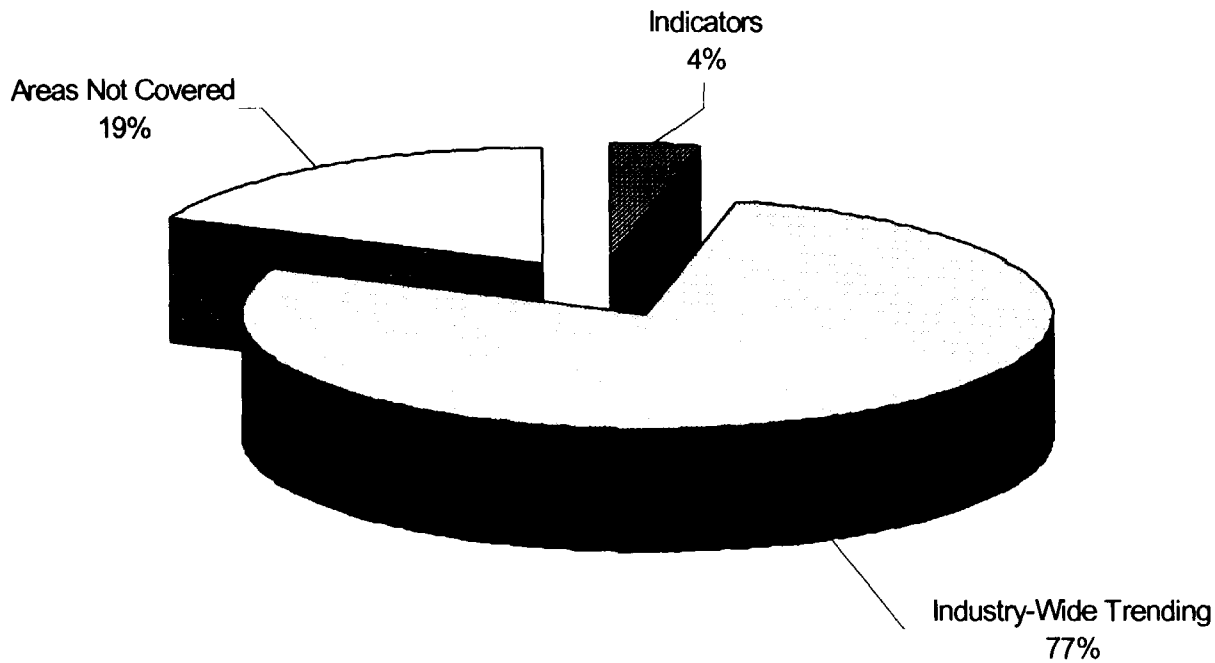

Figure D-1m RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for BWR 3/4 Plants 18&19

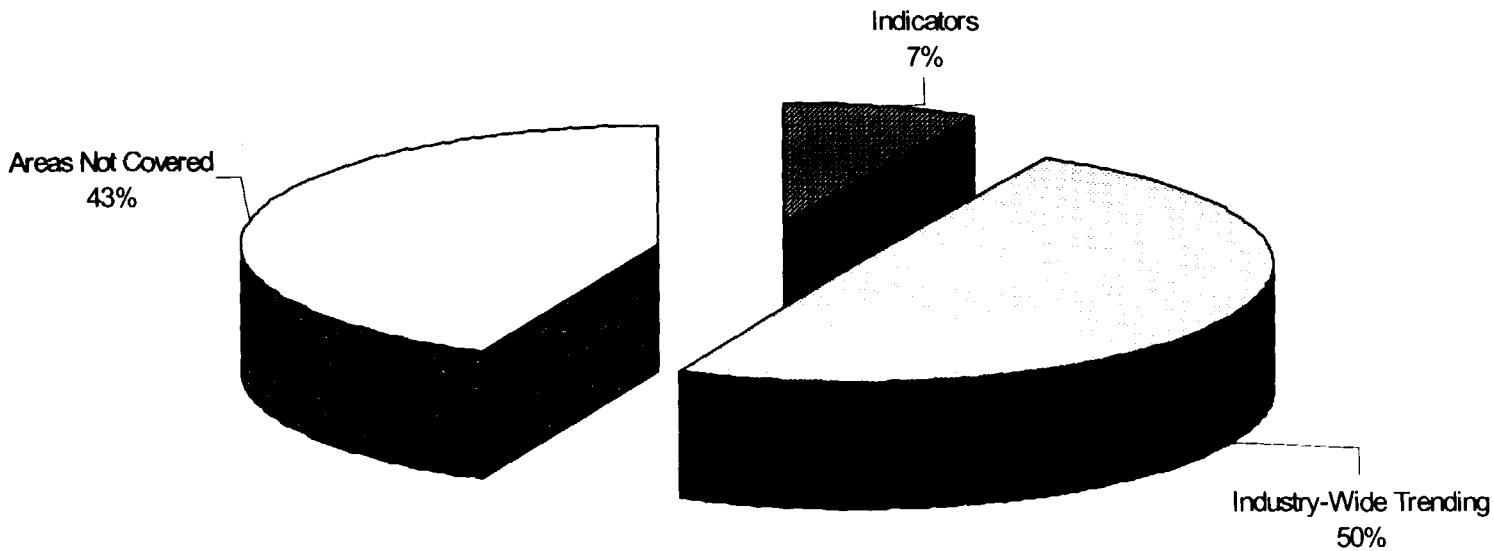

Figure D-1n RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for WE 4-Lp Plants 22&23

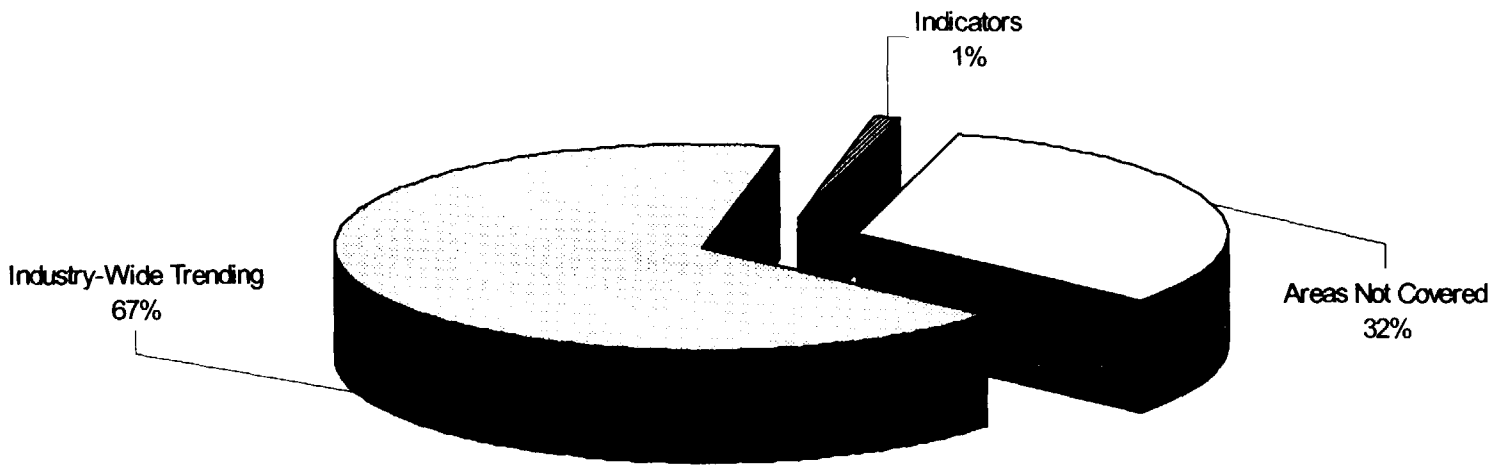

Figure D-1o RBPI Coverage of Dominant Full Power Internal Event Core Damage Sequences by Initiating Events for CE Plant 12

Table D-3 Mitigating System Elements That Appear in Dominant Core Damage Sequences but Are Not Covered by RBPIs

PWRs	
Element	**Reason for No RBPI**
Post-Accident Human Action	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Steam Generator Safety Valves	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Vital AC Buses	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Heating/Ventilation/Air Conditioning	Loss of HVAC with support systems available is not risk-significant at most plants
Reactor Protection System	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Plant-specific Other Onsite AC Backup	Not generically important
Plant-specific Alternate Makeup	Not generically important
Plant-specific Alternate Recirculation	Not generically important
Plant-specific Auxiliary Cooling	Not generically important
Boron Injection	Not generically important
Normally Running Makeup	Not generically important
Containment Spray Recirculation	Not generically important
DC Buses	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Battery-backed DC Buses	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Engineered Safety Actuation System	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Instrument Air Compressors	Not generically important (and industry-trended as initiating event)
Low Pressure Injection	Most hardware shared with Residual/Decay Heat Removal, which is covered by an RBPI
Main Feedwater Pumps	Data not currently available to support RBPI quantification of post-accident reliability; monitored as initiating event RBPI
Main Steam Isolation Valves	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Non-1E Startup Pumps	Not generically important
Plant-specific Alternate Air Systems	Not generically important
Pressurizer Safety Relief Valves	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Reactor Coolant Pump Seals	Not generically important
Steam Generator Atmospheric Dump Valves	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Plant-specific Alternate Service Water Systems	Not generically important
Turbine Bypass Valves	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Vital Instrument AC	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Safety Injection System Accumulators	Not amenable to PI treatment (timely quantification directly from performance data not possible)

Table D-3 (Continued)

BWRs	
Element	**Reason for No RBPI**
Post-Accident Human Action	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Reactor Protection System	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Vital AC Buses	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Automatic Depressurization	Low potential for risk-significant impact
Plant-specific High Pressure Systems	Not generically important
Low Pressure Coolant Injection	Most hardware shared with Suppression Pool Cooling, which is covered by an RBPI
Main Feedwater	Data not currently available to support RBPI quantification
DC Buses	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Alternate Rod Insertion	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Alternate Suppression Pool Cooling	Not generically important
Plant-specific Auxiliary Cooling Systems	Not generically important
Control Rod Drive Pumps	Not generically important
Low Pressure Core Spray	Not generically important
Condensate Pumps	Not generically important
Battery-backed DC Buses	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Heating/Ventilation/Air Conditioning	Loss of HVAC with support systems available is not risk-significant at most plants
Instrument Air Compressors	Not generically important (and industry-trended as an initiating event)
Plant-specific Low Pressure Systems	Not generically important
Main Steam Isolation Valves	Not amenable to PI treatment (timely quantification directly from performance data not possible)
Reactor Building Closed Loop Cooling Water	Not generically important
Recirculation Pumps	Not generically important
Standby Liquid Control	Not generically important
Safety Relief Valves Steam	Not generically important
Plant-specific Alternate Service Water	Not generically important
Turbine Building Closed Loop Cooling Water	Not generically important
Drywell Spray	Most hardware shared with Suppression Pool Cooling, which is covered by an RBPI
Venting	Not amenable to PI treatment (timely quantification directly from performance data not possible)

D.1 References

1. Long, S. M., P. D. Reilly, E.G. Rodrick, and M. B. Sattison, "Current Status of the SAPHIRE Models for ASP Evaluations," Proceedings of the 4th International Conference on Probabilistic Safety Assessment and Management (PSAM 4), pp. 1195-1199, September 13-18, 1998.

2. Su, T. M., et al., "Individual Plant Examination Database – User's Guide," NUREG-1603, U.S. NRC, April 1997.

Appendix E
RBPI Data Collection and Analysis

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Appendix E: RBPI Data Collection and Analysis

E.1 Data Collection Methodology

In order to validate the proposed risk-based performance indicators (RBPIs) developed for at power internal events, data were collected, analyzed, and compared with plant-specific thresholds. That process is summarized in Section 5 of the main report. This appendix presents the actual data collected for the 23 plants (15 sites) covered. The Standardized Plant Analysis Risk (SPAR) models (Ref. 1) used to develop thresholds were baselined to represent industry performance as of 1996. The data collection, in general, covers the period 1997 through 1999.

Proposed full power, internal event RBPIs include initiating events, mitigating system unavailabilities, mitigating system unreliabilities, and component class unreliabilities. The data sources used for each of these RBPI types are listed below:

1. Initiating events – U.S. Nuclear Regulatory Commission report on initiating event frequencies (Ref. 2) for 1997 and 1998; Reactor Oversight Program (ROP) web-based data (Ref. 3) for 1999 for general transient (GT) and loss of heat sink (LOHS). No data are available for loss of feedwater (LOFW) for 1999 (pending analysis of Licensee Event Reports).

2. Mitigating system unavailability – ROP web-based data for 1999.

3. Mitigating system unreliability – Equipment Performance and Information Exchange (EPIX) database (Ref. 4), as processed by the Reliability and Availability Database System (RADS) software (Ref. 5). The years 1997 through 1999 were covered. (Note that the automated demand and operating hours estimation routine in RADS was not fully operational at the time the data collection occurred, so EPIX information was evaluated manually to estimate demands and operating hours.)

4. Component class unreliability – Same as for mitigating system unreliability. However, RADS was used to estimate the numbers of demands and operating hours. The years 1997 through 1999 were covered.

Data collection periods, determined by statistical analyses summarized in Appendix F, are the following:

1. Initiating events – one year (1999) for GT and three years for LOHS and LOFW (1997 – 1999)

2. Mitigating system unavailability – one year (1999)

3. Mitigating system unreliability – three years (1997 – 1999)

4. Component class unreliability – three years (1997 – 1999).

E.2 Data Collection Results

Data collection results for the four types of RBPIs are presented in Tables E-1 through E-4.

Table E-1 Plant Data for Initiating Event RBPIs

Plant	GT [a]	LOHS [b]	LOFW [c]
PWRs			
WE 4-Lp Plant 1	0/8689h [d]	0/23086h	0/14397h
WE 4-Lp Plant 2	3/8094h	0/24247h	1/16153h
CE Plant 2	2/8332h	2/24029h	0/15697h
CE Plant 3	0/7453h	0/23004h	0/15551h
CE Plant 4	0/7836h	0/23265h	0/15429h
CE Plant 5	1/5446h	0/5446h	No data [e]
B&W Plant 4	2/7521h	0/19394h	0/11873h
B&W Plant 5	4/7530h	1/21562h	0/14032h
B&W Plant 6	0/8691h	0/21941h	0/13250h
WE 2-Lp Plant 5	1/7701h	1/22748h	0/15047h
WE 2-Lp Plant 6	0/8726h	0/22555h	0/13829h
CE Plant 12	3/7849h	0/23151h	1/15302h
WE 4-Lp Plant 22	0/8760h	0/24314h	1/15554h
WE 4-Lp Plant 23	0/8226h	0/24954h	1/16728h
BWRs			
BWR 3/4 Plant 5	0/8596h	0/22638h	0/14042h
BWR 3/4 Plant 6	0/7389h	0/23243h	0/15854h
BWR 3/4 Plant 8	2/8367h	0/23605h	0/15238h
BWR 5/6 Plant 2	1/7124h	1/23669h	0/16545h
BWR 3/4 Plant 11	0/7598h	0/23005h	0/15407h
BWR 3/4 Plant 15	1/8664h	0/25316h	0/16652h
BWR 3/4 Plant 16	0/8157h	0/24484h	0/16327h
BWR 3/4 Plant 18	1/8246h	0/20533h	0/12287h
BWR 3/4 Plant 19	0/8562h	0/17573h	0/9011h

a. A one-year data collection interval applies (1999). The 1999 data were obtained from the ROP (Ref. 3).

b. A three-year data collection interval applies (1997 – 1999). 1997 and 1998 data were obtained from the initiating events study update (Ref. 2), while the 1999 data were obtained from the ROP.

c. A three-year data collection interval applies (1997 – 1999). However, this RBPI is not covered under the ROP, so the results presented in this table include only 1997 and 1998. (1999 Licensee Event Reports will need to be reviewed to identify scrams that are LOFW, as defined in the initiating events study.)

d. The numbers indicate the number of events and the number of critical hours.

e. CE Plant 5 was shut down during 1997 and 1998, and no data are available for LOFW for 1999 (pending analysis of Licensee Event Reports).

Table E-2 Plant Data for Mitigating System Train Unavailability RBPIs[a]

Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR
PWRs				
WE 4-Lp Plant 1	61.5h/17520h[b]	113.5h/34756h	MDP (29.8h/8689h) DDP (375.6h/8689h)[c]	1.6h/17520h
WE 4-Lp Plant 2	58.6h/17520h	482.8h/32376h	MDP (19.2h/8094h) DDP (89.9h/8094h)	139.6h/17520h
CE Plant 2	115.2h/17520h	119.6h/16664h	MDP (0.0h/8332h) TDP (48.3h/16665h)	181.4h/17520h
CE Plant 3	131.0h/17520h	165.8h/14906h	MDP (18.0h/7453h) TDP (66.9h/14906h)	243.9h/17520h
CE Plant 4	167.4h/17568h	19.7h/15672h	MDP (7.7h/7836h) TDP (48.9h/7836h)	36.8h/17568h
CE Plant 5	200.2h/17520h	92.5h/11154h	MDP (54.1h/11154h) TDP (35.6h/5577h)	71.8h/17520h
B&W Plant 4	399.7h/17518h[d]	81.4h/15310h	MDP (49.9h/12494h) TDP (0.0h/6247h)	318.1h/17224h
B&W Plant 5	413.9h/17420h[d]	46.8h/15694h	MDP (45.9h/14034h) TDP (22.0h/7017h)	222.0h/17042h
B&W Plant 6	384.2h/17520h[d]	44.5h/17520h	MDP (119.0h/17520h) TDP (7.8h/8760h)	184.7h/17568h
WE 2-Lp Plant 5	236.4h/17520h	21.5h/15402h	MDP (33.5h/7701h) TDP (51.9h/7701h)	286.1h/17520h

Table E-2 (Continued)

PWRs				
Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR
WE 2-Lp Plant 6	176.1h/17520h	21.8h/17452h	MDP (36.4h/8726h) TDP (21.6h/8726h)	44.8h/17520h
CE Plant 12	86.5h/16866h	113.5h/15592h	MDP (83.3h/15694h) TDP (36.2h/7847h)	123.5h/17472h
WE 4-Lp Plant 22	168.0h/17520h	270.0h/35040h	MDP (132.3h/17520h) TDP (34.7h/8760h)	76.7h/17520h
WE 4-Lp Plant 23	207.4h/17520h	162.4h/32908h	MDP (194.4h/16452h) TDP (52.0h/8226h)	143.9h/17520h
BWRs				
BWR 3/4 Plant 5	51.4h/17520h	20.8h/8562h	47.1h/8592h	0.0h/17520h
BWR 3/4 Plant 6	228.8h/17520h	15.4h/7364h	73.7h/7364h	147.2h/17618h
BWR 5/6 Plant 8	661.3h/35040h[e]	233.5h/8367h	419.8h/8367h[f]	137.4h/17520h
BWR 5/6 Plant 2	624.3h/17520h[g]	32.7h/7124h	108.4h/7124h	76.5h/17520h
BWR 3/4 Plant 11	260.1h/35040h	134.7h/7627h	136.2h/7627h	202.9h/17520h
BWR 3/4 Plant 15	270.8h/17514h	140.7h/8664h	74.9h/8664h	158.6h/17520h
BWR 3/4 Plant 16	390.3h/17514h	168.2h/8157h	64.6h/8157h	228.2h/17520h
BWR 3/4 Plant 18[h]	369.8h/17328h	3704.5h/8246h[i]	137.4h/8246h	94.0h/17520h
BWR 3/4 Plant 19[h]	305.4h/17328h	144.7h/8562h	155.1h/8562h	131.6h/17520h

a. Unavailability data obtained from the ROP. Planned outage hours and unplanned outage hours were used. Fault exposure time was used only if a corresponding demand failure is not in the EPIX database. Only data for1999 were used.

b. The hours are the total outage hours (planned, unplanned, and sometimes fault exposure hours) and the total train hours during which the system is required to be available. A footnote indicates the cases where the fault exposure hours were used.

c. Includes fault exposure time of 341.5 hours.

d. B&W Plants 4 through 6 do not have emergency diesel generators. Results are for the two hydro units.

e. Includes fault exposure time of 168 hours.

f. Includes fault exposure time of 361.4 hours.

g. Includes fault exposure time of 324 hours.

h. The swing EDG unavailability was counted for each unit.

i. Includes fault exposure time of 3550.4 hours.

Table E-3 Plant Data for Mitigating System Unreliability RBPIs[a]

Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR
PWRs				
WE 4-Lp Plant 1	EDG FTS (0/109)[b] EDG FTLR (0/3.0) EDG FTR (0/511.3h)	No data[c]	MPD FTS (0/44.5) MDP FTR (0/38.1h) DDP FTS (0/65.0) DDP FTR (0/45.6h)	MDP FTS (0/72.0) MDP FTR (0/1155.4h)
WE 4-Lp Plant 2	EDG FTS (0/125) EDG FTLR (0/0.0) EDG FTR (0/482.4h)	No data	MDP FTS (0/49.5) MDP FTR (0/35.5h) DDP FTS (0/60.0) DDP FTR (0/42.9h)	MDP FTS (0/72.0) MDP FTR (0/1107.5h)
CE Plant 2	EDG FTS (5/178) EDG FTLR (0/147) EDG FTR (0/318.7h)	MDP FTS (0/251.5) MDP FTR (0/72.2h)	MDP FTS (0/74.5) MDP FTR (0/32.6h) TDP FTS (0/127.5) TDP FTR (0/225.5h)	MDP FTS (0/220.3) MDP FTR (0/2321.8h)
CE Plant 3	EDG FTS (1/137) EDG FTLR (0/85) EDG FTR (0/244.6h)	MDP FTS (0/290.5) MDP FTR (0/140.1h)	MDP FTS (0/69.0) MDP FTR (0/29.1h) TDP FTS (1/106.5) TDP FTR (0/180.3)	MDP FTS (0/206.5) MDP FTR (0/2402.7h)

Table E-3 (Continued)

Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR
PWRs				
CE Plant 4	EDG FTS (1/145.8) EDG FTLR (0/92.8) EDG FTR (0/332.4h)	MDP FTS (0/467.0) MDP FTR (0/112.3h)	MDP FTS (0/133.0) MDP FTR (0/230.0h) TDP FTS (2/112.0) TDP FTR (0/114.3h)	MDP FTS (0/136.0) MDP FTR (1/2058.9h)
CE Plant 5	EDG FTS (1/88.4) EDG FTLR (0/79.8) EDG FTR (0/102h)	MDP FTS (0/98.1) MDP FTR (0/334.3h)	MDP FTS (0/78.2) MDP FTR (0/1524.1h) TDP FTS (0/15.5) TDP FTR (0/4.9h)	MDP FTS (no data) MDP FTR (no data
B&W Plant 4	Hydro FTS [d] (0/748.4) Hydro FTLR (0/396.3) Hydro FTR (0/1333.4h)	MDP FTS (0/546.8) MDP FTR (0/67512.5h)	MDP FTS (0/114.6) MDP FTR (0/84.0h) TDP FTS (1/29.1) TDP FTR (0/25.8h)	MDP FTS (0/312.3) MDP FTR (0/6276.6h)
B&W Plant 5	Data listed under B&W Plant 4	MDP FTS (0/575.3) MDP FTR (0/63809.2h)	MDP FTS (0/86.6) MDP FTR (0/84.0h) TDP FTS (0/32.1) TDP FTR (0/25.8h)	MDP FTS (0/294.5) MDP FTR (0/5283.1h)

Table E-3 (Continued)

Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR
B&W Plant 6	Data listed under B&W Plant 4	MDP FTS (0/526.3) MDP FTR (0/60774.8h)	MDP FTS (0/99.6) MDP FTR (0/84.0h) TDP FTS (0/34.1) TDP FTR (0/25.9h)	MDP FTS (0/428.7) MDP FTR (0/7084.4h)
WE 2-Lp Plant 5	EDG FTS (0/75) EDG FTLR (0/75) EDG FTR (0/489.0h)	MDP FTS (0/17) MDP FTR (0/4.4h)	MDP FTS (0/70.0) MDP FTR (0/267.3h) TDP FTS (0/56.5) TDP FTR (0/81.6h)	MDP FTS (0/83.5) MDP FTR (0/1247.0h)
WE 2-Lp Plant 6	EDG FTS (0/85) EDG FTLR (0/84) EDG FTR (0/206.1h)	MDP FTS (No data) MDP FTR (No data)	MDP FTS (0/36.0) MDP FTR (0/2788.7h) TDP FTS (0/36.0) TDP FTR (0/2800.7h)	MDP FTS (0/67.0) MDP FTR (0/4183.7h)
CE Plant 12	EDG FTS (0/72) EDG FTLR (0/72) EDG FTR (0/1307.8h)	MDP FTS (0/79.5) MDP FTR (0/19.9h)	MDP FTS (0/7.0) MDP FTR (0/21.0h) TDP FTS (1/no data) TDP FTR (2/no data)	MDP FTS (0/111.4) MDP FTR (0/732.9h)
WE 4-Lp Plant 22	EDG FTS (1/99.3) EDG FTLR (0/69.0) EDG FTR (0/162.1h)	MDP FTS (0/372) MDP FTR (1/26351.6h)	MDP FTS (1/66.5) MDP FTR (0/583.6h) TDP FTS (4/72.0) TDP FTR (0/66.0h)	MDP FTS (0/63.0) MDP FTR (0/1466.7h)

Table E-3 (Continued)

Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR
WE 4-Lp Plant 23	EDG FTS (1/108.4) EDG FTLR (0/74.2) EDG FTR (1/220.5h)	MDP FTS (1/400.4) MDP FTR (0/26340.9h)	MDP FTS (0/67.6) MDP FTR (1/576.6h) TDP FTS (1/86.6) TDP FTR (1/124.6h)	MDP FTS (0/54.6) MDP FTR (0/1114.8h)
BWRs				
BWR 3/4 Plant 5	EDG FTS (1/75.9) EDG FTLR (0/no data) EDG FTR (0/239.3h)	TDP FTR (0/22) TDP FTR (0/27h) MOV FTO (No data)	TDP FTS (0/15.9) TDP FTR (0/7.8h) MOV FTO (0/15.9)	MDP FTS (0/287.5) MDP FTR (0/8033.2h)
BWR 3/4 Plant 6	EDG FTS (0/67.5) EDG FTLR (0/81.6) EDG FTR (0/153.6h)	TDP FTS (0/58.8) TDP FTR (0/39.3h) MOV FTO (0/62.2)	TDP FTS (0/38.2) TDP FTR (0/45.4h) MOV FTO (0/45.8)	MDP FTS (0/291.2) MDP FTR (0/3732.4h)
BWR 3/4 Plant 8	EDG FTS (1/292) EDG FTLR (0/182.4) EDG FTR (0/175.1h)	TDP FTS (0/28.7) TDP FTR (0/no data) MOV FTO (0/27.5)	TDP FTS (0/20.3) TDP FTR (0/no data) MOV FTO (0/23.3)	MDP FTS (0/257.0) MDP FTR (1/1733.4h)
BWR 5/6 Plant 2	EDG FTS (0/161.0) EDG FTLR (0/91.0) EDG FTR (0/282.8)	MPD FTS (0/29.0) MDP FTR (0/17.9h) MOV FTO (0/15.0)	TDP FTS (0/19.0) TDP FTR (0/17.2h) MOV FTO (0/43.0)	MDP FTS (0/263.7) MDP FTR (0/2519.9h)
BWR 3/4 Plant 11	EDG FTS (0/199.8) EDG FTLR (0/195.6) EDG FTR (0/797.4h)	TDP FTS (0/15.9) TDP FTR (0/12.0h) MOV FTO (0/15.9)	TDP FTS (0/20.5) TDP FTR (1/30.0h) MOV FTO (0/12.0)	MDP FTS (0/194.5) MDP FTR (0/5182.4h)

Table E-3 (Continued)

Plant	EPS	HPI/ HPCI/ HPCS	AFW/ RCIC	RHR
BWR 3/4 Plant 15	EDG FTS (0/209.0) EDG FTLR (0/147) EDG FTR (0/517.5h)	TDP FTS (0/45.0) TDP FTR (0/9.0h) MOV FTO (0/12.0)	TDP FTS (0/37.5) TDP FTR (0/13.5h) MOV FTO (0/15.0)	MDP FTS (0/211.5) MDP FTR (0/1171.5h)
BWR 3/4 Plant 16	EDG FTS (0/218) EDG FTLR (0/143) EDG FTR (0/488h)	TDP FTS (0/42.3) TDP FTR (0/6.0h) MOV FTO (0/12.0)	TDP FTS (0/35.4) TDP FTR (0/13.4h) MOV FTO (0/15.0)	MPD FTS (0/168.0) MDP FTR (0/756.0h)
BWR 3/4 Plant 18	EDG FTS (1/195)[e] EDG FTLR (0/no data) EDG FTR (0/no data)	TDP FTS (0/30.2) TDP FTR (0/no data) MOV FTO (0/13.4)	TDP FTS (0/25.2) TDP FTR (0/37.2h) MOV FTO (0/28.8)	MDP FTS (0/566.4) MDP FTR (0/no data)
BWR 3/4 Plant 19	FTS (0/68.0) FTLR (0/no data) FTR (0/no data)	TDP FTS (0/22.8) TDP FTR (0/no data) MOV FTO (0/13.2)	TDP FTS (1/20.4) TDP FTR (0/31.2h) MOV FTO (0/42.0)	MDP FTS (0/286.2) MDP FTR (0/no data)

a. Three years of EPIX data were used (1997 – 1999). However, we did not have failure information for the fourth quarter of 1999 when these data were collected.

b. The numbers in parentheses indicate the number of failures and the number of demands (or hours).

c. "No data" indicates that either EPIX has no data, or the RADS data load of the EPIX file did not include this component.

d. B&W Plant 4 does not have EDGs. Entries refer to the two hydro units.

e. The swing EDG was included with this plant.

Table E-4 Plant Data for Component Class Unreliability RBPIs[a]

Plant	AOV	MOV	MDP
PWRs			
WE 4-Lp Plant 1	No data[b]	No data	MDP FTS (0/116.5)[c] MDP FTR (0/1193.5h)
WE 4-Lp Plant 2	No data	No data	MDP FTS (0/121.5) MDP FTR (0/1143.0h)
CE Plant 2	AOV FTO/C (0/436.7)	MOV FTO/C (0/166.9)	MDP FTS (0/545.5) MDP FTR (0/2442.1h)
CE Plant 3	AOV FTO/C (1/423.0)	MOV FTO/C (0/166.9)	MDP FTS (0/566.1) MDP FTR (0/2570.0h)
CE Plant 4	AOV FTO/C (2/156.4)	MOV FTO/C (0/232.1)	MDP FTS (6/2373.0) MPD FTR (2/41969.6h)
CE Plant 5	No data	MOV FTO/C (0/313.0)	MDP FTS (0/555.9) MDP FTR (1/102257.2h)
B&W Plant 4	AOV FTO/C (0/315.5)	MOV FTO/C (0/74.8)	MDP FTS (0/580.5) MDP FTR (0/99719.4h)
B&W Plant 5	AOV FTO/C (0/328.8)	MOV FTO/C (0/78.2)	MDP FTS (0/394.3) MDP FTR (0/96287.1h)
B&W Plant 6	AOV FTO/C (0/108.0)	MOV FTO/C (0/51.9)	MDP FTS (0/364.1) MDP FTR (0/97473.9h)
WE 2-Lp Plant 5	AOV FTO/C (0/30.0)	MOV FTO/C (0/138.8)	MDP FTS (1/264.8) MDP FTR (0/27809.0h)
WE 2-Lp Plant 6	AOV FTO/C (0/30.0)	MOV FTO/C (0/42.8)	MDP FTS (2/260.8) MDP FTR (0/33069.4h)
CE Plant 12	AOV FTO/C (0/195.9)	MOV FTO/C (4/172.1)	MDP FTS (2/527.3) MDP FTR (0/112755.9h)
WE 4-Lp Plant 22	AOV FTO/C (0/18.0)	MOV FTO/C (0/149.8)	MDP FTS (3/975.0) MDP FTR (2/171704.8h)
WE 4-Lp Plant 23	AOV FTO/C (0/70.0)	MOV FTO/C (0/165.5)	MDP FTS (1/571.7) MDP FTR (1/56006.7h)
BWRs			
BWR 3/4 Plant 5	No data	MOV FTO/C (0/502.8)	MDP FTS (3/2601.0) MDP FTR (0/174684.0h)
BWR 3/4 Plant 6	No data	MOV FTO/C (0/561.0)	MDP FTS (0/2745.3) MDP FTR (0/8904.1h)
BWR 3/4 Plant 8	No data	MOV FTO/C (0/240.6)	MDP FTS (0/510.7) MDP FTR (1/68787.3h)

Table E-4 (Continued)

Plant	AOV	MOV	MDP
BWR 5/6 Plant 2	AOV FTO/C (0/24.0)	MOV FTO/C (0/580.5)	MDP FTS (0/820.5) MDP FTR (0/12558.4h)
BWR 3/4 Plant 11	No data	MOV FTO/C (0/67.8)	MDP FTS (0/942.5) MDP FTR (0/141480.6h)
BWR 3/4 Plant 15	No data	MOV FTO/C (1/228.3)	MDP FTS (0/969.2) MDP FTR (0/4739.8h)
BWR 3/4 Plant 16	No data	MOV FTO/C (0/267.3)	MDP FTS (1/530.1) MDP FTR (0/3374.3h)
BWR 3/4 Plant 18	No data	MOV FTO/C (0/459.6)	MDP FTS (1/1495.8) MDP FTR (0/no data)
BWR 3/4 Plant 19	No data	MOV FTO/C (0/474.6)	MDP FTS (0/1246.2) MDP FTR (0/no data)

a. Three years of EPIX data were used (1997 – 1999). However, we did not have failure information for the fourth quarter of 1999 when these data were collected. The RADS software was used to determine both the numbers of failures and the numbers of demands or hours.

b. "No data" indicates that either EPIX has no data on this component class, or the RADS data load of the EPIX file did not include this component class.

c. Numbers in parentheses indicate number of failures and number of demands (or hours).

E.3 Data Analysis

Data analysis involves converting the data collected into RBPI values to compare with thresholds. The data conversion and threshold comparison requires a decision rule, as explained in Appendix F. Plant-specific thresholds are presented in Appendix A.

For initiating event RBPIs, the decision rule involves calculation of a frequency using a Bayesian update process. The prior is a constrained, non-informative prior based on the industry mean frequency, as outlined in Appendix F. The data presented in Table E-1 are the evidence. The resulting posterior frequency is then compared with the RBPI's plant-specific thresholds presented in Appendix A to determine whether the indicated performance band is green, white, yellow, or red.

For mitigating system unavailability RBPIs, the decision rule involves calculating train unavailability by dividing the outage hours by the required hours (both presented in Table E-2). A Bayesian update process was not used for unavailability because the data are not available in a format suitable for such a process. (Bayesian updates of unavailability data have been performed in cases where the data were divided into outage frequencies and outage durations, but data available from the ROP are not broken down in this manner.) The resulting train unavailability is then compared with the plant-specific thresholds presented in Appendix A.

Mitigating system unreliability RBPIs are more complex than the unavailability or initiating event RBPIs. Train unreliability typically involves several components and failure modes. The

train unreliability data collected are presented in Table E-3. Each component failure mode (probability or failure rate) was calculated using a Bayesian update process and a constrained, non-informative prior based on the industry mean. These updated component failure mode probabilities (or failure rates) were then inserted into the SPAR train fault tree to determine which performance band was indicated. Train components not covered by the EPIX data were kept at their baseline values in this calculation. (In practice, only a few plant unreliability RBPIs had enough failures to require actual SPAR recalculations of train unreliability.)

Many of the mitigating system unreliability RBPIs did not satisfy all of the misclassification criteria discussed in Appendix F. In particular, most of these RBPIs have the potential for indicating performance in the white band, when performance is actually at its baseline level. Therefore, for each white performance indication, an additional calculation is performed to determine the probability of obtaining the observed data, given that performance is at its baseline level. That calculation is also explained in Appendix F.

Finally, component class unreliability RBPIs were calculated similarly to mitigating system unreliability. For the air-operated and motor-operated valve component classes, unreliability was defined as failure to open or close upon demand. For the motor-operated pump class, unreliability was defined as failure to start and run upon demand. A mission time of 24 hours was assumed for all such pumps. Again, for each white performance indication, an additional calculation is performed to determine the probability of obtaining the observed data, given that performance is at its baseline level.

Results of the data analysis task are presented in Section 5 of this report.

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Appendix F
Statistical Methods and Results

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Appendix F: Statistical Methods and Results

F.1 Basic Definitions

The terminology is as follows.

GW = threshold between green and white performance bands, the value that raises the core damage frequency (CDF) above the baseline value by 1E-6/calendar year.

WY = threshold between white and yellow bands, the value that raises the CDF above the baseline value by 1E-5/calendar year.

YR = threshold between yellow and red bands, the value that raises the CDF above the baseline value by 1E-4/calendar year.

Throughout this appendix, the term "calendar year" is shorthand for "7000 critical hours." The thresholds are shown conceptually in Figure F-1. The solid circle marks the baseline, an industry average, which is in the green band but often rather close to the green-white threshold.

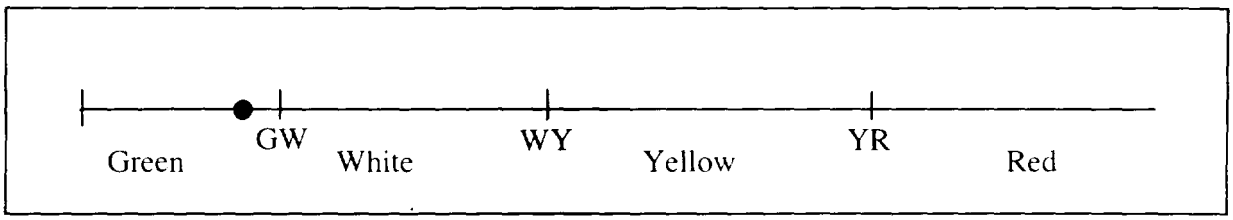

Figure F-1 Diagram of the Performance Bands and Their Thresholds

F.2 Initiating Events

F.2.1 Decision Rules for Declaring Plant in Each Performance Band

Use the following type of rule to declare that the plant is in a particular performance band. The observation time is expressed here in calendar years, treating 7000 critical hours as equivalent to one calendar year. Denote the observation time by t calendar years, and let n be the number of events that occur in a monitoring period of t years.

Estimate the frequency of events, λ, by $\lambda^* = (n + a)/(t + b)$, where a and b are predefined constants. If $a > 0$ and $b > 0$ this is a Bayesian estimate corresponding to a gamma(a, b) prior distribution, with prior mean a/b. The parameters have the intuitive interpretation of a events in time b, prior to the current data.

We consider several choices of a and b:

- a and b correspond to the variability across the industry, as estimated by the initiating-event study (Poloski et al. 1998). The industry mean is a/b, which is also the baseline value used in this study. [In the initiating-event report, several of the relevant Bayes distributions are lognormal. They are converted to gamma distributions here by matching moments. This appears acceptable in this case, because the distributions are not extremely skewed – gamma shape parameters near 0.5 or larger, lognormal error factors smaller than 6.]

- $a = 1/2$ and b is such that a/b equals the industry mean. These are the parameters for the constrained noninformative prior (Atwood 1996), constrained by the mean. This is a generalization of the Jeffreys noninformative prior, corresponding in one formal mathematical sense to knowledge of the mean but ignorance otherwise.
- $a = 0$ and $b = 0$. Then λ^* is the classical maximum likelihood estimate, making no use of prior belief.

The prior distributions considered here are shown in Table F-1. In each case the constrained noninformative prior has a smaller value of a than the industry prior, and therefore a larger variance. The initiating-event report expresses frequencies as events per critical year. They are converted here to per calendar year, assuming 7000 critical hours per calendar year. Therefore, the mean frequencies given here are numerically smaller than those in the report, by a factor of 7000/8760 = 0.8.

Table F-1 Non-zero Prior Distributions Considered for the Initiating Events

Indicator	Type of gamma prior distribution	a	b (cal. years)
Trans.Init., BWR	Industry variability	8.81	6.78
Trans.Init., BWR	Constrained noninformative	0.5	0.385
Trans.Init., PWR	Industry variability	6.59	6.59
Trans.Init., PWR	Constrained noninformative	0.5	0.50
LOFW	Industry variability	0.805	11.85
LOFW	Constrained noninformative	0.5	7.36
LOHS, BWR	Industry variability	23.8	102.6
LOHS, BWR	Constrained noninformative	0.5	2.16
LOHS, PWR	Industry variability	1.11	11.6
LOHS, PWR	Constrained noninformative	0.5	5.23
LOOP	Industry variability	2.0	54.3
LOOP	Constrained noninformative	0.5	13.6

The decision rule is

If $\lambda^* \geq$ GW, the performance indication is white.
If $\lambda^* \geq$ WY, the performance indication is yellow.
If $\lambda^* \geq$ YR, the performance indication is red.

This can be rewritten in terms of cutoffs on the observed number of events, n, in t calendar years.

If $n \geq c_W$, the performance indication is white, where $c_W = (t + b)*\text{GW} - a$.
If $n \geq c_Y$, the performance indication is yellow, where $c_Y = (t + b)*\text{WY} - a$.
If $n \geq c_R$, the performance indication is red, where $c_R = (t + b)*\text{YR} - a$.

In brief, c_X is the number of events that must be seen to declare the performance indication to be in performance band X; because c_X is typically not an integer, the next largest integer must be observed. Table F-2 shows these cutoffs, the numbers of events corresponding to each

performance band, for BWR 3/4 Plant 18. The monitoring periods shown are not the same for all the kinds of initiating events.

Table F-2 Cutoffs for Assigning Performance Bands to BWR 3/4 Plant 18, for Three Decision Rules

Observation time (plant calendar years)	Cutoff [a]								
	Prior from industry variability			Constrained noninformative prior			$a = b = 0$ (cutoffs = expected counts)		
	W	Y	R	W	Y	R	W	Y	R
Transient Initiator									
1	6.8	52.7	512.5	2.3	10.4	92.3	2.0	7.9	67.0
2	8.8	60.6	579.5	4.3	18.3	159.3	4.0	15.8	134.0
3	10.8	68.5	646.5	6.3	26.2	226.3	6.0	23.7	201.0
Loss of Feedwater									
1	3.1	31.3	307.6	2.01	20.4	200.1	0.3	2.5	24.0
2	3.4	33.8	331.6	2.3	22.9	224.1	0.6	5.0	48.0
3	3.7	36.3	355.6	2.6	25.5	248.1	0.9	7.5	72.0
Loss of Heat Sink									
1	18.7	328.4	3395.	0.8	10.2	103.8	0.4	3.4	33.0
2	19.1	331.8	3428.	1.2	13.6	136.8	0.8	6.8	66.0
3	19.5	335.2	3461.	1.6	17.04	169.8	1.2	10.2	99.0
Loss of Offsite Power									
1	0.16	1.2	10.7	0.07	0.3	2.9	0.04	0.06	0.23
2	0.20	1.3	10.9	0.11	0.4	3.1	0.08	0.12	0.46
3	0.23	1.3	11.2	0.15	0.5	3.3	0.12	0.17	0.69
4	0.27	1.4	11.4	0.19	0.5	3.6	0.16	0.23	0.92
5	0.31	1.4	11.6	0.23	0.6	3.8	0.20	0.29	1.15
10	0.51	1.7	12.8	0.42	0.9	4.9	0.39	0.58	2.3
20	0.90	2.3	15.1	0.81	1.4	7.2	0.78	1.16	4.6

a. Declare that the plant is in the corresponding performance zone if and only if the observed number of events is at the cutoff or above.

For example, consider loss of heat sink with three years of monitoring time. The green-white threshold is 0.41 initiators per calendar year. Therefore, the expected count in three years for a GW plant is 1.23 events, shown in the table as 1.2. Two events must be observed in three years for the zero-prior rule to declare the plant white. This is also true if the constrained noninformative prior is used, because the cutoff is 1.6. If instead the industry prior is used, 20 events (the only way to get 19.5 or more) must be observed in three years to declare the plant white.

Note that in many cases, a very large number of events must be observed for a Bayesian rule to declare a yellow or red performance indication. The most extreme example is LOHS with the industry-variability prior. This prior is gamma with shape parameter 23.8 and scale parameter

102.6 calendar years. This distribution has mean 0.25 and standard deviation 0.05. The prior probability of red band performance is the integral of this density from 33 to infinity, and equals 0.0 to the accuracy of SAS calculation. Therefore, it takes over 3000 observed events to overcome the prior distribution and put the indication (the posterior mean) into the red band. This would never happen in practice – plant managers or NRC regulators would intervene first. This illustrates that if the prior distribution makes the red or yellow band incredible, the Bayesian method will not declare that the plant is in that performance band. Nevertheless, the Bayesian method may correctly detect that the plant is worse than green.

LOOP events are too rare to be monitored as a plant-specific indicator. Even if performance is at the yellow-red threshold, it takes nearly five years before a single LOOP event is expected.

Table F-3 shows the same information for WE 4-Lp Plant 22.

Table F-3 Cutoffs for Assigning Performance Bands to WE 4-Lp Plant 22, for Three Decision Rules

Observation time (plant cal. years)	Cutoff [a]								
	Prior from industry variability			Constrained noninformative prior			$a = b = 0$ (cutoffs = expected counts)		
	W	Y	R	W	Y	R	W	Y	R
Transient Initiator									
1	7.1	60.2	585.4	2.2	12.7	116.5	1.8	8.8	78.0
2	8.9	69.01	663.4	4.0	21.5	194.5	3.6	17.6	156.0
3	10.7	77.8	741.4	5.8	30.3	272.5	5.4	26.4	234.0
Loss of Feedwater									
1	9.5	91.7	950.1	6.19	59.7	618.1	0.8	7.2	74.0
2	10.3	98.9	1024.1	6.99	66.9	692.1	1.6	14.4	148.0
3	11.1	106.1	1098.1	7.79	74.1	766.1	2.4	21.6	222.0
Loss of Heat Sink									
1	1.9	17.8	187.9	0.99	8.8	92.9	0.24	1.5	15.0
2	2.2	19.3	202.9	1.2	10.3	107.9	0.48	3.0	30.0
3	2.4	20.8	217.9	1.5	11.8	122.9	0.72	4.5	45.0
Loss of Offsite Power									
1	0.16	1.26	12.9	0.07	0.36	3.4	0.04	0.06	0.27
2	0.20	1.32	13.2	0.11	0.42	3.7	0.08	0.12	0.54
3	0.23	1.38	13.5	0.15	0.48	4.0	0.12	0.18	0.81
4	0.27	1.44	13.7	0.19	0.54	4.3	0.16	0.24	1.08
5	0.31	1.5	14.01	0.23	0.60	4.5	0.20	0.30	1.4
10	0.51	1.8	16.7	0.62	0.89	5.9	0.39	0.59	2.7
20	0.90	2.4	18.1	0.81	1.5	8.6	0.78	1.18	5.4

a. Declare that the plant is in the corresponding performance zone if and only if the observed number of events is at the cutoff or above.

F.2.2 Properties of Rules, as Function of Monitoring Period

How long a monitoring period should be used? A shorter time period gives quicker decisions, but a longer time has smaller probability of a misclassification. To help evaluate the tradeoff, consider now the probability of various misclassifications.

The following false positives and false negatives were judged to be of greatest interest:

- Declare performance white (or worse), if it is truly at baseline – a false positive
- Declare performance green, if it is truly YR – a false negative
- Declare performance green, if it is truly WY – a false negative

In every case, the true state of the plant is separated from the declared state, although in the first case the separation is small if the baseline is close to the green-white threshold. Of the two false negatives, the first is a particular instance of "declare performance green if it is red," because YR is one of the possible values in the red band. This false negative may have very small probability for many decision rules, and may not lead to a good way of selecting a decision rule. Therefore, the second false negative is also considered.

The probability of a false positive or false negative will be written using the notation for conditional probability, and abbreviated as follows:

- Pr(W | baseline) = Pr(declare performance white or worse, if it is truly at baseline)
- Pr(G | YR) = Pr(declare performance green, if truly at the yellow-red threshold)
- Pr(G | WY) = Pr(declare performance green, if truly at the white-yellow threshold)

In terms of the number of events in the observation time, the above misclassification probabilities are:

- Pr(W | baseline) = Pr(observe c_W or more events | frequency = baseline)
- Pr(G | YR) = Pr(observe fewer than c_W events | frequency = YR)
- Pr(G | WY) = Pr(observe fewer than c_W events | frequency = WY)

These numbers are easily calculated using the Poisson distribution. The Poisson distribution is commonly used for modeling event counts. It arises whenever:

- events occur with a constant frequency
- the event count in one time period is independent of the event count in any nonoverlapping period
- exactly simultaneous events do not occur (that is, common-cause events can be ignored)

The calculation is illustrated for Pr(W | baseline) for loss of heat sink at Quad Cities, with 3 years of observation, and use of the constrained noninformative prior. Let N denote the random number of transients involving loss of heat sink that might occur.

$$
\begin{aligned}
\Pr(W \mid \text{baseline} &= \Pr(\text{declare performance white or worse} \mid \text{true frequency} = \text{baseline}) \\
&= \Pr(N > 1.6 \mid \lambda = 0.232,\ t = 3) && \text{from Table F-2} \\
&= \Pr(N \,{}^{3}\, 2 \mid \lambda t = 0.696\ ) \\
&= 1 - \Pr(N < 2 \mid \lambda t = 0.696\ ) \\
&= 1 - e^{-0.696}[0.696^{0}/0! + 0.696^{1}/1!] && \text{by the formula for Poisson probabilities} \\
&= 0.154
\end{aligned}
$$

Calculations for the other cases are similar.

F.2.3 Choice of a Rule and a Monitoring Period

To choose an appropriate rule and monitoring period, the following criteria were used:

$$
\begin{aligned}
&\Pr(\ W \mid \text{baseline}\ ) \le 0.20 \\
&\Pr(\ G \mid YR\ ) \le 0.05 \\
&\Pr(\ G \mid WY\ ) \le 0.10\ .
\end{aligned}
$$

These three probability criteria were chosen for the following reasons. One very important characteristic of RBPIs is that they must not indicate green performance when the RBPI is actually performing at the red level (an unacceptable level of performance). This is termed a false-negative misclassification. Therefore, the probability criterion for this characteristic was chosen to be a very low value, 0.05. This criterion implies that if the RBPI is actually performing at the level of the YR interface, then there is less than a 0.05 probability that the RBPI performance evaluation will indicate green. However, it was found during the statistical analysis that this criterion generally did not distinguish between the rules and monitoring periods evaluated. (This criterion is generally easy to meet.) Therefore, a second, similar criterion was added, that of indicating green when the RBPI performance is actually at the WY interface. Because this type of false-negative misclassification is not as important as the green indication when performance is at the YR interface, a higher misclassification probability was used, 0.10. Finally, another important characteristic of RBPIs is that they should not indicate white performance when the RBPI is actually at baseline (green) performance. This criterion can be difficult to meet if the GW threshold is close to the baseline performance level, which is often the case for some RBPIs. Therefore, a 0.20 probability was chosen for this false-positive criterion.

The approach used was to select the prior distribution that satisfied all three criteria in the shortest monitoring period. Monitoring periods of from one to five years were considered.

Sometimes the criteria on the false negatives could not be met with a monitoring period of up to five years. This was the case for LOOP. In such a case, no RBPI was defined. That kind of initiating event will be treated by other means.

Sometimes, on the other hand, the two criteria on false negatives were met, but the criterion on false positives could not be met. This is the case when the baseline and the green-white threshold are very close together, but the other thresholds are farther apart. In this case, an RBPI rule and a monitoring period were selected, but it was recognized that false positives are relatively frequent, and a declaration of white should not be regarded as definitive. To quantify

the departure from greenness, a supplementary probability was calculated. For example, suppose that two events occurred, and that this was enough to declare performance white. The probability

Pr(two or more events | baseline)

was calculated, to indicate the likelihood of observing such data even when performance is at baseline. If this probability is large, then the observed data are consistent with baseline performance, and there is a significant possibility that this indication is a false positive. If instead the probability is small, then the data are not consistent with baseline performance, and the declaration of white should be regarded more seriously.

Calculated misclassification probabilities, for various priors and monitoring periods, are shown in Section F.6.

F.3 Mitigating Systems

F.3.1 Unreliability

F.3.1.1 Decision Rules

Because some systems have diverse trains, it was decided to base the decision rules on trains, not systems. Even for a train, however, the unreliability depends on several parameters. For example, pump failure to start, pump failure to run, and valve failure to open are distinct train failure modes, corresponding to distinct parameters p_{FTS}, λ_{FTR}, and p_{FTO}.

This multiplicity of parameters has the following consequence. Different combinations of parameters can result in the same CDF, but different train unreliabilities. This occurs, for example, in a multiple train system when the different failure modes have different susceptibility to common-cause failures. Nevertheless, for simplicity of presentation, it was decided to base the RBPI on train unreliability. Examination of the cutsets in the SPAR model allowed the train unreliability to be expressed as a simple algebraic function of the parameters. The base calculation was made assuming that Pr(FTS), Pr(FTR during the PRA mission), and any other parameters were each above their baseline values by the same multiplicative factor. This gave values of the parameters for ΔCDF = 1.E-6, 1.E-5, and 1.E-4. The corresponding threshold train unreliabities were then found, using the previously found algebraic function. The decision rule then was based on monitoring the plant and collecting data, estimating the parameters, calculating the corresponding estimate of train unreliability, and comparing this estimate to the previously calculated thresholds.

F.3.1.2 Performance of Decision Rules

Several misclassification probabilities then had to be calculated. For example, consider the calculation of Pr(G | YR). The plant is assumed to be at the YR threshold, but this can occur in many ways – various combinations of the parameters can result in ΔCDF = 1.E-4. For example, suppose that the train has three failure modes that are monitored, so three parameters to be considered. Then four sets of assumptions were made. First, it was assumed that exactly one of

the three parameters was high and that the others remained at their baseline values. This gave three sets of assumptions, one set for each selected parameter. Finally, it was assumed that all the parameters were above their baseline values by the same multiplicative factor. For each of these four sets of assumptions, the probability that the plant would be declared green was found. This gave four values for Pr(G | YR). All of these probabilities should be acceptably small if the decision rule and corresponding monitoring period are to be used.

The actual calculation of the misclassification probabilities was performed by Monte Carlo simulation, as follows. One of the above sets of assumptions was made, defining the parameter values. A monitoring period was assumed, giving an assumed total number of demands and running hours for all the similar trains at the plant under consideration. Random "data" were then generated using a random number generator. For example a number of failures to start in the plant's assumed number of demands was randomly generated, as was a number of failures to run in the plant's assumed hours. From these data, the Bayesian estimates of the parameters were constructed. These estimates were plugged into the algebraic formula to calculate estimated train unreliability. The estimated unreliability was compared with the thresholds, and performance was assigned to the appropriate performance band. If the assumption was that performance was at YR, and the "data" resulted in a classification of green, this was a misclassification. The process was repeated many times, with many randomly generated "data" sets. The true probability, Pr(G | YR), was estimated as the fraction of times that misclassifications occurred. When 400,000 "data" sets were used, the estimated misclassification probability was accurate except perhaps in the third significant digit.

Some calculated misclassification probabilities, for various priors and monitoring periods, are shown in Section F.6.

Just as discussed above for initiating events, for some mitigating systems the desired misclassification probabilities could not be achieved. If the criteria on false negatives were not met, industry trending was recommended.

In some cases the criterion on false positives could not be met, because the GW threshold is very close to the baseline. Therefore, a supplementary probability was calculated as follows. First, the estimated train unreliability was calculated; for this discussion, call the value $UR_{est.}$ If $UR_{est.}$ was larger than GW, performance was declared white. Then the probability was found of getting data that would produce a value this large or larger, if in fact performance were at the baseline level. Conceptually, we considered all possible data sets (for example, possible counts of failures to start in the monitored number of demands and of failures to run in the monitored number of hours) that could have been obtained. We then noted which ones would result in an estimated train unreliability as large as $UR_{est.}$ or larger. We then calculated the total probability of those data sets, assuming that performance was at the baseline level. If this probability is large, it means that the observed data could easily arise when performance is at the baseline level. If the probability is small, on the other hand, it means that the observed data are inconsistent with the baseline probabilities. This probability, a "p-value" for testing whether the plant is at baseline, was reported along with the declaration that the plant is white.

F.3.2 Unavailability

The general method is illustrated here by the emergency power (EP) and reactor core isolation cooling (RCIC) systems at BWR 3/4 Plant 18.

The WANO EDG data for planned and unplanned unavailability were studied, covering the last quarter of 1995 through the first two quarters of 1999, 45 months at 71 sites. The data were taken from recent electronic files, similar to those described by INPO (1996). The observed unavailability for each site was computed as:

(planned outage EDG-hours + unplanned outage EDG-hours)/(total required EDG-hours).

The observed variability varied greatly across the industry, from 2.5E-4 for BWR 123 Plant 3 to 2.9E-2 for WE 2-Lp Plant 3. The 5th and 95th percentiles (4th and 68th ranked sites) differed by a factor of 9.

Likewise, the WANO RCIC data were studied over the same time period, at 20 BWR units. The observed unavailability for each unit was computed as:

(planned outage RCIC-hours + unplanned outage RCIC-hours)/(total required RCIC-hours).

The observed variability varied greatly, from 3E-3 at BWR 3/4 Plant 4 to 5.6E-2 at BWR 5/6 Plant 3. The 5th and 95th percentiles (2nd and 29th ranked units) differed by a factor of 12.5.

Quick examination of data for other systems revealed similar variation among units. Therefore, we decided that only site-specific data were appropriate for estimating the variability of outage data at a plant. Site-specific, rather than plant-specific, data seemed acceptable, because for most systems the differences between plants at a single site were small. The calculations are illustrated below for EDGs and RCIC at BWR 3/4 Plant 18.

At BWR 3/4 Plant 18, data on required EDG hours were present for 126 EDG-months (3 EDGs, 45 months, with data missing for one calendar quarter) and data on outages were present for 125 EDG-months (for the above 126 EDG-months, outage data was missing for one case). The observed outage hours did not follow any simple distribution; 38% of the values were zero, and the largest value was 107 hrs. Similarly, the required hours did not follow any simple distribution; for three fourths of the EDG-months, the EDG was expected to be available for the entire calendar time, but there was one case when an EDG was expected to be available only 1.8 hours. Therefore, we did not model these distributions by simple parametric distributions such as lognormal or beta, but instead treated the observed values as the exact discrete distribution.

Similarly, at BWR 3/4 Plant 18, data on RCIC required hours were present for 84 RCIC months (2 RCIC systems, 45 months, with data missing for one calendar quarter). The reactor was too cold for the RCIC system to operate at all during 19 of those months, so there were 65 calendar months when the system was expected to be available for at least part of the month.

For EDGs we simulated from the observed distribution of required hours by making many copies of this data set of 126 records, and then putting the values of each variable in random order. Similarly, we made many copies of the 125 outage values and put them in random order. This gave 2,048,000 pairs (outage hours, required hours), with the values randomly paired. Table F-4 shows records 100-110 of this data set. Note that for most records the outage hours are smaller than the required hours. For record 108, however, the random pairing resulted in outage hours that are greater than the required hours. Such cases are unusual – record 108 is the first such occurrence in the data set.

Table F-4 Selected Records from the Constructed EDG Data Set

Record number	Outage hours	Required hours
100	9.5	744
101	0.0	745
102	0.0	720
103	2.7	179
104	0.0	720
105	0.0	744
106	0.0	744
107	0.0	206
108	2.1	1.8
109	42.6	744
110	2.2	720

The same method was used to simulate RCIC unavailability data.

To simulate GW, WY, or YR, we multiplied the outage hours by a factor, called a *multiplier* in the discussion here. Whatever multiplier was tried, the same multiplier was used for every record in the data set of about two million pairs. For any record, if the resulting outage hours (= original outage hours times the multiplier) were more than the required hours, the outage hours for that record were reduced to the required hours. The unavailability was then calculated, as the total outage hours divided by the total required hours. Trial and error found that the multipliers led to the corresponding unavailabilities shown in Table F-5.

Table F-5 Multipliers to Produce Selected Unavailabilities in Simulated Data

EDG		RCIC	
Multiplier	Resulting Unavailability	Multiplier	Resulting Unavailability
1.0	0.0123	1.0	0.00760
2.87	0.0350 (=GW)	2.91	0.0220 (=GW)
5.64	0.0680 (=WY)	19.8	0.120 (=WY)
133.6	0.4000 (=YR)		

The multiplier of 1.0 should produce an unavailability of 0.0125 for EDGs and 0.00766 for RCIC, the unavailabilities seen in the data. Instead, it produces slightly smaller unavailabilities because some of the random pairings gave outage times greater than the required times, and those outage times were reduced.

The next task was to estimate the probability of misclassification, assuming that the true unavailability was at one of the thresholds. Therefore, we applied the appropriate multiplier to the data, so that the overall unavailability was equal to the threshold of interest. We then treated the records as sequential months for one EDG train or one RCIC system, and calculated the total outage hours and required hours during various time periods such as 12 months. For example, each 12-record subset of the data gave a simulated observed unavailability for one year. Based on the many time periods, such as the nonoverlapping 12-month periods, that occurred in the data set of approximately two million months, we found the fraction of times when the observed unavailability fell above or below the various thresholds.

Results are shown in Section F.6.

F.4 Component Classes

A *component class* consists of all components of a particular type, such as all turbine-driven pumps, or all motor-operated valves in selected systems. The individual components in a component class may have different parameters or mission times. If the parameters or mission times differed greatly between systems, so that the components had widely varying baseline unreliabilities, a different approach would be required. However, in each group considered the components have similar unreliabilities. Therefore, the thresholds used are based on the *typical* component unreliabilities. This is the same approach as used above for identical trains, only now the component unreliabilities are used instead of the train unreliabilities.

Only unreliability is considered for component classes, not unavailability. This is because an appropriate way to analyze unavailability is not clear.

F.5 Trending

If the data are too sparse for trustworthy RBPIs, an alternative is to trend data from the industry as a whole. One must then decide exactly what should be measured for trending. This section discusses ways to make the trending portion of the effort consistent with the plant-specific monitoring portion.

For a class of initiating events (such as LOOP events), the Bayes estimate of the event frequency is calculated for each year, using a prior distribution related to historic industry performance and using the data from the entire industry for the year. The approach was chosen to keep the presentation consistent with the other RBPIs.

The rules used for plant-specific RBPIs for unreliability of mitigating systems are based on estimated unreliability. Therefore, for consistency of presentation, any industry unreliabilities that are trended are treated in a similar way. The train unreliability is estimated, using a prior distribution related to historic industry performance and a Bayesian estimate based on all the data from all the plants (or all the plants from a portion of the industry, such as the PWRs or the BWRs, if more appropriate). A value is calculated based on each year's data, and the values are plotted.

F.6 Results for Decision Rules and Data Collection Intervals

This section summarizes the performance of the various decision rules and monitoring periods. Detailed results are given for one initiating event, illustrating the method. A later table summarizes the conclusions from examination of the full results for all initiating events, mitigating systems, and component classes.

Table F-6 shows the misclassification probabilities for loss-of-heat-sink initiating events, for monitoring periods from one to five years. The calculations were performed for two plants, WE 4-Lp Plant 22 and BWR 3/4 Plant 18. The recommended rule and monitoring period is **highlighted**. This is the rule that satisfies, in the shortest time, the three constraints on the misclassification probabilities listed in Section F-2.3.

Table F-6 Misclassification Probabilities for Loss-of-Heat-Sink (LOHS) Initiating Events

Baseline and Threshold Values

Site	Baseline	G-W Threshold DCDF = 1.0E-6/y	W-Y Threshold DCDF = 1.0E-5/y	Y-R Threshold DCDF = 1.0E-4/y
WE 4-Lp Plant 22	0.096/y (PWR average)	0.24/y	1.5/y	15/y
BWR 3/4 Plant 18	0.23/y (BWR average)	0.41/y	3.4/y	33/y

Data Rule and Data Collection Interval Selection

One-Year Data Collection Interval Results

Data Rule	Predicted/Baseline (No Events During Data Collection Interval)	Misclassification Probability (G|YR) (P < 0.05)	Misclassification Probability (G|WY) (P < 0.10)	Misclassification Probability (W|Base) (P < 0.20)
Zero prior	0.00 (0.00)[a]	0.000 (0.000)	0.223 (0.033)	0.091 (0.207)
Constrained	0.84 (0.68)	0.000 (0.000)	0.223 (0.033)	0.091 (0.207)
Industry prior	0.92 (0.99)	0.000 (0.003)	0.558 (1.000)	0.004 (0.000)

	Number of Events Required During Data Collection Interval to Exceed Threshold		
Data Rule	G-W	W-Y	Y-R
Zero prior	1 (1)[a]	2 (4)	15 (33)
Constrained	1 (1)	9 (11)	93 (104)
Industry prior	19 (9)	18 (329)	188 (3395)

a. Format is: result for WE 4-Lp Plant 22 (result for BWR 3/4 Plant 18)

Two-Year Data Collection Interval Results

Data Rule	Predicted/Baseline (No Events During Data Collection Interval)	Misclassification Probability (G|YR) (P < 0.05)	Misclassification Probability (G|WY) (P < 0.10)	Misclassification Probability (W|Base) (P < 0.20)
Zero prior	0.00 (0.00)[a]	0.000 (0.000)	0.050 (0.001)	0.174 (0.371)
Constrained	0.72 (0.52)	0.000 (0.000)	0.199 (0.009)	0.016 (0.079)
Industry prior	0.85 (0.98)	0.000 (0.000)	0.423 (1.000)	0.001 (0.000)

Table F-6 (Continued)

	Number of Events Required During Data Collection Interval to Exceed Threshold		
Data Rule	G-W	W-Y	Y-R
Zero prior	1 (1) [a]	3 (7)	30 (66)
Constrained	2 (2)	11 (14)	108 (137)
Industry prior	3 (20)	20 (332)	203 (3428)

a. Format is: result for WE 4-Lp Plant 22 (result for BWR 3/4 Plant 18)

Three-Year Data Collection Interval Results

Data Rule	Predicted/Baseline (No Events During Data Collection Interval)	Misclassification Probability (G|YR) (P < 0.05)	Misclassification Probability (G|WY) (P < 0.10)	Misclassification Probability (W|Base) (P < 0.20)
Zero prior	0.00 (0.00) [a]	0.000 (0.000)	0.011 (0.000)	0.249 (0.154)
Constrained	**0.63 (0.42)**	**0.000 (0.000)**	**0.061 (0.000)**	**0.034 (0.154)**
Industry prior	0.79 (0.97)	0.000 (0.000)	0.174 (0.996)	0.003 (0.000)

	Number of Events Required During Data Collection Interval to Exceed Threshold		
Data Rule	G-W	W-Y	Y-R
Zero prior	1 (2) [a]	5 (11)	45 (99)
Constrained	**2 (2)**	**12 (18)**	**123 (170)**
Industry prior	3 (20)	21 (336)	218 (3461)

a. Format is: result for WE 4-Lp Plant 22 (result for BWR 3/4 Plant 18)

Four-Year Data Collection Interval Results

Data Rule	Predicted/Baseline (No Events During Data Collection Interval)	Misclassification Probability (G|YR) (P < 0.05)	Misclassification Probability (G|WY) (P < 0.10)	Misclassification Probability (W|Base) (P < 0.20)
Zero prior	0.00 (0.00) [a]	0.000 (0.000)	0.002 (0.000)	0.318 (0.237)
Constrained	0.57 (0.35)	0.000 (0.000)	0.017 (0.000)	0.057 (0.067)
Industry prior	0.74 (0.96)	0.000 (0.000)	0.062 (0.939)	0.007 (0.000)

	Number of Events Required During Data Collection Interval to Exceed Threshold		
Data Rule	G-W	W-Y	Y-R
Zero prior	1 (2) [a]	6 (14)	60 (132)
Constrained	2 (3)	14 (21)	138 (203)
Industry prior	3 (20)	23 (339)	233 (3494)

a. Format is: result for WE 4-Lp Plant 22 (result for BWR 3/4 Plant 18)

Five-Year Data Collection Interval Results

Data Rule	Predicted/Baseline (No Events During Data Collection Interval)	Misclassification Probability (G|YR) (P < 0.05)	Misclassification Probability (G|WY) (P < 0.10)	Misclassification Probability (W|Base) (P < 0.20)
Zero prior	0.00 (0.00) [a]	0.000 (0.000)	0.005 (0.000)	0.084 (0.111)
Constrained	0.51 (0.30)	0.000 (0.000)	0.005 (0.000)	0.084 (0.111)
Industry prior	0.70 (0.95)	0.000 (0.000)	0.020 (0.805)	0.013 (0.000)

Table F-6 (Continued)

	Number of Events Required During Data Collection Interval to Exceed Threshold		
Data Rule	G-W	W-Y	Y-R
Zero prior	2 (3))[a]	8 (17)	75 (165)
Constrained	2 (3)	15 (24)	153 (236)
Industry prior	3 (21)	24 (343)	248 (3527)

a. Format is: result for WE 4-Lp Plant 22 (result for BWR 3/4 Plant 18)

Summary

Using the misclassification probability limits shown in the tables for G|YR, G|WY, and W|Base, the constrained, non-informative prior and a three-year data collection interval are appropriate for the LOHS RBPI.

Two sites, BWR 3/4 Plant 18 and WE 4-Lp Plant 22, were used for the study of most decision rules and monitoring periods. The unreliabilities of mitigating systems and component classes were more complex, and the results seemed more variable, than for initiating events or unavailabilities. Therefore, two additional sites were used for unreliability: BWR 5/6 Plant 2 and CE Plant 2.

Some of the plants have not reported demands for some components of some systems. For those systems at those plants, data could not be simulated and misclassification probabilities could not be found. Table F-7 shows the mitigating systems and component classes that were studied, and the failure modes that were modeled.

F.7 References

Atwood, C. L., 1996, "Constrained Noninformative Priors in Risk Assessment," *Reliability Engineering and System Safety*, Vol. 53, pp. 37-46.

Poloski, J. P., et al., 1998, *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987-1995*, NUREG/CR-5750, INEEL/EXT-98-00401.

INPO, 1996, "World Association of Nuclear Operations (WANO) Performance Indicator Program Utility Data Coordinator Reference Notebook," INPO 96-003, Institute of Nuclear Power Operations, September 1996.

Table F-7 Plants and Systems Examined for Misclassification Probabilities

	BWR 3/4 Plant 18	WE 4-Lp Plant 22	BWR 5/6 Plant 2	CE Plant 2
EP	no run hours reported	FTS, FTLR, FTR	FTS, FTLR, FTR	FTS, FTLR, FTR
HPCI, HPCS, HPI	no run hours reported (HPCI)	not analyzed – yellow not reached	FTS, FTR, FTO (inj. valve), no other valves (HPCS)	FTS, FTR (HPI)
RCIC	Unit 2: FTS, FTR, FTO	—	FTS, FTR, FTO	—
AFW motor train	—	FTS, FTR	—	FTS, FTR
AFW turbine train	—	FTS, FTR	—	FTS, FTR
RHR	no run hours reported	FTS, FTR, no valves	FTS, FTR, no valves	FTS, FTR, no valves
AOVs	no demand data	FTO/C	FTO/C	FTO/C
MOVs	FTO/C	FTO/C	FTO/C	FTO/C
MDPs	FTS, FTR	FTS, FTR	FTS, FTR	FTS, FTR

A summary of the results is given in Table F-8.

Table F-8 Recommended Decision Rules and Data Collection Intervals

RBPI	Prior Distribution	Data Collection Interval	Comments
Initiating Event			
GT	Constr. Noninf.	1 year	
LOHS and LOFW	Constr. Noninf.	3 years	For LOFW, 1 year with a zero-prior rule could also have been chosen
Mitigating System			
Unavailability	Zero prior	1 year	Given the format of the unavailability data, only a non-Bayesian decision rule was evaluated (Sec. F-3.2).
Unreliability	Constr. Noninf.	3 years	In general, the unreliability RBPIs do not meet all three misclassification probability goals. They almost always meet the goal of Pr(G|YR) < 0.05, generally do not meet the goal of Pr(G|WY) < 0.10, and several do not meet the goal of Pr(W|baseline) < 0.20. Therefore, for cases where a white color is indicated, the probability of observing that performance, given that the plant is still at baseline, is also printed.
Component Class	Constr. Noninf.	3 years	Same comments as those listed for mitigating system unreliability.

Appendix G
Development of Risk-Based Performance Indicators: Program Overview

Technical Proposal

1. UNDERSTANDING OF THE PROBLEM AND TECHNICAL APPROACH

The NRC is in the process of reevaluating the exemptions from licensing in 10 CFR Parts 30 and 40, including the requirements for distributors of material and products containing byproduct material to exempt persons in Subpart A of 10 CFR Part 32.

2. OBJECTIVE

The purpose of this task order is to provide technical assistance and support to provide the basis for determination of need for and best approach to rulemaking to modify or revoke exemptions from licensing as well as limited additional issues related to risk-informed, performance-based regulations. Addtionally, assistance will be provided, if needed, to develop the resulting proposed rule(s) concerning byproduct material, including preparation of supporting documents and analysis of public comments.

3. SCOPE OF WORK

ICF will provide the requested support through the following activities:

Subtask A: Recommendations for Rulemaking

In this task, ICF will develop recommendations for rulemaking, including a cost-benefit analysis, in the area of exemptions from licensing in 10 CFR Part 30. Cost-benefit analyses will be performed for fourteen issues as follows:

1. Manufacturer's Modification of Product Without Prior NRC Approval
2. Revise prescriptive requirements for distributors of generally licensed devices such as prototype testing, sampling procedures, and quality control procedures.
3. ALARA
4. Welding Rods- § 40.13(c)(1)(iii)
5. Glassware Containing Not More than 10% Source Material - § 40.13(c)(2)(iii)
6. Gas Mantles Containing Thorium- § 40.13(c)(1)(i)
7. Exempt concentrations - § 30.14
8. Class Exemptions for Self-luminous Products and Gas and Aerosol Detectors
9. Establish a New Class Exemption for Certain Industrial Products
10. Exempt Quantities - § 30.18
11. When Does Part 20 Apply to the Use of "Exempt" Materials and Products by Specific Licensees?
12. Optical Lenses containing up to 30% by weight thorium - § 40.13(c)(7)
13. Depleted Uranium in Aircraft Counterweights - § 40.13(c)(5)

14. Finished Tungsten- or Magnesium-Thorium Alloy Products or Parts - § 40.13(c)(4) and Aircraft Engine Parts containing Nickel-Thoria Alloy - § 40.13(c)(8)

Deliverables for Subtask A

Draft cost-benefit analyses	Delivered to the NRC Technical Project Manager individually as completed, with all to be completed by June 15, 2001.
Revised draft analyses	Due two weeks after receipt of NRC comments on individual analyses.

4. KEY PERSONNEL

ICF is proposing the following key personnel, including subcontractors from ISL, Inc.

Mr. Paul Bailey

Mr. Craig Dean

Mr. Kevin Blake

Dr. James Meyer

Ms. Kim Green

Mr. Christopher Smith

5. CERTIFICATION ON CURRENT/FORMER NRC EMPLOYEES

No current or NRC Employees have been or will be involved, directly or indirectly, in developing this proposal, or in negotiating on behalf of ICF Incorporated, or in managing, administering, or performing any contracts, consulting agreements, or subcontracts resulting from this proposal.

6. CERTIFICATION ON POTENTIAL CONFLICT OF INTEREST ISSUES

I represent, to the best of my knowledge and belief that the award to ICF Consultants under Task Order No. 006, Contract No. NRC-02-00-003 does not involve situations or relationships of the type set forth in 41 CFR 20-1.5403(b)(1).