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Baseline Risk Index for Initiating Events (BRIIE)

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ABSTRACT

This report summarizes an effort to enhance the U.S. Nuclear Regulatory Commission Industry Trends Program in the area of initiating events. The proposed enhancement is termed the Baseline Risk Index for Initiating Events (BRIIE). The BRIIE includes two tiers. Tier 1 involves the monitoring of individual initiating events at the industry level against performance-based prediction limits, while Tier 2 involves an integrated, risk-informed indicator at the industry level that combines the risks from individual initiating events. Technical bases for decisions made in the development of the BRIIE are also presented, as well as historical results at both the Tier 1 and Tier 2 levels.

FOREWORD

This report documents the bases for the Baseline Risk Index for Initiating Events (BRIIE) under the U.S. Nuclear Regulatory Commission's (NRC's) Industry Trends Program (ITP). BRIIE is an integrated industry-level initiating event performance indicator that is risk informed. Performance-based limits are also included for individual initiating events. The report documents the selection of initiating events for monitoring, identification of risk-informed weights for these initiating events (Birnbaum importance measures), determination of performance-based limits for individual initiating events (at the industry level), and selection of a risk threshold for reporting purposes. Reasons for developing the BRIIE and the development process are outlined below.

NRC oversees plant safety performance for individual plants using both inspection findings and plant-specific performance indicators as part of its Reactor Oversight Process. NRC staff address individual issues that have generic safety significance using other processes, including the generic communications process and the generic issue process. As discussed in SECY-01-0111, "Development of an Industry Trends Program for Operating Power Reactors," the NRC's Office of Nuclear Reactor Regulation (NRR) initiated the ITP in 2001 to complement these processes. NRR uses the ITP to monitor and assess industry-level trends in safety performance. As indicated in the SECY, NRR recognized the need to investigate alternative performance indicators that are more risk informed and more integrated than those initially included in the ITP. Such enhancements allow for more accurate and transparent evaluations of risk implications of adverse trends. In addition, if lower-level results are integrated at a higher level, the enhancements lead to fewer indicators. This stated need led to user need requests to the NRC's Office of Nuclear Regulatory Research, asking for support in this area.

This report outlines a three-step process to enhance the ITP coverage of the Initiating Events Cornerstone of Safety. The Initiating Events Cornerstone of Safety was chosen for this development effort because of its importance to risk and the availability of industry-wide data for a variety of initiating events. The first step was to identify an appropriate set of risk-significant initiating events. The BRIIE covers nine initiating events applicable to boiling water reactors (BWRs) and ten applicable to pressurized water reactors (PWRs). The second step was to establish performance-based prediction limits for each initiating event. The third and final step was to develop an integrated, risk-informed indicator by combining the individual initiating event information.

The Tier 1 activity under the BRIIE involves monitoring yearly industry performance of risk-significant initiating events against prediction limits. To accomplish this, the staff established up-to-date baseline frequencies for each of the risk-significant initiating events. The staff then determined performance-based prediction limits using these baseline frequencies and estimated yearly industry reactor critical years of operation. If a prediction limit (number of events within a year) is exceeded, it indicates that industry performance has degraded relative to baseline performance. Data for these initiating events (numbers of event occurrences and corresponding reactor critical years) are already being collected and analyzed by NRC on a continual basis, so no additional data collection is needed to support the Tier 1 activity.

Yearly evaluation of the integrated performance indicator provides the BRIIE Tier 2 coverage of the Initiating Events Cornerstone of Safety. This Tier 2 activity evaluates the risk significance of changes in industry initiating event performance (the results of the Tier 1 activity). Risk significance is evaluated in terms of estimated change in core damage frequency (CDF). Birnbaum importance measures provide the appropriate risk-informed weights for the various initiating event performance changes.

Using the BRIIE Tier 2 integrated indicator, NRC staff are able to combine changes in initiating event frequency performance from a number of initiators into a single risk measure at the cornerstone of safety level. Results of this evaluation will help the ITP communicate industry-level information to Congress and other stakeholders in an effective and timely manner.

As described in this report, BRIIE enhances the existing ITP coverage of initiating events as follows:

- Expands initiating event coverage from several to nine BWR and ten PWR initiating events, which expands the CDF risk coverage of internal events from less than 20% to approximately 60%
- Eliminates the overlap of initiating event indicators
- Provides performance-based prediction limits for each of the initiating events (BRIIE Tier 1)
- Converts the current performance of the individual initiating events into an integrated risk measure (approximating changes in CDF) to assess the risk significance of changes in BWR and PWR initiating event performance (BRIIE Tier 2)
- Provides a threshold of risk significance for the integrated risk measure.

The BRIIE will be implemented following the process outlined in the *NRC Inspection Manual*, Manual Chapter 0313, “Industry Trends Program.”

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The Baseline Risk Index for Initiating Events (BRIIE) described in this document is an enhancement to the Industry Trends Program (ITP) in the Initiating Events Cornerstone of Safety. The BRIIE enhances the ITP coverage of initiating events by the following:

- Expanding initiating event coverage from several to nine boiling water reactor (BWR) and ten pressurized water reactor (PWR) initiating events, which expands the core damage frequency (CDF) risk coverage from internal events from less than 20% to approximately 60%
- Eliminating overlapping of initiating event indicators
- Providing performance-based prediction limits (yearly numbers of events) for each of the initiating events (BRIIE Tier 1) that, if reached or exceeded, indicate potential degradation of industry performance
- Assembling the individual initiating event current performance along with Birnbaum importance measures into an integrated risk measure (approximating CDF) that can be used to assess the risk significance of changes in BWR and PWR initiating event performance (BRIIE Tier 2)
- Providing a threshold of risk significance for the integrated risk measure.

Existing U.S. Nuclear Regulatory Commission (NRC) programs provide the yearly initiating event data and the Birnbaum importance measures needed for the BRIIE, so no additional data collection is needed. At present the BRIIE addresses only internal event CDF, and does not include external events or large early release frequency. The following provides an introduction to the ITP and the development of the BRIIE.

NRC provides oversight of plant safety performance on a *plant-specific* basis using both inspection findings and plant-level performance indicators as part of its Reactor Oversight Process (ROP). Public health and safety assurance is divided into three strategic performance areas: reactor safety, radiation safety, and safeguards. These areas are subdivided into seven cornerstones of safety: initiating events, mitigating systems, barrier integrity, emergency preparedness, public radiation safety, occupational radiation safety, and physical protection. Individual issues that are identified as having generic safety significance are addressed using other NRC processes, including the generic communications process and the generic issue process.

As discussed in SECY-01-0111, "Development of an Industry Trends Program for Operating Power Reactors," the NRC's Office of Nuclear Reactor Regulation initiated the ITP in 2001 to complement these processes by monitoring and assessing *industry-level* trends in safety performance. The purposes of the ITP are to provide a means to confirm that the nuclear industry is maintaining the safety performance of operating reactors and, by clearly demonstrating that performance, to enhance stakeholder confidence in the efficacy of the NRC's processes. Objectives of the ITP are the following:

- Collect and monitor industry-wide data that can be used to assess whether the nuclear industry is maintaining the safety performance of operating plants and to provide feedback on the ROP.
- Assess the safety significance and causes of any statistically significant adverse industry trends, determine if the trends represent an actual degradation in overall industry safety performance, and respond appropriately to any safety issues that may be identified.
- Communicate industry-level information to Congress and other stakeholders in an effective and timely manner.
- Support the NRC's performance goal of ensuring safety while enhancing public confidence in the agency's regulatory process.

From SECY-06-0076, current uses of the ITP results include the following:

- Annual results are reported to Congress in the NRC's Performance and Accountability Report Fiscal Year 200X (NUREG-1542 series) and Budget Estimates and Performance Plan Fiscal Year 200X (NUREG-1100 series). These reports indicate whether NRC has met the performance goal of "no statistically significant adverse industry trends in safety performance."
- ITP results are posted on the NRC public website.
- ITP results are a key element reviewed by senior NRC management in the Agency Action Review Meeting (AARM).
- ITP results are reported to the Commission in an annual report coinciding with the AARM.
- The Commission uses ITP results to present the status of industry performance to NRC's oversight committees and at major conferences with industry.
- NRC managers use ITP results in presentations to industry, such as the NRC's Regulatory Information Conference.

Additional information on the ITP and how enhancements to the program will be incorporated can be found in the *NRC Inspection Manual*, Manual Chapter 0313, "Industry Trends Program."

Current ITP performance indicators have both strengths and weaknesses. Strengths include availability of historical results, continuity and consistency in yearly evaluations, and broad coverage of the cornerstones of safety. However, weaknesses in the Initiating Events Cornerstone of Safety include (1) overlapping coverage for certain cornerstones, (2) limited risk coverage, and (3) difficulties in interpreting the risk significance of significant adverse trends.

To enhance the ITP coverage of the Initiating Events Cornerstone of Safety, a three-step process was used. The first step identified appropriate initiating events included in the standardized plant analysis risk (SPAR) models. Table ES-1 lists the initiating events chosen. These are risk-significant and monitorable at the plant-type or industry level (i.e., they have occurred in the last 15 years). Also shown in Table ES-1 are the existing ITP performance indicators covering initiating events.

The second step developed performance-based prediction limits for these individual initiating events (BRIIE Tier 1). The prediction limits, listed in Table ES-2, are performance based and include both aleatory uncertainty (the randomness of the event count in the future year) and epistemic uncertainty (lack of perfect knowledge of the value of the baseline frequency). They represent upper limits of initiating event counts in a year that, if reached or exceeded, indicate a potential degradation in plant-group or industry performance. In recent years, these prediction limits were exceeded twice. In fiscal year (FY) 2003, the loss of offsite power (LOOP) event count was 12, which exceeded the prediction limit of eight listed in Table ES-2. However, eight of the 12 LOOPs that year were the result of a single grid-related event. Also in FY 2003, the prediction limit for PWR general transients was exceeded. Multiple causes appeared to contribute to the large number of such events that year.

The third step developed an integrated, risk-informed indicator at the industry level by combining the individual initiating event information with Birnbaum importance measures for each initiating event (BRIIE Tier 2, or BRIIE for short). NRC-developed standardized plant analysis risk (SPAR) models covering U.S. commercial nuclear power plants provided the Birnbaums. The BRIIE estimates the change in CDF (ΔCDF) for an average plant resulting from changes in industry initiating event performance. Comprehensive uncertainty and sensitivity studies were conducted to characterize the BRIIE. Historical results for the BRIIE are presented in Figure ES-1. Using the ΔCDF format, the BWR, PWR, and industry baselines are 0.0. Therefore, bars extending above the zero horizontal line represent worse than baseline performance in terms of CDF, and bars extending below the zero horizontal line represent better than baseline performance. An expert panel proposed the threshold for the BRIIE for reporting to

Congress, a ΔCDF of 1.0E–05 per reactor critical year. BRIIE results indicate that this threshold was exceeded in FY 1989, but recent results lie significantly below this threshold.

Table ES-1. BRIIE initiating events.

Initiating Event	Identifier	PWR	BWR	Industry	Related ROP Initiating Event Performance Indicator	Related Ex-AEOD Initiating Event Performance Indicator
General Transient	TRAN	X	X		Unplanned Scrams	Automatic Reactor Scrams while Critical (does not include unplanned manual scrams)
Loss of Condenser Heat Sink	LOCHS	X	X		Scrams with Loss of Normal Heat Removal	Counted under the Automatic Reactor Scrams while Critical indicator. However, the functional and risk impacts on the plant are not covered.
Loss of Main Feedwater	LOMFW			X	Scrams with Loss of Normal Heat Removal	Same comment
Loss of Offsite Power	LOOP			X	Counted under the Unplanned Scrams indicator. However, the functional and risk impacts on the plant are not covered. Also, this event is too rare to monitor separately on a plant-specific basis.	Same comment
Loss of Vital AC Bus	LOAC			X	Same comment	Same comment
Loss of Vital DC Bus	LODC			X	Same comment	Same comment
Stuck Open SRV	SORV	X	X		Same comment	Same comment
Loss of Instrument Air	LOIA	X	X		Same comment	Same comment
Very Small LOCA	VSLOCA			X	Same comment	Same comment
Steam Generator Tube Rupture	SGTR	X	N/A		Same comment	Same comment

Stakeholder interaction associated with three main activities benefited the BRIIE effort: a request for public review of a draft version of the BRIIE, a presentation to the Advisory Committee on Reactor Safeguards (ACRS), and a public workshop. These occurred in 2003. In addition to the stakeholder interaction, an expert panel was convened in July 2006 to provide suggestions concerning the draft BRIIE effort and to recommend thresholds for the BRIIE Tier 2.

The BRIIE development effort also benefited from experience and lessons learned from the recent implementation of the Mitigating Systems Performance Index (MSPI) within the ROP. Implementation of the MSPI included significant effort in the area of probabilistic risk assessment (PRA) quality, including a comprehensive comparison of licensee risk models with the NRC's SPAR models. That effort helped to improve both the licensee and NRC risk models. Also, the method used in the MSPI to estimate impacts on CDF of changes in mitigating systems performance is similar to the final approach used in the BRIIE.

Table ES-2. BRIIE Tier 1 performance-based prediction limits.

Initiating Event	Identifier	Mean (1/rcry)	Estimated rcry Per Year for Plant Group (note a)	Expected Number of Events Per Year (note b)	95% Prediction Limit
General Transient—PWR	TRAN (PWR)	7.51E–01	62.1	46.6	59
General Transient—BWR	TRAN (BWR)	8.30E–01	30.6	25.4	35
Loss of Condenser Heat Sink—PWR	LOCHS (PWR)	8.11E–02	62.1	5.0	10
Loss of Condenser Heat Sink—BWR	LOCHS (BWR)	1.97E–01	30.6	6.0	11
Loss of Main Feedwater	LOMFW	9.59E–02	92.7	8.9	15
Loss of Offsite Power	LOOP	3.59E–02	92.7	3.3	8
Loss of Vital AC Bus	LOAC	8.80E–03	92.7	0.8	3
Loss of Vital DC Bus	LODC	1.17E–03	92.7	0.1	2
Stuck Open SRV—PWR	SORV (PWR)	2.88E–03	62.1	0.2	2
Stuck Open SRV—BWR	SORV (BWR)	2.23E–02	30.6	0.7	3
Loss of Instrument Air —PWR	LOIA (PWR)	9.81E–03	62.1	0.6	3
Loss of Instrument Air —BWR	LOIA (BWR)	1.02E–02	30.6	0.3	2
Very Small LOCA	VSLOCA	1.55E–03	92.7	0.1	2
Steam Generator Tube Rupture—PWR	SGTR (PWR)	3.54E–03	62.1	0.2	2

Note a – There are 34 BWRs and 69 PWRs (total of 103) in the U.S. commercial nuclear power plant industry. The rcry estimates represent 90% critical operation during a calendar year. Rcry is reactor critical year.
Note b – The expected number of events is the mean frequency multiplied by the plant group rcry.

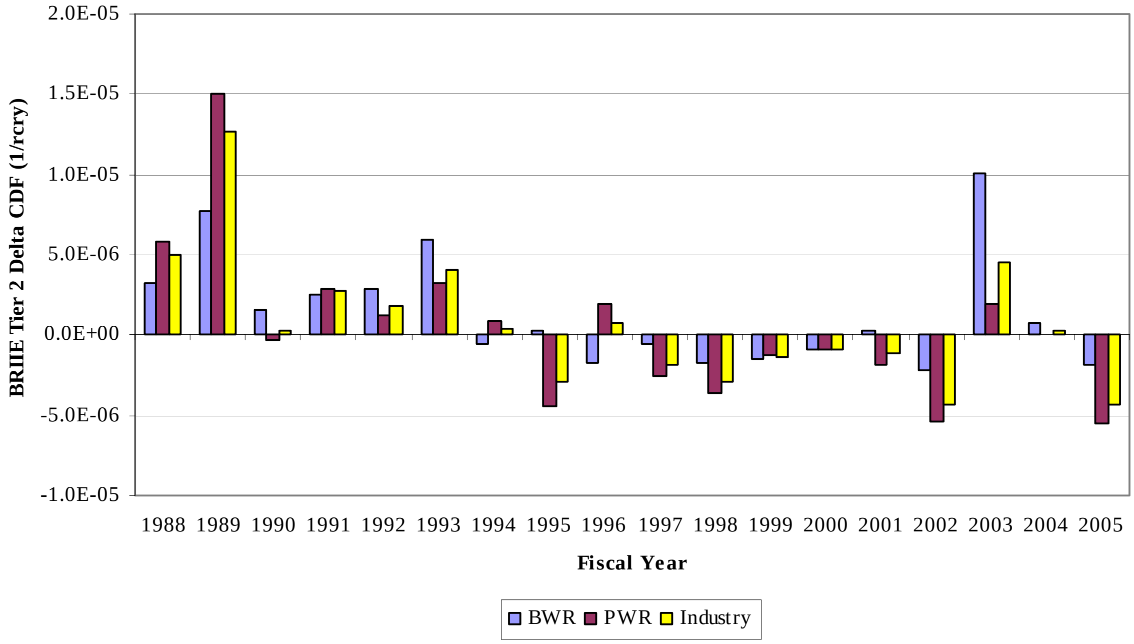

Figure ES-1. BRIIE ΔCDF historical results.

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ABBREVIATIONS

AARM	Agency Action Review Meeting
ac	alternating current
ACRS	Advisory Committee on Reactor Safeguards
ADAMS	Agencywide Documents Access and Management System
AEOD	Office for Analysis and Evaluation of Operational Data
AIT	augmented inspection team
ASP	Accident Sequence Precursor
BRIIE	Baseline Risk Index for Initiating Events
BWR	boiling water reactor
CCDP	conditional core damage probability
CDF	core damage frequency
CNID	constrained noninformative distribution
CY	calendar year
dc	direct current
EB	empirical Bayes
ERO	Emergency Response Organization
FY	fiscal year
IEDB	initiating events database
IIT	incident investigation team
IPE	Individual Plant Examination
ITP	Industry Trends Program
LER	licensee event report
LOAC	loss of vital ac bus
LOCA	loss-of-coolant accident
LOCHS	loss of condenser heat sink
LODC	loss of vital dc bus
LOIA	loss of instrument air
LOMFW	loss of main feedwater
LOOP	loss of offsite power
MLE	maximum likelihood estimate
MSPI	Mitigating Systems Performance Index
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
ODCM	offsite dose calculation manual
PDR	Public Document Room
PRA	probabilistic risk assessment
PWR	pressurized water reactor

RADS	Reliability and Availability Database System
RETS	radiological effluent technical specification
rcry	reactor critical year
ROP	Reactor Oversight Process
SGTR	steam generator tube rupture
SI	surveillance inspection
SORV	stuck open SRV
SPAR	standardized plant analysis risk
SRV	safety relief valve
TRAN	general transient
VSLOCA	very small LOCA
ΔCDF	change in core damage frequency

Baseline Risk Index for Initiating Events (BRIIE)

1. INTRODUCTION

This report documents the development process and bases for the Baseline Risk Index for Initiating Events (BRIIE). The BRIIE was developed to enhance the U.S. Nuclear Regulatory Commission's (NRC's) Industry Trends Program (ITP) (Ref. 1) monitoring of industry performance in the area of initiating events. The BRIIE enhances the ITP coverage of initiating events by the following:

- Expanding initiating event coverage from several to nine boiling water reactor (BWR) and ten pressurized water reactor (PWR) initiating events, which expands the core damage frequency (CDF) risk coverage from internal events from less than 20% to approximately 60%
- Eliminating overlapping of initiating event indicators
- Providing performance-based prediction limits (yearly numbers of events) for each of the initiating events (BRIIE Tier 1) that, if reached or exceeded, indicate potential degradation of industry performance
- Assembling the individual initiating event current performance along with Birnbaum importance measures into an integrated risk measure (approximating CDF) that can be used to assess the risk significance of changes in BWR and PWR initiating event performance (BRIIE Tier 2)
- Providing a threshold of risk significance for the integrated risk measure.

Existing NRC programs provide the yearly initiating event data and the Birnbaum importance measures needed for the BRIIE, so no additional data collection is needed.

At present the BRIIE addresses only internal event CDF, and does not include external events or large early release frequency. In addition, the BRIIE includes yearly comparisons of initiating event performance against prediction limits and BRIIE Tier 2 result against a risk significant threshold. The BRIIE does not include trending, but the ITP may decide to include BRIIE results (individual initiating events and the BRIIE Tier 2) in its trending program. Finally, the BRIIE is designed to detect performance deviations at the industry, BWR, or PWR level. Performance deviations within smaller groups of plants may not be detected without additional analyses (not planned at this time).

The ITP and the development of the BRIIE are discussed in the following sections. Section 2 of this report summarizes the current ITP, Section 3 explains why an enhancement was desired in the area of initiating events, Section 4 describes the BRIIE, and Section 5 describes the review and expert panel processes used to provide guidance in the BRIIE development. Historical results for the BRIIE are presented in Section 6 and potential NRC responses to such results are described in Section 7. Technical bases for various aspects of the BRIIE are presented in Section 8. Various characteristics of the BRIIE, including uncertainty and sensitivity, are presented in Section 9. Section 10 summarizes the overall results of the BRIIE development process and references are presented in Section 11. Finally, Appendices A through F provide detailed information on initiating event performance, initiating event prediction limits, Birnbaum importance measures, BRIIE formulations, expert panel, and resolution of comments.

2. INDUSTRY TRENDS PROGRAM

The NRC provides oversight of plant safety performance on a plant-specific basis using both inspection findings and plant-level performance indicators as part of its Reactor Oversight Process (ROP) (Ref. 2). The regulatory framework for the ROP is illustrated in Figure 2-1. Inputs to this regulatory framework are the seven cornerstones of safety: initiating events, mitigating systems, barrier integrity, emergency preparedness, public radiation safety, occupational radiation safety, and physical protection. These inputs can take two forms—performance indicators or inspection findings. Individual issues that are identified as having generic safety significance are addressed using other NRC processes, including the generic communications process and the generic issue process.

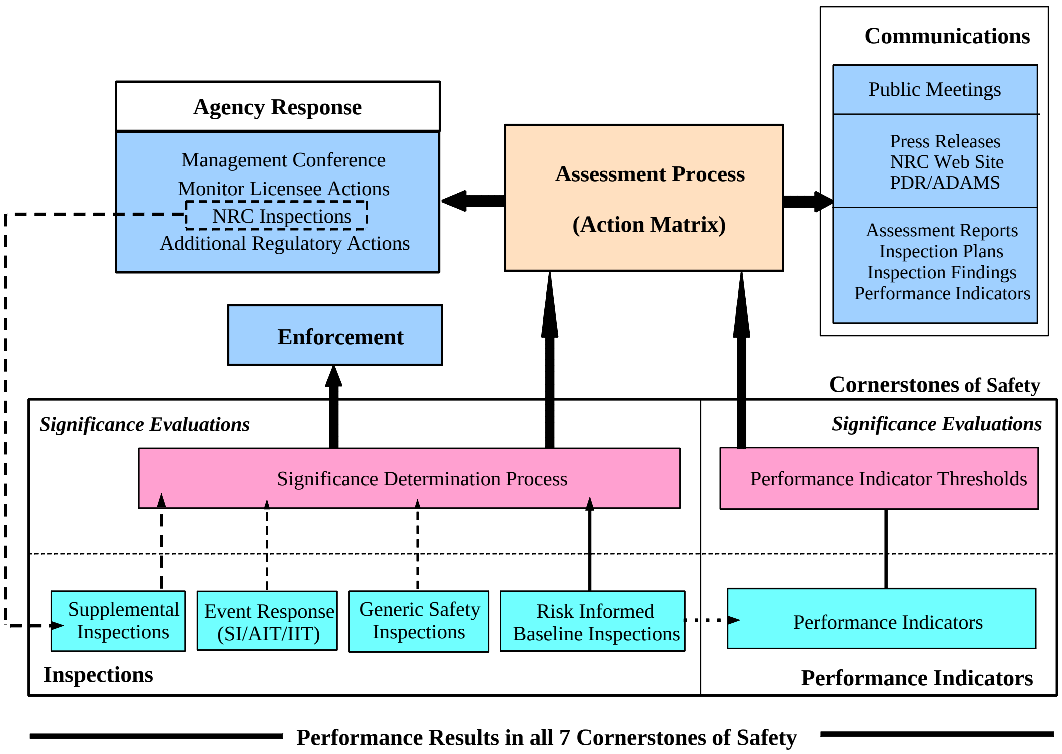

Figure 2-1. Regulatory framework for the Reactor Oversight Process.

As discussed in SECY-01-0111, "Development of an Industry Trends Program [ITP] for Operating Power Reactors" (Ref. 3), the NRC's Office of Nuclear Reactor Regulation (NRR) initiated the ITP in 2001 to complement these existing processes by monitoring and assessing industry-level trends in safety performance. The purposes of the ITP are to provide a means to confirm that the nuclear industry is maintaining the safety performance of operating reactors and, by clearly demonstrating that performance, to enhance stakeholder confidence in the efficacy of the NRC's processes. The objectives of the ITP are the following:

- Collect and monitor industry-wide data that can be used to assess whether the nuclear industry is maintaining the safety performance of operating plants and to provide NRC feedback to its nuclear reactor safety inspection and licensing programs.
- Assess the safety significance and causes of any statistically significant adverse industry trends,

determine if the trends represent an actual degradation in overall industry safety performance, and respond appropriately to any safety issues that may be identified.

- Communicate industry-level information to Congress and other stakeholders in an effective and timely manner.
- Support the NRC's performance goal of ensuring safety while enhancing public confidence in the agency's regulatory process.

Yearly summaries of ITP results and development efforts are presented in the following documents:

- SECY-02-0058, "Results of the Industry Trends Program for Operating Power Reactors and Status of Ongoing Development" (Ref. 4)
- SECY-03-0057, "FY 2002 Results of the Industry Trends Program for Operating Power Reactors and Status of Ongoing Development" (Ref. 5)
- SECY-04-0052, "FY 2003 Results of the Industry Trends Program for Operating Power Reactors and Status of Ongoing Development" (Ref. 6)
- SECY-05-0069, "FY 2004 Results of the Industry Trends Program for Operating Power Reactors and Status of Ongoing Development" (Ref. 7)
- SECY-06-0076, "FY 2005 Results of the Industry Trends Program for Operating Power Reactors and Status of Ongoing Development" (Ref. 8)

According to the ITP website (Ref. 1), the ITP is monitoring the performance of six industry indicators developed by the former NRC Office for Analysis and Evaluation of Operational Data (AEOD), 17 ROP performance indicators (the indicators for the Physical Protection Cornerstone of Safety are not publicly available), and two indicators from the Accident Sequence Precursor (ASP) Program. These indicators are listed in Table 2-1, organized by cornerstones of safety. The AEOD performance indicators, termed "ex-AEOD" performance indicators, were reported annually in the NUREG-1187 series (Ref. 9) up through 1999. Although there are eight ex-AEOD indicators, only six are included in the present ITP. The indicators "Significant Events" and "Cause Codes" are excluded. The ROP performance indicators are evaluated quarterly and presented on the NRC website. The ASP results were reported annually in the NUREG/CR-4674 series up through 1998 (Ref. 10). The current status of the ASP program is summarized in SECY-06-0208 (Ref. 11). This current set of diverse performance indicators was chosen for initial inclusion in the ITP based mainly on historical precedent and availability.

From SECY-06-0076, current uses of the ITP results include the following:

- Annual results are reported to Congress in the NRC's Performance and Accountability Report Fiscal Year 200X (NUREG-1542 series, Ref. 12) and Budget Estimates and Performance Plan Fiscal Year 200X (NUREG-1100 series, Ref. 13). These reports indicate whether NRC has met the performance goal of "no statistically significant adverse industry trends in safety performance."
- Results are posted on the NRC public website.
- Results are a key element reviewed by senior NRC management in the Agency Action Review Meeting (AARM).
- Results are reported to the Commission in an annual report coinciding with the AARM.

- The Commission uses ITP results to present the status of industry performance to NRC’s oversight committees and at major conferences with industry.
- NRC managers use ITP results in presentations to industry, such as the NRC’s Regulatory Information Conference.

Additional information on the ITP and how enhancements to the program will be incorporated can be found in the *NRC Inspection Manual*, Manual Chapter 0313, “Industry Trends Program” (Ref. 14).

Table 2-1. Current ITP performance indicators grouped by cornerstone of safety.

Program	Initiating Events	Mitigating Systems	Barrier Integrity	Emergency Preparedness	Public Radiation Safety	Occupational Radiation Safety
Ex-AEOD	Automatic reactor scrams while critical	Safety system actuations				Collective radiation exposure
		Safety system failures				
		Forced outage rate				
		Equipment forced outage rate/1000 critical hours				
ROP	Unplanned scrams	Mitigating Systems Performance Index (MSPI) – emergency ac power systems	Reactor coolant system activity	Drill/exercise performance	Radiological effluent technical specification (RETS)/offsite dose calculation manual (ODCM) radiological effluent	Occupational exposure control effectiveness
	Unplanned scrams with loss of normal heat removal	MSPI – high-pressure injection systems	Reactor coolant system leakage	Emergency Response Organization (ERO) drill participation		
	Unplanned power changes	MSPI – heat removal systems		Alert and notification system		
		MSPI – residual heat removal systems				
		MSPI – cooling water systems				
		Safety system functional failures – BWR				
		Safety system functional failures – PWR				
ASP	Precursor occurrence rate					
	Conditional core damage probability					

3. REASONS FOR ENHANCING CURRENT ITP PERFORMANCE INDICATORS

Current ITP performance indicators have both strengths and weaknesses. Strengths include availability of historical results, continuity and consistency in yearly evaluations, and broad coverage of the cornerstones of safety. However, weaknesses in the Initiating Events Cornerstone of Safety include (1) overlapping coverage for certain cornerstones, (2) limited risk coverage, and (3) difficulties in interpreting the risk significance of significant adverse trends. The next paragraphs elaborate on these three points.

As an example, the Initiating Events Cornerstone of Safety includes the ex-AEOD indicator "automatic reactor scrams while critical," while the ROP includes "unplanned scrams" and "scrams with loss of normal heat removal." The indicators "automatic reactor scrams while critical" and "unplanned scrams" are similar except that unplanned manual scrams are included in the ROP indicator. In addition, an initiating event that fits within the ROP "scrams with loss of normal heat removal" would generally be counted in all three performance indicators.

In terms of risk coverage, work documented in NUREG-1753, *Risk-Based Performance Indicators: Results of Phase 1 Development* (Ref. 15) indicates that the ROP indicators "unplanned scrams" and "scrams with loss of normal heat removal" probably include less than 20% of the total internal event core damage risk for the Initiating Events Cornerstone of Safety. (The other 80% of risk involves less frequent initiating events that cannot be monitored on a plant-specific basis over the limited, three-year time period covered by the ROP indicators.) This limited coverage of risk by the ROP performance indicators is supplemented by inspections.

Finally, if an adverse trend is detected, for example for the ROP "unplanned scrams," there would be difficulty in determining whether the adverse trend is risk significant. This is because not all scrams are equally serious in terms of risk. Also, an adverse trend in "unplanned scrams" might be offset by a favorable (decreasing frequency) trend in "scrams with loss of normal heat removal." The current ITP has established neither a method for determining risk significance of broad categories such as "unplanned scrams," nor a mechanism for aggregating and interpreting offsetting trends at the cornerstone of safety level.

As a first step in enhancing the ITP to remedy the weaknesses discussed above, the Initiating Event Cornerstone of Safety was chosen as the area of focus. Work focused on development of performance indicators that did not overlap in coverage, significantly increased the risk coverage, and provided a mechanism for determining the risk significance of changes in performance, at both the individual initiating event level and at the integrated, cornerstone of safety level. The process and results are documented in the following sections.

4. BRIIE

To enhance the ITP coverage of the Initiating Events Cornerstone of Safety, a three-step process was used, termed the BRIIE. The first step was to identify appropriate initiating event categories. [The term “initiating event categories” indicates that the initiating events referred to in this attachment may include more than one initiating event type as defined in NUREG/CR-5750 (Ref. 16). For the rest of this document, the term “initiating events” is used instead of “initiating event categories” to make the reading easier.] Then methods for trending and establishing performance-based prediction limits for these individual initiating events were developed (BRIIE Tier 1). Finally, an integrated, risk-informed indicator at the industry level was developed by combining the individual initiating event information (BRIIE Tier 2). Figure 4-1 shows the ITP process with respect to the BRIIE. The process steps are also listed in Table 4-1. Each of these steps is discussed in this section.

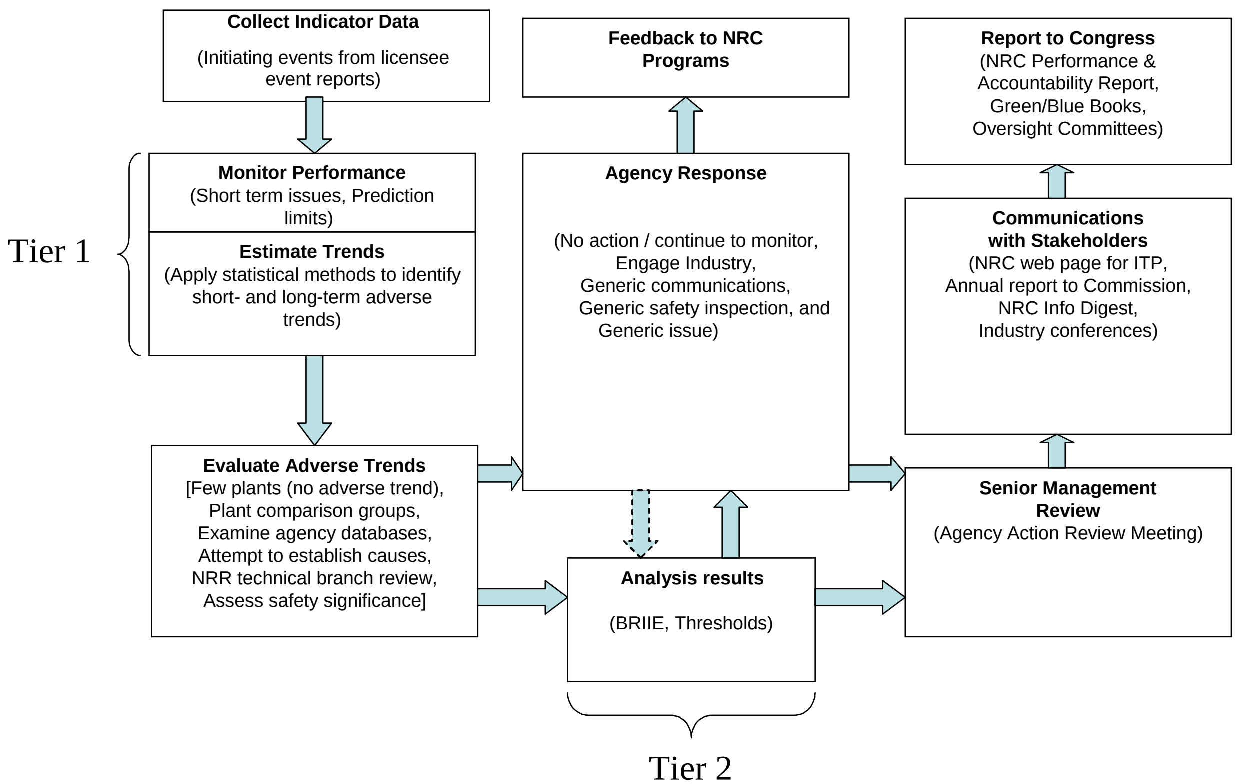

Figure 4-1. BRIIE and the ITP process.

Table 4-1. Summary of the BRIIE development process.

Tier	Step	Comment
Common to both	Identify subset of initiating events that are monitorable over a short period (one or several years)	NUREG/CR-5750 starting point
	Determine baseline frequencies for monitorable initiating events: • Identify baseline period (ending in CY 2002) • Determine baseline frequency distribution	NUREG/CR-6928 (Ref. 17)
	Collect industry data (events and reactor critical years [rcry] for BWRs and PWRs) by FY	NRC initiating events database (IEDB)
Tier 1	Determine prediction limits for monitorable initiating events: • # events in a year indicating potential degradation in performance	Section 8.3
	Compare FY events for each initiator with prediction limits	Section 6
Tier 2	Develop BRIIE equations: • Risk implications of FY initiating event performance	Section 8.5
	Determine PWR- and BWR-average Birnbaum importance measures: • Risk-based “weight” for each initiating event	Section 8.4
	Calculate FY BWR and PWR BRIIE results (ΔCDF)	Section 6
	Compare FY BRIIE results with threshold	Section 6

4.1 Identification of Risk-Significant and Monitorable Initiating Events

NUREG/CR-5750 provides data for a large number of initiating events for the period calendar year (CY) 1987 through CY 1995. (NRC is continually updating these data, but updates to this NUREG are no longer being published. Instead, the results are posted on the NRC website, http://nrcoe.inel.gov/results/.) Initiating events are defined in that study to be unplanned reactor trips that occur while a plant is critical and at or above the point of adding heat. A subset of these events was identified as being risk significant in NUREG-1753. The list of risk-significant initiating events included in the BRIIE is presented in Table 4-2.

The list in Table 4-2 includes ten initiating events applicable to PWRs and nine applicable to BWRs. Initiating events broken down into separate PWR and BWR plant groups were shown to have statistically significant differences in frequencies in the original initiating events study. For the other initiating events, PWR and BWR frequencies were not significantly different, and both types of reactors were combined to obtain frequencies. That historical breakdown of initiating events is preserved in the BRIIE. In general, these risk-significant initiating events account for approximately 60% of the current internal event CDF risk (excluding internal flooding) from the 103 operating commercial nuclear power plants in the U.S. (The types of initiating events not included in the BRIIE, contributing the other 40%, are listed in Section 8.1.) In addition, there is no overlap among these initiating events.

The three BRIIE initiating events in Table 3 [general transient (TRAN), loss of condenser heat sink (LOCHS), and loss of main feedwater (LOMFW)] that roughly correspond with ROP performance indicators (Table 2-1) occur frequently and can be monitored on a plant-specific basis over a period of 1 to 3 years. However, their coverage of internal events CDF is less than 20%. The BRIIE includes the other risk-significant initiating events listed in Table 4-2 for two reasons: including these other events increases the industry average risk coverage to approximately 60% and these events are frequent enough to monitor at the plant-group (BWR or PWR) or industry-wide level on a yearly basis.

Table 4-2. BRIIE initiating events.

Initiating Event	Identifier	PWR	BWR	Industry	Related ROP Initiating Event Performance Indicator	Related Ex-AEOD Initiating Event Performance Indicator
General Transient	TRAN	X	X		Unplanned Scrams	Automatic Reactor Scrams while Critical (does not include unplanned manual scrams)
Loss of Condenser Heat Sink	LOCHS	X	X		Scrams with Loss of Normal Heat Removal	Counted under Automatic Reactor Scrams while Critical. However, the functional and risk impacts on the plant are not covered.
Loss of Main Feedwater	LOMFW			X	Scrams with Loss of Normal Heat Removal	Same comment
Loss of Offsite Power	LOOP			X	Counted under the Unplanned Scrams indicator. However, the functional and risk impacts on the plant are not covered. Also, this event is too rare to monitor separately on a plant-specific basis.	Same comment
Loss of Vital AC Bus	LOAC			X	Same comment	Same comment
Loss of Vital DC Bus	LODC			X	Same comment	Same comment
Stuck Open SRV	SORV	X	X		Same comment	Same comment
Loss of Instrument Air	LOIA	X	X		Same comment	Same comment
Very Small LOCA	VSLOCA			X	Same comment	Same comment
Steam Generator Tube Rupture	SGTR	X	N/A		Same comment	Same comment

4.2 Performance Monitoring of Risk-Significant Initiating Events (Tier 1)

The proposed Tier 1 activity involves monitoring yearly plant-group or industry (depending upon the initiating event) performance against prediction limits. To accomplish this, up-to-date baseline frequencies were obtained for each of the risk-significant initiating events from NUREG/CR-6928 (Ref. 17). Those baseline frequency distributions are presented in Table 4-3. Methods for establishing the baseline periods and resulting distributions are described in Section 8.2 and Appendix B.

The baseline frequency distributions cover industry performance up through CY 2002 (except for loss of offsite power, which extends through CY 2004). At the high end of the frequencies are TRANs for BWRs and PWRs. These two initiating event categories have mean frequencies of 8.3E–01 per reactor critical year (rcry) and 7.5E–01/rcry, respectively. Therefore, many TRAN events are expected each calendar year at the plant-group level (BWRs or PWRs). (Typical commercial nuclear power plant operation involves approximately 0.9 rcry per CY.) At the low end of the frequencies is loss of a vital dc bus (LODC), with a frequency of 1.17E–03/rcry. LODC events are rare and are not expected across the entire industry in a given calendar year.

Given these baseline frequencies and estimated yearly industry, BWR, or PWR rcry of operation, performance-based prediction limits were established (Table 4-4). These prediction limits are explained further in Section 8.3 and Appendix B. The prediction limits in Table 4-4 are performance based, and include both aleatory uncertainty (the randomness of the event count in the future year) and epistemic uncertainty (lack of perfect knowledge of the value of the baseline frequency). They represent upper limits of initiating event counts in a year that, if reached or exceeded, indicate a potential degradation in plant-group or industry performance.

Ten risk-significant initiating events are covered for PWRs, while nine are covered for BWRs. Data for these initiating events—numbers of events and corresponding rcry—are already being collected and analyzed by the NRC on a continual basis, so no additional data collection is needed to support the Tier 1 activities.

4.3 Risk-Informed Monitoring of Initiating Events Cornerstone of Safety (Tier 2)

The BRIIE uses an integrated performance indicator for the Tier 2 coverage of the Initiating Events Cornerstone of Safety. This integrated indicator involves evaluating the risk significance of changes in industry initiating event performance (the results of the Tier 1 activity). Risk significance is evaluated in terms of a measure related to CDF, or changes in this measure (ΔCDF). The indicator combines operating experience for risk-significant initiating events with associated internal event CDF-based importance information.

BRIIE is able to appropriately combine frequent and infrequent initiating events with different risk measures (Birnbaum importances). Table 4-5 lists the average initiating event Birnbaum importance measures used for the BRIIE. These importance measures were obtained from the standardized plant analysis risk (SPAR) models representing the U.S. commercial nuclear power plants. BRIIE solves two deficiencies in the present ITP: no systematic and defined method for determining whether individual initiating event performance changes or adverse trends are risk significant, and no systematic and defined method for integrating individual initiating event performance changes into an overall risk result at the cornerstone of safety level.

The Birnbaum risk importance measure was selected to characterize ΔCDF due to the occurrence or not of a particular initiating event. To determine the Birnbaum importance, the plant CDF is calculated using 1.0/rcry and 0.0/rcry for the initiating event of interest and the difference is determined. Therefore, the Birnbaum is an approximation of the derivative of CDF with respect to the initiating event of interest. More information on the Birnbaums is presented in Section 8.4 and Appendix C.

Table 4-3. BRIIE initiating event baseline data and frequency distributions.

Initiating Event	Identifier	Baseline Period	Baseline Data (note a)		Gamma Frequency Distribution (note a)		
			Events	Exposure (rcry)	Mean (1/rcry)	α	β (rcry)
General Transient —PWR	TRAN (PWR)	1998–2002	228	304.0	7.51E–01	17.77	23.66
General Transient —BWR	TRAN (BWR)	1997–2002	149	180.2	8.30E–01	149.5	180.2
Loss of Condenser Heat Sink—PWR	LOCHS (PWR)	1995–2002	38	475.0	8.11E–02	38.50	475.0
Loss of Condenser Heat Sink—BWR	LOCHS (BWR)	1996–2002	41	208.6	1.97E–01	11.08	56.38
Loss of Main Feedwater	LOMFW	1993–2002	84	881.9	9.59E–02	1.326	13.83
Loss of Offsite Power	LOOP	1997–2004	24	724.3	3.59E–02	1.580	44.02
Loss of Vital AC Bus	LOAC	1992–2002	8	965.8	8.80E–03	8.500	965.8
Loss of Vital DC Bus	LODC	1988–2002	1	1282.4	1.17E–03	0.500	427.5
Stuck Open SRV —PWR	SORV (PWR)	1988–2002	2	866.6	2.88E–03	0.500	173.3
Stuck Open SRV —BWR	SORV (BWR)	1993–2002	6	291.7	2.23E–02	6.500	291.7
Loss of Instrument Air —PWR	LOIA (PWR)	1997–2002	3	356.9	9.81E–03	0.500	50.99
Loss of Instrument Air —BWR	LOIA (BWR)	1991–2002	3	343.3	1.02E–02	3.500	343.3
Very Small LOCA	VSLOCA	1992–2002	1	965.8	1.55E–03	0.500	321.9
Steam Generator Tube Rupture —PWR	SGTR (PWR)	1991–2002	2	706.4	3.54E–03	0.500	141.3

Note a – Rcry is reactor critical year.

Table 4-4. BRIIE Tier 1 performance-based prediction limits.

Initiating Event	Identifier	Mean (1/rcry)	Estimated rcry Per Year for Plant Group (note a)	Expected Number of Events Per Year (note b)	95% Prediction Limit
General Transient—PWR	TRAN (PWR)	7.51E–01	62.1	46.6	59
General Transient—BWR	TRAN (BWR)	8.30E–01	30.6	25.4	35
Loss of Condenser Heat Sink—PWR	LOCHS (PWR)	8.11E–02	62.1	5.0	10
Loss of Condenser Heat Sink—BWR	LOCHS (BWR)	1.97E–01	30.6	6.0	11
Loss of Main Feedwater	LOMFW	9.59E–02	92.7	8.9	15
Loss of Offsite Power	LOOP	3.59E–02	92.7	3.3	8
Loss of Vital AC Bus	LOAC	8.80E–03	92.7	0.8	3
Loss of Vital DC Bus	LODC	1.17E–03	92.7	0.1	2
Stuck Open SRV—PWR	SORV (PWR)	2.88E–03	62.1	0.2	2
Stuck Open SRV—BWR	SORV (BWR)	2.23E–02	30.6	0.7	3
Loss of Instrument Air—PWR	LOIA (PWR)	9.81E–03	62.1	0.6	3
Loss of Instrument Air—BWR	LOIA (BWR)	1.02E–02	30.6	0.3	2
Very Small LOCA	VSLOCA	1.55E–03	92.7	0.1	2
Steam Generator Tube Rupture—PWR	SGTR (PWR)	3.54E–03	62.1	0.2	2

Note a – There are 34 BWRs and 69 PWRs (total of 103) in the U.S. commercial nuclear power plant industry. The rcry estimates represent 90% critical operation during a calendar year. Rcry is reactor critical year.
Note b – The expected number of events is the mean frequency multiplied by the plant group rcry.

Table 4-5. Plant-group average Birnbaum values for initiating events.

Initiating Event		Birnbaum	
Description	Identifier	BWR Average	PWR Average
General Transient	TRAN	5.51E–07	7.97E–07
Loss of Condenser Heat Sink	LOCHS	4.31E–06	2.32E–05
Loss of Main Feedwater	LOMFW	2.32E–06	2.01E–06
Loss of Offsite Power	LOOP	6.15E–05	1.12E–04
Loss of Vital AC Bus	LOAC	6.85E–05	4.22E–05
Loss of Vital DC Bus	LODC	2.61E–04	9.39E–04
Stuck Open SRV	SORV	4.59E–06	7.14E–04
Loss of Instrument Air	LOIA	3.40E–05	6.57E–05
Very Small LOCA	VSLOCA (note a)	5.51E–07	7.97E–07
Steam Generator Tube Rupture	SGTR	--	3.89E–04

Note a – The Birnbaum importance measures for VSLOCA are identical to that for TRAN.

Two formats for presenting quantification results were considered for the BRIIE. One presentation format represents an absolute measure of CDF for the selected initiating events:

$$BRIIE = \sum_{i=1}^{m} \overline{B_i} \lambda_{ic}^{*} , \quad (4\text{-}1)$$

where

m = number of initiating events covered in the BRIIE

$\overline{B_i}$ = plant-group average Birnbaum for initiating event i

λ_{ic}^{*} = plant-group average current frequency for initiating event i.

Another formulation, related to changes in CDF (ΔCDF), is given by the following equation:

$$BRIIE = \sum_{i=1}^{m} \overline{B_i} \left(\lambda_{ic}^{*} - \lambda_{ib} \right), \quad (4\text{-}2)$$

where

λ_{ib} = baseline frequency for initiating event i.

Note that both equations predict plant-average results, rather than plant-group total results. Plant-average results were judged to be more comprehensible because most NRC programs deal with plant results rather than industry total results.

In both equations, the plant-group average current frequency is calculated using a Bayesian update process, as indicated below:

$$\lambda_{ic}^{*} = \frac{\alpha_{prior,i} + x_i}{\beta_{prior,i} + t_i} , \quad (4\text{-}3)$$

where

$\alpha_{prior,i}$ = 0.5

$\beta_{prior,i}$ = 0.5/mean (using the mean from Table 4-3)

x_i = number of plant-group (BWR or PWR) events during fiscal year for initiating event i

t_i = number of plant-group rcry during fiscal year.

This approach to calculating the plant-group current frequency uses a constrained noninformative distribution (CNID) (Ref. 18) with mean values from Table 4-3. However, rather than using α's from Table 4-3 (mostly larger than 0.5), the CNID uses $\alpha = 0.5$ in all cases. The β parameter is then determined by dividing α by the mean from Table 4-3. This approach for calculating current frequencies was recommended in NUREG-1753 and is also the approach used in the MSPI (Ref. 19) for the ROP. The smaller α is, the weaker the prior distribution, allowing the plant-group data to more heavily influence the posterior distribution.

BWRs and PWRs have different CDFs, which depend to some extent on different initiating events and plant response to different initiating events. The risk weights for various initiating events are also different for the two types of reactors. Therefore, BRIIE results are calculated for each reactor type (plant group) and then the industry result is just a weighted average of the BWR and PWR results:

$$BRIIE_{industry} = \frac{(BRIIE_{BWRs} * 34 + BRIIE_{PWRs} * 69)}{(34 + 69)} \quad (4\text{-}4)$$

The BRIIE formulations in Equations (4-1) and (4-2) use PWR- or BWR-average Birnbaums (see Table 4-5) and combine the plant-group data to generate the "plant-group average current frequency" for each initiating event. Alternative formulations are possible using plant-specific Birnbaums and plant-specific initiating event data and then averaging the individual plant results to obtain an industry-average result. Results using all of the various calculation methods indicated that the proposed formulations in Equations (4-1) and (4-2) provide an appropriate BRIIE sensitivity to group yearly performance. (See Section 8.5 and Appendix D for more details.)

As formulated in Equations (4-2) and (4-3), the BRIIE is similar to the MSPI in the ROP. Both the BRIIE and the MSPI use Birnbaum importance measures as weighting factors. In addition, both determine current performance and compare that with baseline performance to evaluate changes in performance. However, the MSPI applies to the Mitigating Systems Cornerstone of Safety on a plant-specific basis, while the BRIIE applies to the Initiating Events Cornerstone of Safety on an industry-wide or plant-group (BWR or PWR) basis. In addition, the BRIIE integrates all of the initiating events into a single indicator at the cornerstone of safety level, while the MSPI does not integrate the results for the five individual mitigating system results into a single indicator.

Tier 2 ΔCDF results will be calculated on a yearly basis, using plant-group data for the initiating events covered under the BRIIE. Results will be compared with a threshold value. The threshold value was determined using an expert panel process (described in Sections 5 and 8.6). If the threshold value is exceeded, responses are outlined in Section 7.

5. STAKEHOLDER AND MSPI INTERACTION AND EXPERT PANEL

The BRIIE development effort benefited from stakeholder interaction associated with three main activities: a request for public review of a draft version of the BRIIE, a presentation to the Advisory Committee on Reactor Safeguards (ACRS), and a public workshop. The request for public review is covered in Appendix F. Also included in that appendix are the resolutions of comments received through the public review process. A detailed presentation of the draft BRIIE methods and results was given to the ACRS on May 7, 2003. The meeting minutes (Ref. 20) describe additional comments and suggestions for final development of the BRIIE. Finally, a public workshop on the draft BRIIE methodology was held at NRC Headquarters on July 30, 2003. That interaction also resulted in stakeholder feedback concerning the draft BRIIE (Ref. 21).

In addition, the BRIIE benefited from work leading up to implementation of the MSPI in 2006. Included was significant effort to address issues related to the quality of licensee and SPAR risk models. That work led to a comprehensive program to upgrade the SPAR models based on cut-set-level comparisons with licensee risk models. This helped to improve the Birnbaum importance measures used in the BRIIE and ensure that they are adequate for this application. Other MSPI issues and concerns (Ref. 19) also helped to shape the final BRIIE. For example, the MSPI includes a performance limit for insensitive indicators, which is similar in concept to the prediction limits for the BRIIE Tier 1 monitoring. Also, the MSPI contains a “frontstop” to ensure that no single event (assuming other contributors are at their baseline performance) can result in an indicator changing from green to white. In the BRIIE no single initiating event occurrence can trip either a Tier 1 prediction limit or the Tier 2 threshold. (The methods used to develop the Tier 1 prediction limits and the Tier 2 threshold were developed independent of this concern.) Finally, the MSPI approach for calculating current component performance, using a Bayesian update with a CNID prior, is the approach used in the BRIIE [Equation (4-3)], and so is the approach to estimating ΔCDF [Equation (4-2)].

Finally, an expert panel was convened in July 2006 to provide suggestions concerning the BRIIE and to recommend thresholds for the Tier 2 BRIIE. The peer review panel process is described in more detail in Appendix E. Recommendations from the expert panel included the following:

1. Maintain the two-tiered approach for BRIIE.
2. Present Tier 2 BRIIE results for BWRs, PWRs, and the overall industry.
3. Present Tier 2 BRIIE results on a ΔCDF basis using Equation (4-2) with Bayesian updating [Equation (4-3)].
4. Use a Tier 2 BRIIE threshold of 1.0E–05/rcry (ΔCDF basis), applied only to the overall industry result.
5. Also present BRIIE results on a CDF basis using maximum likelihood estimates (MLEs, events divided by rcry) for yearly initiating event frequencies to clearly show the dominant yearly contributors to CDF.

6. BRIIE HISTORICAL PERFORMANCE

BRIIE historical performance includes both Tier 1 and Tier 2 results. Both are evaluated on an NRC FY basis (October 1 through September 30), similar to other ITP performance indicators. The Tier 1 results are the yearly initiating event frequencies evaluated at the plant-group (BWR and PWR) or industry level. These results are compared with the prediction limits to identify instances where plant-group or industry performance might have degraded. If a prediction limit is exceeded for an initiating event, then an engineering analysis is recommended to determine the causes. The Tier 1 results are presented in Appendix A. Because the baseline periods end in CY 2002, only the results for FY 2003 through FY 2005 are compared with the prediction limits. (Results before the baseline period often are above the prediction limits because of improved plant-group performance reflected in the baselines.)

Two of the initiating events exceeded their Tier 1 prediction limits: TRAN (PWR) exceeded the prediction limit in FY 2003, and so did loss of offsite power (LOOP). Results for these initiating events are presented in Figure 6-1 and Figure 6-2. Results in those figures are presented as yearly frequencies (events divided by rcry), rather than as events per year. Therefore, the prediction limits were also converted to frequencies, using the prediction limit counts and assumed rcry listed in Table 4-4. An engineering analysis of TRAN (PWR) performance in FY 2003 was not performed. However, as part of the existing ITP, the ex-AEOD indicator "Automatic Reactor Scrams while Critical" also exceeded its prediction limit in FY 2003. That indicator covers both BWRs and PWRs and includes events such as LOOP. The discussion in SECY-04-0052, Attachment 2 illustrates the type of engineering analysis that might be performed when Tier 1 prediction limits are exceeded.

LOOP exceeded its prediction limit in FY 2003 because of the widespread grid disturbance on August 14, 2003. That single event resulted in eight LOOPs at plants that were in critical operation at the time. Therefore, that single grid event resulted in the prediction limit of eight being reached. Four additional LOOPS in FY 2003 also occurred, resulting in a total of 12 LOOP events.

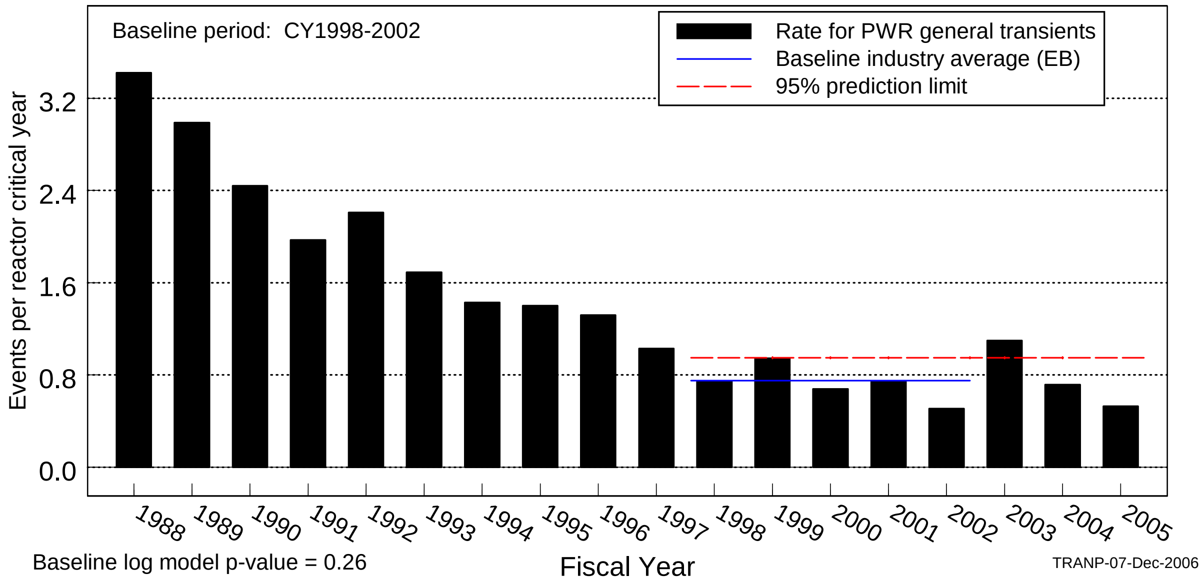

Figure 6-1. Tier 1 historical performance for TRAN (PWR).

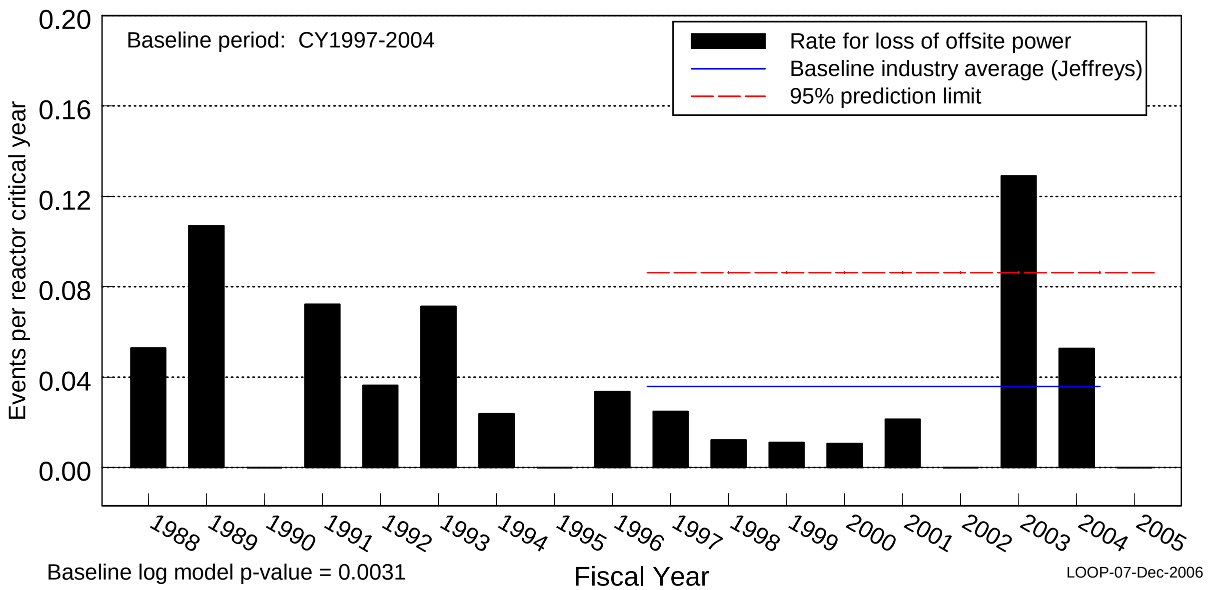

Figure 6-2. Tier 1 historical performance for LOOP.

Historical performance of the BRIIE Tier 2 [ΔCDF basis, Equation (4-2)] is shown in Figure 6-3 for FY 1988 through FY 2005. Using the ΔCDF format, the BWR, PWR, and industry baselines are 0.0. Therefore, bars extending above the zero horizontal line represent worse than baseline performance in terms of CDF, and bars extending below the zero horizontal line represent better than baseline performance. Looking at the FY 2003 through FY 2005 results, none of those years resulted in an industry ΔCDF greater than the threshold of 1.0E–05/rcry. (The BWR result for FY 2003 lies slightly above this threshold, but because the PWR result is lower, the industry result is significantly below the threshold.) Note that the industry result is a weighted average of the PWR and BWR results, using the numbers of plants as weights as indicated by Equation (4-4).

Figure 6-4 for BWRs and Figure 6-5 for PWRs show the breakdowns of CDF by initiating events. These figures were recommended by the expert panel for illustration purposes, to qualitatively show the individual initiating event contributions to CDF. In these figures, the current frequency for each initiating event is just the MLE (events divided by rcry). Using such an approach, if no event occurs during the fiscal year in question, then the contribution to CDF for that initiating event is zero. (If a Bayesian update approach were to be used to generate this figure, even with no events there would still be a non-zero estimate for the current frequency, so there would be a non-zero contribution to CDF.) LOOP events drive the BWR and PWR CDFs in FY 2003 and FY 2004. Table 6-1 and Table 6-2 show the initiating event counts for each plant group by fiscal year (limited to the 103 currently-operating plants).

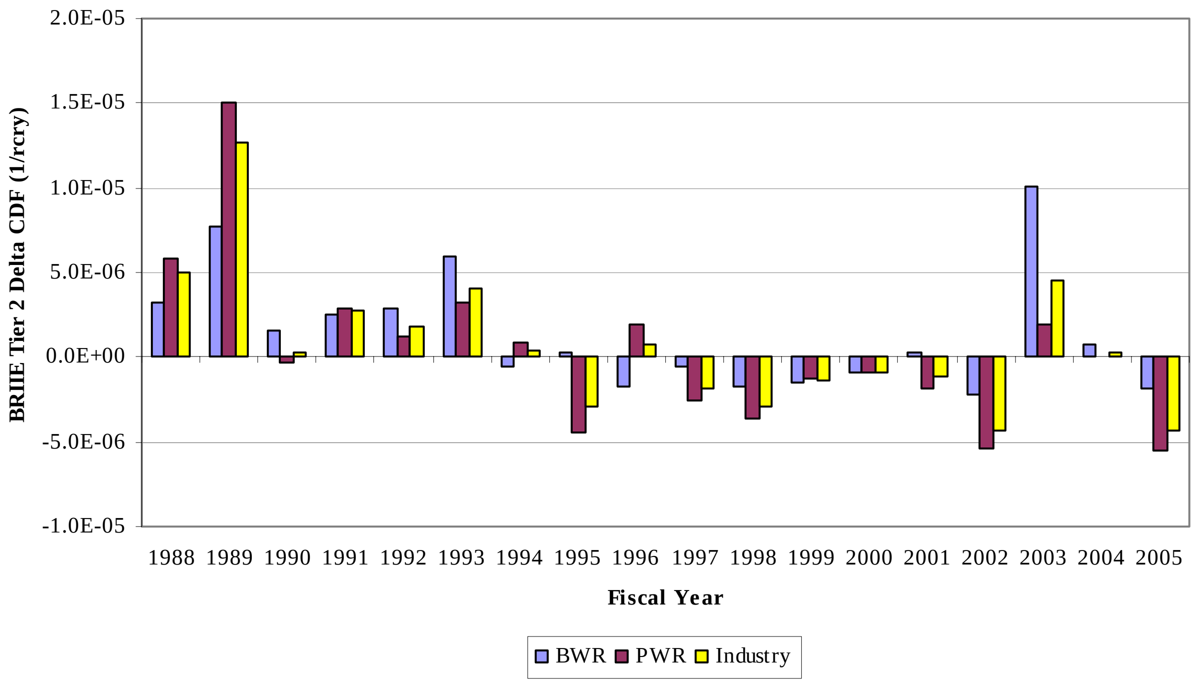

Figure 6-3. BRIIE Tier 2 (ΔCDF) historical performance.

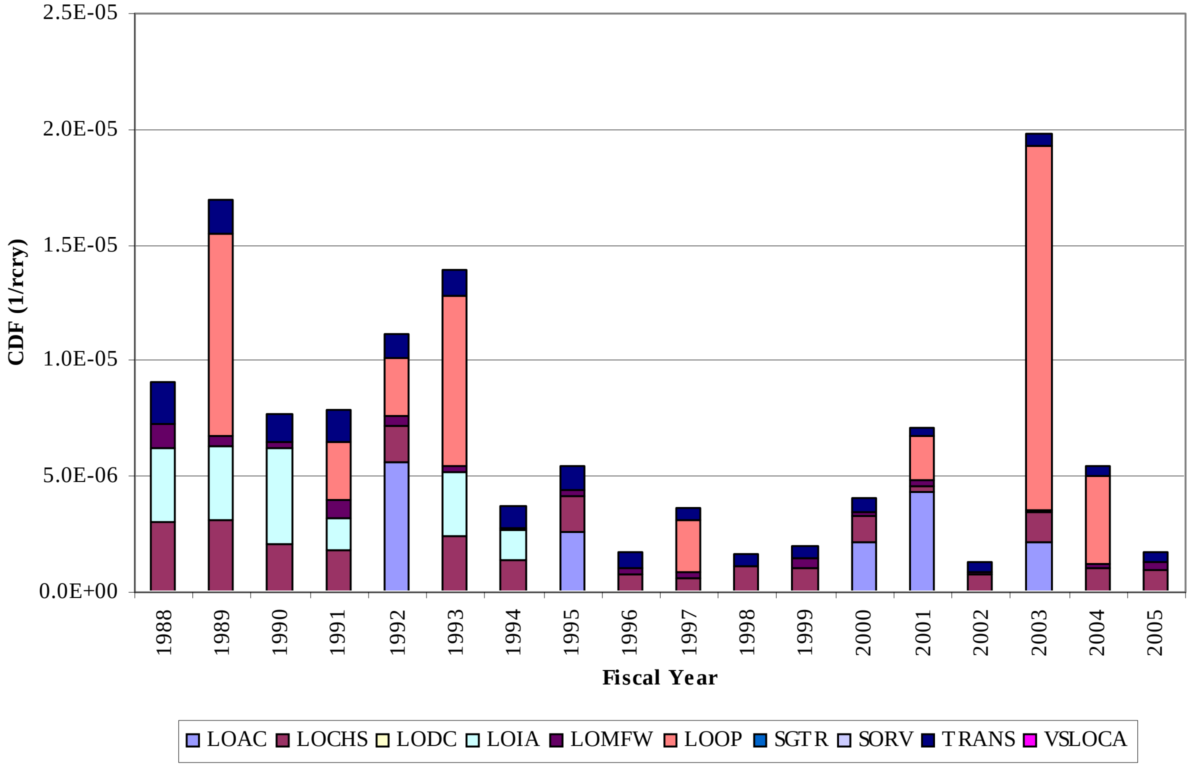

Figure 6-4. BWR CDF breakdown by FY.

Table 6-1. BWR initiating event counts by FY.

Initiating Event (note a)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
LOAC					2			1					1	2		1		
LOCHS	15	15	12	10	9	14	8	10	5	4	7	7	8	2	6	9	8	7
LODC																		
LOIA	2	2	3	1		2	1											
LOMFW	10	4	3	8	4	3	1	3	3	2		6	3	3	1	2	2	4
LOOP		3		1	1	3				1				1		8	2	
SGTR																		
SORV	1	1	2		3	2		1						2	1		1	
TRANS	70	56	56	61	48	48	44	51	38	24	26	28	30	23	24	28	22	24
VSLOCA									1									1

Note a – These event counts include only the 34 BWRs that are currently operating.

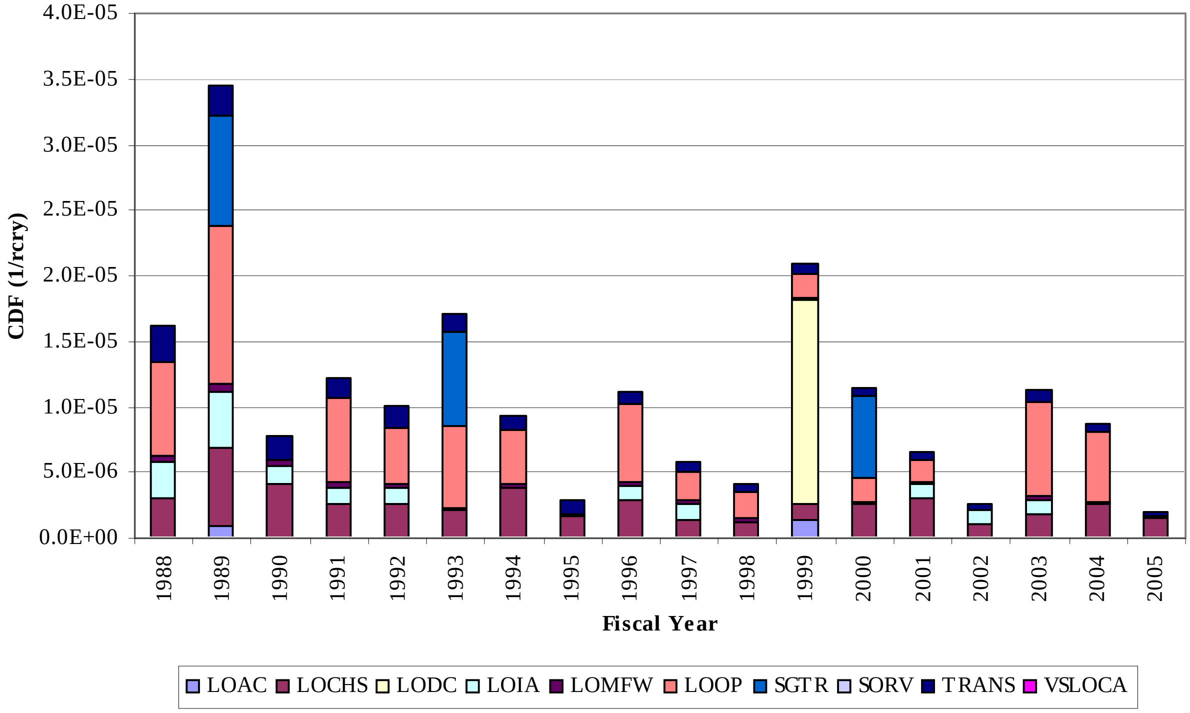

Figure 6-5. PWR CDF breakdown by FY.

Table 6-2. PWR initiating event counts by FY.

Initiating Event (note a)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
LOAC		1										2						
LOCHS	6	12	9	6	6	5	9	4	7	3	3	3	7	8	3	5	7	4
LODC												1						
LOIA	2	3	1	1	1				1	1				1	1	1		
LOMFW	11	14	12	12	8	3	8	7	7	9	7	5	5	4	1	7	5	4
LOOP	3	5		3	2	3	2		3	1	1	1	1	1		4	3	
SGTR		1				1							1					
SORV					1		1											
TRANS	164	134	122	105	116	92	78	80	74	54	41	57	42	46	32	68	45	33
VSLOCA	1	1			1													

Note a – These event counts include only the 69 PWRs that are currently operating.

7. RESPONSES TO TIER 1 AND TIER 2 RESULTS

Table 7-1 shows the relationships between the ROP, the ITP, and the report to Congress. The table shows the potential actions that the ITP might take if a BRIIE Tier 1 prediction limit or Tier 2 threshold is exceeded. Two examples illustrate how the ITP might treat initiating event performance changes.

Table 7-1. Relationship between the ROP, ITP and report to Congress.

Initiating Event Class	Reactor Oversight Process						Industry Trends Program	Report to Congress
	Agency Responses to Individual Occurrences of Initiating Events						Annual Occurrences of Initiating Events	Integrated Indicator
	Early Notification (10CFR 50.72)	Incident Investigation (MD 8.3)	Routine or Special Inspections	Significance Determination Process	Licensee Event Report (10CFR 50.73)	Accident Sequence Precursor Analysis	Action To Be Taken If Tier 1 Industry Prediction Limit Is Exceeded for Indicated Initiating Event Category:	Action To Be Taken If Tier 2 ΔCDF Threshold Is Exceeded:
General Transient	X				X		Investigate to determine reasons for exceedance. Document actions taken in ROP.	Document reasons for the exceedance and what has been done to address them.
Loss of Condenser Heat Sink	X				X			
Loss of Main Feedwater	X				X			
Loss of Offsite Power	X	X	X	X	X	X		
Loss of Vital AC Bus	X	X	X	X	X	X		
Loss of Vital DC Bus	X	X	X	X	X	X		
Stuck Open SRV	X	X	X	X	X	X		
Loss of Instrument Air	X	X	X	X	X	X		
Very Small LOCA	X	X	X	X	X	X		
Steam Generator Tube Rupture	X	X	X	X	X	X		

For the first example, suppose four very small loss-of-coolant accident (VSLOCA) events occur in FY 2007 at separate plants. This initiating event is historically rare. The 95% industry prediction limit is two events (Table 4-4). Because the number of actual events exceeds the prediction limit, this initiating event is a candidate for further investigation.

Because VSLOCAs do not occur very often, NRC would look at each event in more detail after it had occurred. Thus, NRC would have inspectors and staff reviewing each event. The ITP would look at these events to see if there were similarities among the events and to provide any lessons learned from this evaluation. These lessons would be communicated to the industry via some type of generic communication. Further regulatory action would probably not be necessary since the NRC investigated each event in detail.

If all of these events had occurred at PWRs, the incremental increase to the FY 2007 PWR Tier 2 ΔCDF would be approximately 8.0E–09/ rcry (per PWR) for this hypothetical case. The incremental decrease for BWRs (assuming no additional VSLOCAs) would be essentially zero. Therefore, the incremental increase for the industry from VSLOCAs would be less than 8.0E–09/rcry. This is significantly below the recommended industry threshold of 1.0E–05/rcry. The BRIIE report to Congress would identify VSLOCA as a departure from expected baseline performance, but would indicate that this departure is not risk significant.

As another example, suppose five LODC events occur in FY 2007, with two involving BWRs and three involving PWRs. This example exceeds the Tier 1 prediction limit for LODC of two events (Table 4-4). The incremental increase to the BWR Tier 2 ΔCDF would be approximately 1.7E–06/ rcry (per BWR) for this hypothetical case. For PWRs, then the incremental increase is approximately 3.7E-06/rcry. The industry average incremental increase is

[(1.7E–06/rcry)(34) + (3.7E–06/rcry)(69)]/(34 + 69) = 3.0E–06/rcry.

This is below the Tier 2 threshold at the industry level of 1.0E–05/rcry recommended by the expert panel. Therefore, the report to Congress would indicate that the industry LODC performance is a departure from baseline performance but the departure is not risk significant.

8. BASES FOR THE BRIIE

This section summarizes the bases for a variety of decisions made during the BRIIE development process. Additional information is provided in the appendices.

8.1 Selection of Initiating Events

NUREG/CR-5750 identified initiating events that met the following criteria:

- Included an unplanned reactor trip
- Sequence of events started when the reactor is critical and at or above the point of adding heat
- Occurred during CY 1987 through CY 1995
- Was reported by a licensee event report (LER).

In addition, certain rare events such as loss-of-coolant accidents (LOCAs) were added to the list. The resulting list of initiating events from that study includes 48 individual initiating events grouped under 13 categories.

The NUREG/CR-5750 list was reviewed against Individual Plant Examination (IPE) study CDF results (Ref. 22) to identify the subset of risk-significant initiating events presented in NUREG-1753. For an initiating event to be risk significant at the industry or plant-group (BWR or PWR) level, it needed to have a conditional core damage probability (CCDP) ≥ 1.0E–06 and a contribution to industry-wide or plant-group CDF ≥ 1%. That screening process resulted in the list of initiating events presented in Table 4-2.

NUREG-1753 was concerned with monitoring plant-specific performance rather that industry-wide or plant-group performance, so it chose only the most frequent risk-significant events (TRAN, LOCHS, and LOMFW) as monitorable at the plant level over a 3-year period. Monitorable in this context indicates that there is a reasonable probability (approximately ≥ 0.1) of observing the event over the monitoring period. For the BRIIE, only 1 year of data is used. However, the BRIIE does not monitor at the plant-specific level; it monitors at the industry or plant-group level. Based on initiating event data for U.S. commercial nuclear power plants over CY 1988 through CY 2002, all of the risk-significant events identified in NUREG-1753 (except for those outside the scope of this effort, such as internal flooding and initiators evaluated under the ASP Program) were chosen for inclusion in the BRIIE.

A review of SPAR model CDF results for the 103 operating U.S. commercial nuclear power plants indicates that the BRIIE initiating events cover approximately 60% of the total internal event CDF from these models. Other initiating events within these models (covering the remaining 40% of CDF) that are not included within the BRIIE include such events as loss of service water, loss of component cooling water, medium and large LOCAs, and interfacing system LOCAs. These events are rare and generally would not be expected over the lifetimes of the plants. Therefore, such events are not monitorable on a yearly basis.

8.2 Determination of Initiating Event Baselines

Initiating event data from LERs are available in the initiating event database (IEDB) (Ref. 23), covering CY 1987 through the present. NUREG/CR-6928 (Ref. 17) established baseline periods and associated frequency distributions for all of the initiating events within the IEDB, using methods first developed within the ITP. Those same baseline periods and associated frequency distributions are used for the BRIIE and are presented in Table 4-3.

In NUREG/CR-6928, baseline periods to characterize current industry performance were chosen using the following process. The Reliability and Availability Database System (RADS, Ref. 24) software was used to search the IEDB for specific initiating event information and process that information. RADS processes initiating event data to determine total number of events and total rcry over the period specified. In addition, RADS presents yearly results for the period chosen.

Initial RADS searches were performed using data from CY 1988 through CY 2002. These data were then examined to determine an optimized baseline period (ending in CY 2002). Optimization in this case indicates that yearly data were examined, starting with CY 2002 and working backward in time, to identify a baseline period with performance representative of CY 2000. In addition, a minimum of 5 years was specified for potential baseline periods. Often the initiating event data indicate more events in the early years and fewer events in the latter years, so the early years with poorer performance were not included in the baseline period used to quantify the initiating event frequencies. Statistical trend evaluations were performed for all potential baseline periods. The starting year that resulted in the weakest evidence for existence of a trend was then chosen. Additionally, if there were no events or only one event during CY 1988 through CY 2002, then the entire period was chosen as the baseline. Finally, if there were only two events and they occurred during the first 3 years (probability of this is less than 0.05 assuming a constant occurrence rate), then the baseline period started with the first year with no events. This optimization of the period used to characterize current performance resulted in baseline periods with start years of CY 1988 to CY 1998, but all ending in CY 2002. Appendix A presents the initiating event data by year and the resulting baseline periods obtained using this process.

Once the baseline period was determined, RADS again was used to collect the initiating event data over that period. These data (total events and total reactor critical years by plant) were then analyzed statistically to determine gamma frequency distributions. An empirical Bayes analysis with a Kass-Steffey adjustment (Ref. 25) was performed to assess plant-to-plant variation and obtain a frequency distribution. If the empirical Bayes analysis failed to converge (indicating little variation between plants), then the frequency distribution was obtained using a Bayesian update of the Jeffreys noninformative prior with the baseline period data. Finally, if there were three or fewer events over the baseline period and the empirical Bayes analysis failed, then the CNID was assumed, with a mean obtained from the Bayesian update of the Jeffreys noninformative prior. Use of the CNID in these cases reflected the belief that significant plant-to-plant variation probably exists for these less frequent initiating events, but there were insufficient data to determine that actual variability. The statistical analysis process is explained in more detail in Appendix B and NUREG/CR-6928.

In NUREG/CR-6928, the IEDB events for six initiating events were reviewed to screen out events that were not applicable with respect to the SPAR event tree modeling of such events. This screening effort was needed only for those six initiating events; other modeling in SPAR agreed with the initiating event definitions used in the IEDB.

8.3 Tier 1 Prediction Limits

Tier 1 prediction limits for the BRIIE initiating events are presented in Table 4-4. The prediction limits are performance based, and include both aleatory uncertainty (the randomness of the event count in the future year) and epistemic uncertainty (lack of perfect knowledge of the value of the baseline frequency). They represent upper limits of initiating event counts in a year that, if reached or exceeded, indicate a potential degradation in plant-group or industry performance. For example, for TRAN (PWR), the expected number of events in a future year is 46.6 (assuming the 69 PWRs are in critical operation an average of 90% of the calendar time). The predictive distribution for such events indicates that the 95% prediction limit is 60, indicating there is a 0.05 probability that 60 or more events will be observed in a year if the baseline frequency distribution applies. Therefore, if 60 or more TRAN (PWR) events are observed in a year, then there is significant evidence that the plant-group performance has degraded.

A discussion of predictive distributions and prediction limits is presented in Appendix B. These distributions can be generated assuming there is no significant plant-to-plant variation in the baseline frequency distribution, resulting in closed form equations (a gamma-Poisson distribution). They can also be generated assuming there is plant-to-plant variation. However, in that case simulation must be used unless all plants have the same time (rcry). Both approaches were investigated. Because of the belief that there is always plant-to-plant variation in initiating event frequencies (even when the baseline data set may not appear to indicate such variation), the second approach (assuming plant-to-plant variation) was used.

8.4 Tier 2 Birnbaum Importances

The BRIIE Tier 2 monitoring of initiating event performance requires an initiating event importance measure to convert changes in performance (relative to baseline performance) to a ΔCDF risk index. Similar to the MSPI Program, the BRIIE Tier 2 uses the Birnbaum importance measure. This importance measure is the derivative of CDF with respect to the initiating event of interest. Therefore, the Birnbaum is a measure of the sensitivity of CDF to changes in the initiating event frequency.

Birnbaum importance measures for BRIIE were obtained from the SPAR models covering the 103 operating commercial nuclear reactors in the U.S. The SAPHIRE code (Ref. 26) calculates Birnbaum importance measures for both initiating events and basic events in the SPAR models. To calculate the Birnbaum for an event, SAPHIRE evaluates the CDF with the event probability (or frequency) set to 1.0 and 0.0 (or 1.0/rcry and 0.0/rcry). The difference in CDF is the Birnbaum importance measure. Note that this importance measure is unitless for initiating events.

The BRIIE Tier 2 requires plant-group (BWR or PWR) average Birnbaums. Therefore, individual plant Birnbaums were quantified using the SPAR models. Then the BWR-average Birnbaum was determined by summing the results across the 34 BWRs and dividing by 34. A similar process was used for the 69 PWRs. For plants with no Birnbaum (the SPAR model did not include the initiating event in question), the Birnbaum was assumed to be zero. This is appropriate because the SPAR model would have included the initiating event in question if it contributed significantly to the overall CDF. The SPAR models used for the calculations were the internal event models released in December 2005. The SPAR models are continually being improved and modified, so a re-evaluation of Birnbaums with a different set of models might result in some different plant-specific Birnbaums. However, the plant-group averages are expected to be less sensitive to typical SPAR model changes.

Plant-group average Birnbaums obtained from the SPAR models are presented in Table 4-5. Additional details concerning the generation of Birnbaum importance measures are provided in Appendix C.

8.5 BRIIE Tier 2 Formulations

Many different formulations for the BRIIE Tier 2 were considered before deciding to use Equations (4-2) and (4-3) as the final quantification approach. Four different approaches addressed whether to use plant-group (BWR or PWR) or plant-specific Birnbaums and initiating event current frequencies. These four different approaches are identified in Table 8-1. Equations for each of the four approaches are presented following the table.

Table 8-1. Plant-specific versus group approaches to quantifying the BRIIE Tier 2.

Initiating Event Current Frequency	Birnbaum Importance Measure	
	Plant Specific	Plant Group
Plant Specific	Equation (8-1)	Equation (8-2)
Plant Group	Equation (8-3)	Equation (8-4)

If the BRIIE Tier 2 is calculated by evaluating results on a plant-specific basis (using plant-specific current initiating event frequencies and plant-specific Birnbaum importance measures) and then averaging the results, the following equation applies:

$$BRIIE_{Tier\,2} = \frac{1}{N}\sum_{i=1}^{m}(\sum_{u=1}^{N} B_{ui}(\lambda_{uic} - \lambda_{ib})) \,. \qquad (8\text{-}1)$$

If plant-specific current frequencies are combined with group-average Birnbaum importance measures, the result is the following:

$$BRIIE_{Tier\,2} = \frac{1}{N}\sum_{u=1}^{m}\overline{B_i}\sum_{u=1}^{N}(\lambda_{uic} - \lambda_{ib}) = \sum_{i=1}^{m}\overline{B_i}(\overline{\lambda_{ic}} - \lambda_{ib}) \,. \qquad (8\text{-}2)$$

If the initiating event data (events and rcry) are aggregated at the plant-group level to determine a group initiating event current frequency and plant-specific Birnbaums are used, the following applies:

$$BRIIE_{Tier\,2} = \frac{1}{N}\sum_{i=1}^{m}\sum_{u=1}^{N} B_{ui}(\lambda_{ic}^{*} - \lambda_{ib}) = \sum_{i=1}^{m}\overline{B_i}(\lambda_{ic}^{*} - \lambda_{ib}) \,. \qquad (8\text{-}3)$$

Finally, using initiating event data aggregated at the plant-group level and group-average Birnbaums, the expression is the following:

$$BRIIE_{Tier\,2} = \sum_{i=1}^{m}\overline{B_i}(\lambda_{ic}^{*} - \lambda_{ib}) \,. \qquad (8\text{-}4)$$

Terms in the above equations are the following:

m	=	number of initiating events covered under the BRIIE
N	=	number of plants within the plant group
λ_{uic}	=	plant-specific current frequency for initiating event *i* and plant *u*
λ_{ic}^{*}	=	common group-level current initiating event frequency for initiating event *i*
λ_{ib}	=	baseline frequency for initiating event *i*
$\overline{\lambda_{ic}} = \frac{1}{N}\sum_{u=1}^{N}\lambda_{uic}$	=	arithmetic mean of plant-specific current frequencies
B_{ui}	=	plant-specific Birnbaum for initiating event *i* and plant *u*

$$\overline{B_i} = \frac{1}{N}\sum_{u=1}^{N} B_{ui} =$$ arithmetic mean of plant-specific Birnbaums for initiating event *i*.

Equation (8-4) is the approach chosen for the BRIIE Tier 2 monitoring and is the same as Equation (4-2). Note that Equation (8-3) also reduces to Equation (8-4). Of these three approaches (given that two of the four result in the same final equation), the most meaningful ones are the purely plant-group-level approach modeled by Equation (8-4) and the purely plant-specific approach modeled by Equation (8-1).

In addition to the plant-specific versus group-level approach issue, there is also an issue related to how initiating event current frequencies should be calculated. The preferred approach, Equation (4-3), uses a Bayesian update with a CNID prior and the plant-group-level data. An alternative approach is to use an MLE (events divided by rcry). These two alternatives can be applied at either the plant-specific level or the plant-group level. Therefore, there are four main alternatives as shown in Table 8-2. BRIIE Tier 2 results by year were quantified using the four alternatives in Table 8-2. Results indicated that the plant-group-level quantification approach combined with using MLEs for the current initiating event frequencies was the most sensitive in terms of showing the widest variations in Tier 2 ΔCDF predictions. The approach selected, using plant-group-average Birnbaums and a plant-group current frequency determined by Bayesian update, was next highest in terms of sensitivity. Quantifying ΔCDF at the plant-specific level (and then averaging the results) and using MLEs for initiating event current frequencies was approximately as sensitive as the approach selected, while the plant-specific quantification using Bayesian updates to determine current frequencies exhibited very little sensitivity.

Table 8-2. Evaluation level and frequency calculation approaches to quantifying the BRIIE Tier 2.

Evaluation Level	Initiating Event Current Frequency Calculation	
	Bayes	MLE
Plant Specific	Plant Specific and Bayes	Plant Specific and MLE
Plant Group	Plant Group and Bayes (approach selected)	Plant Group and MLE

Based on the results of various quantification methods discussed above, the quantification at the plant-group level using Bayesian updating to determine initiating event frequencies was chosen as the preferred approach to quantifying the BRIIE Tier 2 ΔCDF. Details concerning these analyses are presented in Appendix D. Also, the approach selected is consistent with the MSPI Program in terms of using a Bayesian update approach with the CNID to determine current performance.

8.6 Tier 2 Threshold

The BRIIE Tier 1 prediction limits indicate whether industry or plant-group performance of initiating events has degraded relative to the established baselines for performance. These prediction limits are performance based and do not provide an indication of whether such performance degradation is risk significant. That is the reason the BRIIE Tier 2 ΔCDF estimator was developed. The BRIIE Tier 2 ΔCDF is risk based.

A threshold for the BRIIE Tier 2 ΔCDF is needed to specify when significant risk-based performance degradation has occurred. If the threshold is reached or exceeded, then the result will be reported to Congress. The BRIIE Tier 2 ΔCDF threshold was developed using an expert panel approach. Information given to the expert panel to help them determine a threshold included the following:

- BRIIE Tier 2 historical results (BWRs , PWRs, and industry) in Figure 6-3

- BRIIE Tier 2 simulations to determine the 95% prediction limits (BWRs and PWRs) assuming current industry performance is maintained (Figure 9-3 and Figure 9-4 in Section 9).

The expert panel decided that the BRIIE Tier 2 threshold should be 1.0E–05/rcry, applied to the industry-level ΔCDF result as defined in Equation (4-4). The threshold is not to be applied at the BWR and PWR levels. The expert panel decided on this threshold based on considerations of NRC safety goals and Regulatory Guide 1.174 (Ref. 27) and on the desire to be consistent with the MSPI Program and the ASP Program. The threshold was derived from coherency with current NRC metrics and the surrogates for the safety goals discussed in RG 1.174. Two scenarios were discussed during the deliberations. The first was that a single event at 1.0E–03/rcry (ΔCDF basis), which is the current ASP indicator threshold for reporting significant events to Congress, converts approximately to 1.0E–05/rcry per plant on an industry basis (assuming approximately 100 plants). Also if 10% of plants each had a problem equal to 1.0E–04/rcry (ΔCDF basis), this converts again to approximately 1.0E–05/rcry per plant on an industry basis. Details concerning the expert panel process are provided in Appendix E.

8.7 Data Period

To determine the plant-group average frequencies, a data collection period needs to be specified. The ROP uses 1 year of data for its unplanned scrams indicator and 3 years of data for its unplanned scrams with loss of normal heat sink indicator. Also, the MSPI uses 3 years of data for components and trains within its five monitored safety systems. However, the ROP and MSPI are focused on plant-specific results, while the BRIIE is concerned with plant-group (BWR or PWR) and industry results. With 34 BWRs and 69 PWRs, the time period for the BRIIE data collection does not necessarily need to be as long as the ROP time periods. Both 1 year and 3 years were considered for the BRIIE to estimate initiating event current frequencies. A 3-year period provides more data, but since the BRIIE results are evaluated yearly, events in a given year impact the BRIIE results for 3 successive years, until they drop out of the 3-year period. A 1-year data collection period was chosen for the BRIIE based on the following:

- Data over a 1-year period are considered sufficient to characterize plant-group or industry initiating event frequencies for use in a BRIIE-type indicator.
- A 1-year data collection period eliminates any dependencies between successive-year BRIIE results (events that occur impact the BRIIE results only for that specific year).

9. BRIIE TIER 2 UNCERTAINTY AND SENSITIVITY

The historical performance of the BRIIE over the period FY 1988 through FY 2005 provides a limited picture of the expected performance of the BRIIE. To provide additional insight, this section considers four topics:

- The baseline CDF, including a breakdown to show which initiating events contribute most to the value and to its uncertainty, and a simulation to show the full uncertainty distribution
- The predictive distribution for the BRIIE, as evaluated by simulation
- The sensitivity of BRIIE to various high but plausible counts of each individual type of initiating event
- The sensitivity of BRIIE to non-baseline conditions, that is, the distribution of BRIIE if the initiating event frequencies increase by certain assumed amounts.

9.1 Baseline CDF

The BRIIE Tier 2 plant-group average Birnbaums and initiating event baseline frequencies can be combined to obtain an estimate of baseline CDF for an average plant within the group. That CDF estimate is the following:

$$CDF_{BRIIE,\,plant-average} = \sum_{i=1}^{m} \overline{B_i}\lambda_{ib} \qquad (9\text{-}1)$$

where

m	=	number of initiating events covered under the BRIIE
$\overline{B_i}$	=	plant-group average Birnbaum for initiating event *i* (Table 4-5)
λ_{ib}	=	baseline frequency for initiating event *i*.

CDF estimates using Equation (9-1) can be generated for BWRs and PWRs. However, because the BRIIE does not include all initiating events within the SPAR models, the BRIIE baseline CDF estimates do not cover all of the internal event model risk. As indicated in Section 8.1, the initiating events contained with the BRIIE cover approximately 60% of the overall CDF in the SPAR models. The remaining 40% of risk comes from other initiating events such as loss of service water, loss of component cooling water, interfacing system LOCAs, medium and large LOCAs, and others. These other initiating events are too rare to be monitored within the BRIIE.

The various initiating event baseline frequencies λ_{ib} are modeled by Bayesian distributions based on the data from the baseline period, as explained in Section 8.2. When these baseline distributions of λ_i are inserted into the equation for CDF, the result is a Bayesian distribution for the baseline CDF. Elsewhere in this section, when the baseline CDF is given as a number, it is the mean of this distribution.

The contributions of the initiating events to baseline CDF are shown in Table 9-1 and Table 9-2. The terms α and β refer to the baseline gamma(α, β) distributions of the initiating events, with mean α/β. The element in the i^{th} row of the "Mean" column is of the form $B_i\alpha_i/\beta_i$. Each element of the "Variance" column is of the form $B_i\alpha_i/\beta_i^2$.

Table 9-1. Breakdown of BRIIE baseline CDF for BWRs.

Initiating Event	Mean CDF (rcry) (note a)		Variance of CDF		α	β	Average Birnbaum Importance *B*
Loss of Offsite Power—LOOP	2.21E–06	43%	3.08E–12	89%	1.6	44.0	6.15E–05
BWR Loss of Condenser Heat Sink—LOCHS (BWR)	8.47E–07	17%	6.48E–14	2%	11.1	56.4	4.31E–06
Loss of Vital AC Bus—LOAC	6.03E–07	12%	4.28E–14	1%	8.5	966	6.85E–05
BWR General Transient—TRAN (BWR)	4.57E–07	9%	1.40E–15	0%	149.5	180	5.51E–07
BWR Loss of Instrument Air—LOIA (BWR)	3.47E–07	7%	3.43E–14	1%	3.5	343	3.40E–05
Loss of Vital DC Bus—LODC	3.05E–07	6%	1.86E–13	5%	0.5	428	2.61E–04
Loss of Main Feedwater—LOMFW	2.22E–07	4%	3.73E–14	1%	1.3	13.8	2.32E–06
BWR Stuck Open SRV—SORV (BWR)	1.02E–07	2%	1.61E–15	0%	6.5	292	4.59E–06
Very Small LOCA—VSLOCA	8.56E–10	0%	1.46E–18	0%	0.5	322	5.51E–07
Total	5.09E–06	100%	3.45E–12	100%			

Note a – Other initiating events not covered under the BRIIE also contribute to the overall CDF for BWRs. The total CDF in this table is only from the BRIIE initiating events and represents approximately 60% of the overall CDF for BWRs. Rcry is reactor critical year.

Table 9-2. Breakdown of BRIIE baseline CDF for PWRs.

Initiating Event	Mean CDF (rcry) (note a)		Variance of CDF		α	β	Average Birnbaum Importance *B*
Loss of Offsite Power—LOOP	4.02E–06	33%	1.02E–11	39%	1.6	44.0	1.12E–04
PWR Stuck Open SRV—SORV (PWR)	2.06E–06	17%	8.49E–12	33%	0.5	173	7.14E–04
PWR Loss of Condenser Heat Sink—LOCHS (PWR)	1.88E–06	15%	9.18E–14	0%	38.5	475	2.32E–05
Steam Generator Tube Rupture—SGTR	1.38E–06	11%	3.79E–12	15%	0.5	141	3.89E–04
Loss of Vital DC Bus—LODC	1.10E–06	9%	2.41E–12	9%	0.5	428	9.39E–04
PWR Loss of Instrument Air—LOIA (PWR)	6.44E–07	5%	8.30E–13	3%	0.5	51.0	6.57E–05
PWR General Transient—TRAN (PWR)	5.99E–07	5%	2.02E–14	0%	17.8	23.7	7.97E–07
Loss of Vital AC Bus—LOAC	3.71E–07	3%	1.62E–14	0%	8.5	966	4.22E–05
Loss of Main Feedwater—LOMFW	1.93E–07	2%	2.80E–14	0%	1.3	13.8	2.01E–06
Very Small LOCA—VSLOCA	1.24E–09	0%	3.07E–18	0%	0.5	322	7.97E–07
Total	1.22E–05	100%	2.59E–11	100%			

Note a – Other initiating events not covered under the BRIIE also contribute to the overall CDF for PWRs. The total CDF in this table is only from the BRIIE initiating events and represents approximately 60% of the overall CDF for PWRs. Rcry is reactor critical year.

The full Bayesian distributions for BWR and PWR BRIIE CDF were obtained by simulation: A value of each λ_i was randomly generated from its baseline distribution and the full set of values was inserted into Equation (9-1) to get a value of CDF. This was done many times, and the resulting CDFs are shown in Figure 9-1 and Figure 9-2. The vertical line in the figures shows the mean, whose values are taken from Table 9-1 and Table 9-2. The 5^{th} and 95^{th} percentiles for BWRs are 2.9E–06 and 8.7E–06/rcry. The 5^{th} and 95^{th} percentiles for PWRs are 5.8E–06 and 2.2E–05/rcry. The BRIIE CDF for the average BWR is definitely smaller than for the average PWR. Not only is the BWR mean smaller, the mean for the average BWR is below the 5^{th} percentile for the average PWR.

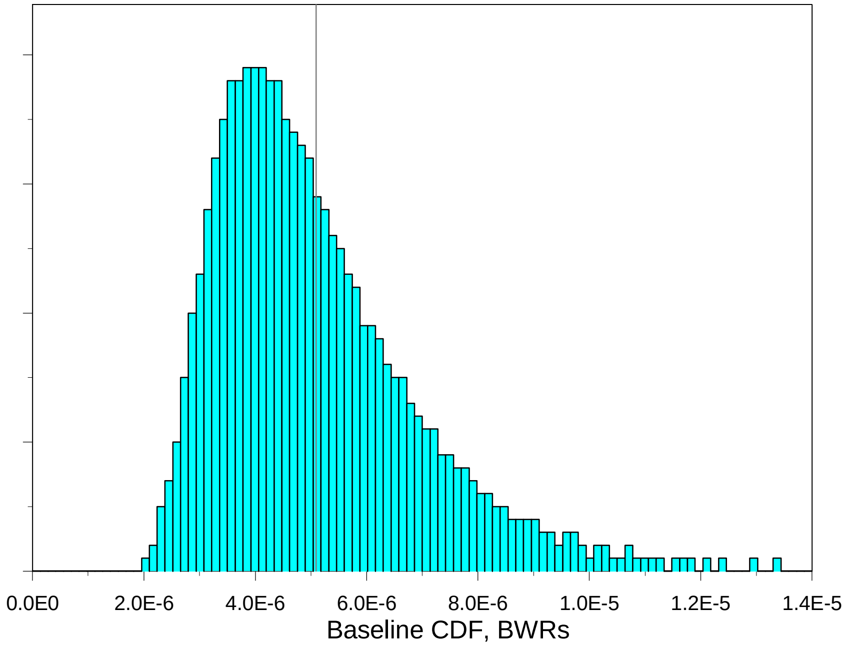

Figure 9-1. Simulated baseline BRIIE CDF distribution for an average BWR.

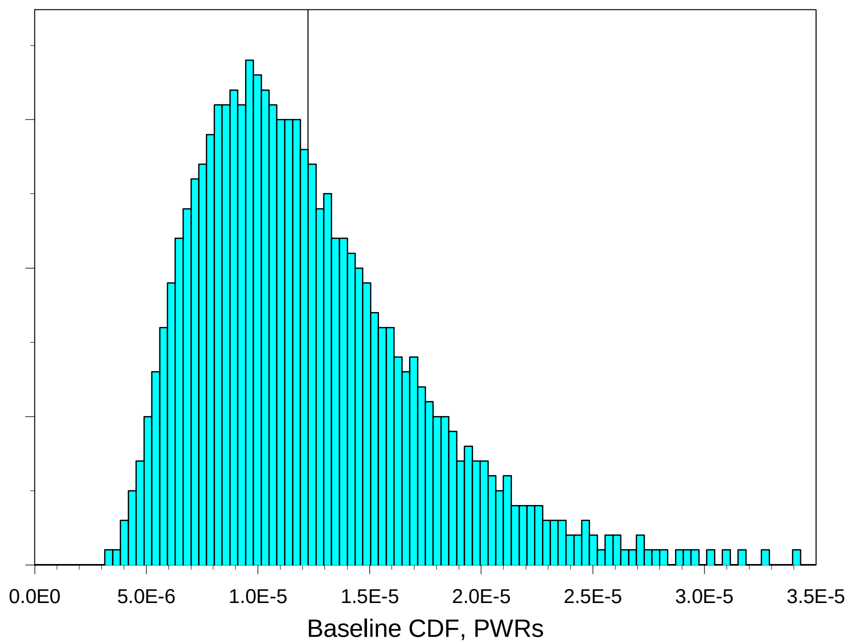

Figure 9-2. Simulated baseline BRIIE CDF distribution for an average PWR.

9.2 Predictive Distribution for BRIIE

The predictive distribution for BRIIE is the distribution that is conditional on the data that have already been observed—the data that determined B_i and λ_{ib} in Equation (9-1). When this conditional distribution is used, B_i and λ_{ib} are treated as known values, and the uncertainty distribution of λ_i is conditional on the known baseline data. This conditional distribution is the posterior distribution of λ_i given x_{ib} and t_{ib}. The predictive distribution for BRIIE can be simulated as explained below.

First, one must do some preliminary work for each initiator *i* (from 1 to *m*). Use the Jeffreys noninformative prior, a gamma(0.5, 0) distribution. If x_{ib} events were seen in t_{ib} rcry, the posterior distribution of λ_{ib} is gamma(x_{ib} + 0.5, t_{ib}). Now perform the simulation:

1. For each initiating event *i* from 1 to *m*, generate λ_i from the posterior distribution of λ_{ib}.
2. Generate X_i from its Poisson distribution conditional on λ_i (using the appropriate rcry exposure from Table 4-4).
3. Calculate λ_i using Equation (4-3).
4. Calculate the resulting value of BRIIE using Equation (4-1) to obtain a CDF estimate rather than a ΔCDF estimate.
5. Repeat this many times, obtaining many values from the predictive distribution for BRIIE.

Figure 9-3 shows the simulated predictive distribution for the BWR BRIIE. The calculations assume 1 year of data to construct a Bayes estimate of the current initiating event frequencies for BWRs, and use Equation (4-2) for BRIIE. This BRIIE is an estimate of the current ΔCDF. The vertical line in the graph identifies the mean, which is zero. The 95th percentile is 2.9E–06/rcry. Surprisingly, this percentile of the estimator is smaller than the corresponding percentile of the baseline ΔCDF (8.7E–06/rcry − 5.1E-06/rcry = 3.6E–06/rcry). The reason is that we have assumed between-plant variation. Therefore, for each initiating event the frequency is randomly generated at each plant, with large values partially canceling small ones. The resulting data tend to reflect the mean frequency, yielding an estimate with a more concentrated distribution than the distribution of ΔCDF at an average plant. If Equation (4-1) had been used instead of Equation (4-2) to define BRIIE, the graph would simply be shifted sideways so that the mean is 5.1E–06/rcry (the mean CDF for BWRs from initiating events covered under the BRIIE, as indicated in Table 9-1).

Figure 9-4 shows the simulated predictive distribution for the PWR BRIIE. The mean is marked by a vertical line at zero. The 95th percentile is 5.3E–06/rcry, which is smaller than the 95th percentile of the baseline ΔCDF (2.18E–05/rcry − 1.22E–05/rcry = 9.6E–06/rcry), just as for BWRs.

One striking feature of Figure 9-3 is that the distribution is "lumpy"; that is, the histogram has multiple local maxima and minima. This is explained as follows. The quantity BRIIE is an estimate of ΔCDF. The estimated ΔCDF is discrete, because it is constructed from discrete counts. Table 9-1 shows that LOOP contributes nearly half the mean and about nearly 90% of the variance of the CDF for BWRs. The CDF can be thought of as the sum of two pieces: the piece from LOOP, and the piece from everything else. The two pieces have similar means, but the estimate of the piece from LOOP has a highly discrete distribution, because typically there are three or fewer LOOP events in one year. This discreteness is visible in Figure 9-3.

This discreteness is not visible in Figure 9-4 for PWRs. Table 9-2 shows that no single initiating event dominates the variance as was the case in Table 9-2. Therefore, various event counts combine to give a relatively smooth distribution for BRIIE.

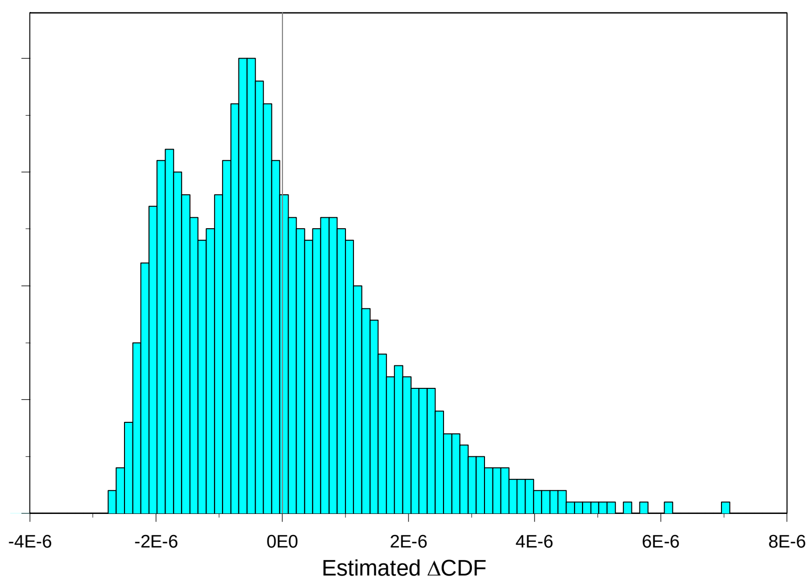

Figure 9-3. Simulated predictive distribution of BRIIE for BWRs.

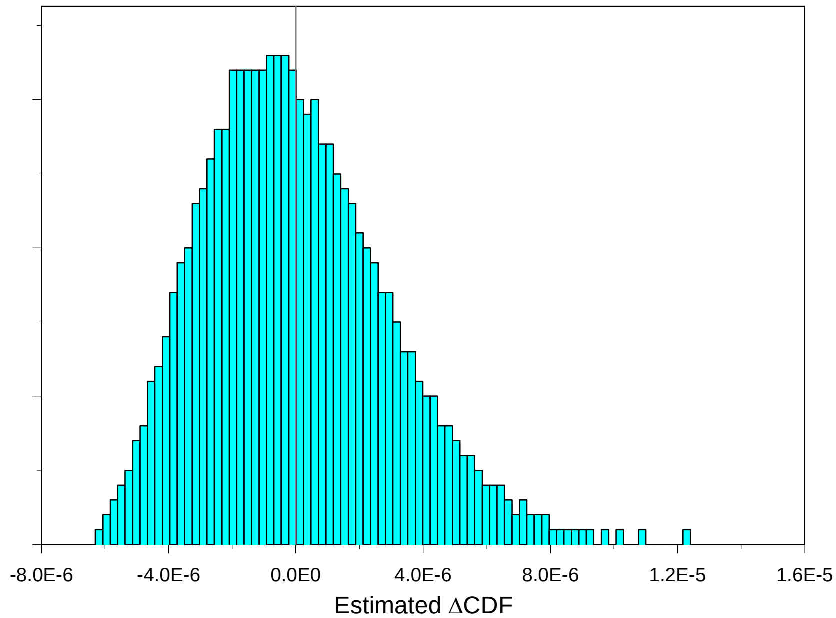

Figure 9-4. Simulated predictive distribution of BRIIE for PWRs.

An earlier draft of this report also considered the effect of the uncertainty in the Birnbaum importances. If the purpose of this task were to obtain as accurate an uncertainty distribution as possible for the baseline CDF (Figure 9-1 and Figure 9-2), then the uncertainty in the Birnbaum importances would have to be considered. This uncertainty is not considered here for three reasons:

1. It is difficult to quantify the uncertainties in the Birnbaum importances. This uncertainty involves the uncertainties of all the cut sets in the risk model, as well as the variation between models.
2. The primary purpose of the BRIIE is to detect risk-significant changes in the initiating event frequencies. Preliminary work showed that the ΔCDF version of BRIIE is not very sensitive to uncertainty in the Birnbaum importances, at least in the upper tail of the distribution.
3. The portion of CDF covered by BRIIE is only about 60% of the total CDF, so there is little value in trying to estimate it as accurately as possible.

Therefore, this report considers BRIIE as an index, constructed as an estimate of the ΔCDF that will be sensitive to changes in the initiating event frequencies. It treats the SPAR models and the resulting Birnbaum uncertainties as given, and it looks for any increases in the estimated BRIIE ΔCDF.

9.3 Sensitivity of BRIIE to High Counts for Individual Initiators

A sensitivity study was performed to evaluate the impacts on the BRIIE from individual initiating events. For each initiator, the 95% prediction limit (from Table 4-4) was inserted into the BRIIE, while keeping other initiating events at their baseline frequencies. (For those initiating events without BWR and PWR breakdowns, the prediction limit was divided into BWR and PWR contributions, based on the numbers of plants in each plant type.) The results of these sensitivity evaluations are presented in Figure 9-5 and Figure 9-6 for BWRs and PWRs, respectively. For BWRs, the largest contributors to the BRIIE are LOOP, LOAC, LODC, LOIA, and LOCHS. For PWRs, the largest contributors are SORV, LOOP, LODC, SGTR, and LOCHS. These events are the same ones that contribute most to the variance of BRIIE, as shown in Table 9-1 and Table 9-2.

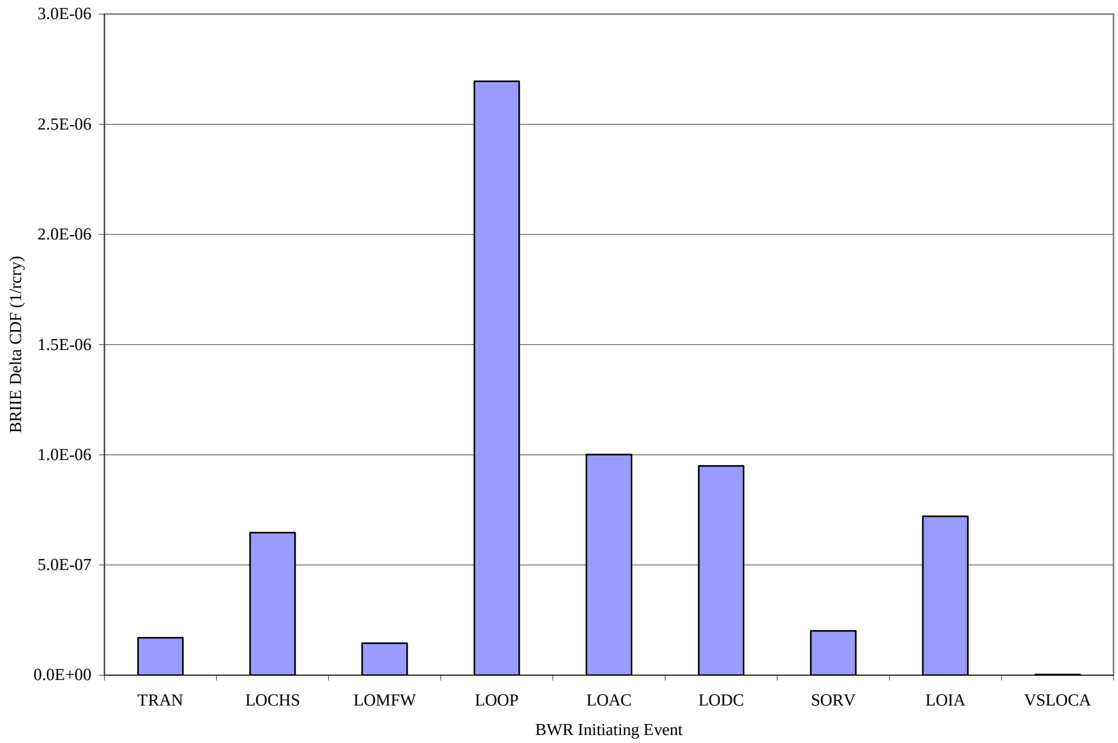

Figure 9-5. BWR BRIIE ΔCDF sensitivity to individual initiating event 95% prediction limits.

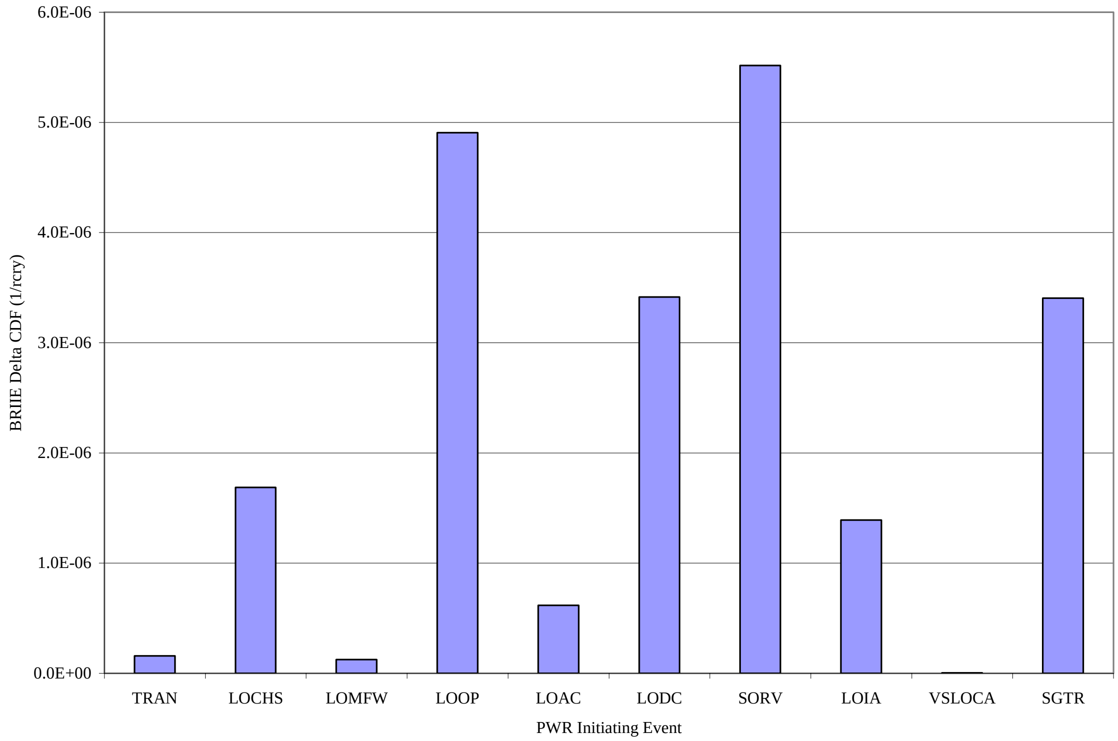

Figure 9-6. PWR BRIIE ΔCDF sensitivity to individual initiating event 95% prediction limits.

9.4 Sensitivity of BRIIE to Non-Baseline Conditions

The distribution of BRIIE was simulated to see how successful BRIIE was at detecting off-baseline situations. Figure 9-7 shows the cumulative distributions of BRIIE under three assumptions. The first is that the initiating event frequencies have their baseline distributions. The resulting distribution (solid line in Figure 9-7) is the predictive distribution shown earlier. The second assumption (long dash line) is that all the initiating event frequencies are 1.5 times the baseline distributions. That is, the baseline α is retained, but β is divided by 1.5. The third assumption (short dash line) is that the initiating event frequencies are 2.0 times the baseline distributions. As can be seen in Figure 9-7, the distribution of BRIIE is moved to the right under the assumed non-baseline conditions. The vertical line in Figure 9-7 is the threshold, 1.0E–05/rcry.

The graph shows at baseline conditions the industry BRIIE virtually will never exceed the threshold. Even if the industry has degraded to the point that every initiating event frequency has a distribution twice as large as the baseline distribution (i.e. α at the baseline value and β cut in half), then there is only a 0.10 probability that the industry data will show enough events to exceed the threshold.

The threshold suggested by the expert panel was based on consistency with other NRC programs, which tend to focus on individual plants. However, the BRIIE looks at a year of industry data. Therefore, it is not surprising that BRIIE can detect off-baseline conditions at thresholds lower than 1.0E–05/rcry. For example, simulations show that 5.0E–06/rcry is exceeded with probability less than 0.02 under baseline conditions, but is exceeded with probability > 0.6 when each initiating event frequency distribution is twice as large as the baseline distribution. Values less than 1.0E–05/rcry could be used as an early-warning threshold for internal NRC use.

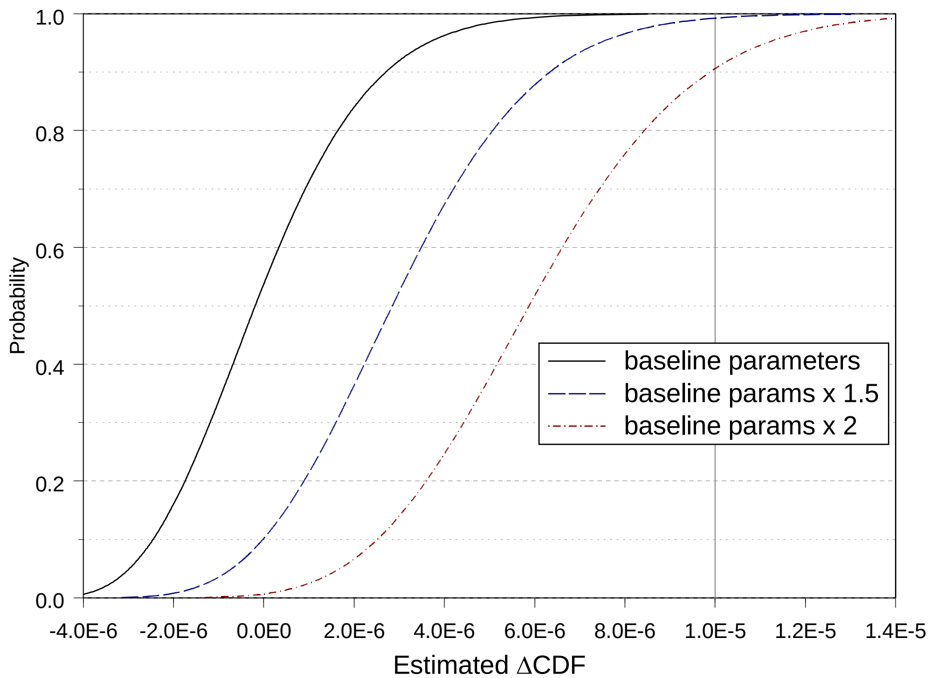

Figure 9-7. Simulated cumulative distribution of BRIIE (ΔCDF) for industry under three assumptions.

10. SUMMARY

The existing ITP includes several initiating event indicators, obtained from various NRC programs that have differing definitions and overlap. The BRIIE described in this document is an enhancement to the ITP in the Initiating Events Cornerstone of Safety. The BRIIE enhances the ITP coverage of initiating events by the following:

- Expanding initiating event coverage from several to nine (BWRs) and ten (PWRs) different initiating events, which expands the CDF risk coverage from internal events from less than 20% to approximately 60%
- Eliminating overlapping of initiating event indicators
- Providing performance-based prediction limits for each of the initiating events (BRIIE Tier 1)
- Assembling the individual initiating event current performance into an integrated risk measure (approximating ΔCDF) that can be used to assess the risk significance of changes in BWR and PWR initiating event performance (BRIIE Tier 2)
- Providing a threshold of risk significance for the integrated risk measure.

The BRIIE outlined in this report includes a Tier 1 monitoring of initiating event performance and a Tier 2 integrated risk indicator based on initiating event performance. Existing NRC programs provide the yearly initiating event data and the Birnbaum importance measures needed for the BRIIE, so no additional data collection is needed.

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GLOSSARY

Bayesian update—the process by which a posterior initiating event distribution is obtained using Bayes Theorem. The process uses a prior initiating event frequency distribution representing industry-average performance and evidence [plant-specific, plant-type, or industry data (events and reactor critical years)] to obtain the posterior distribution.

Baseline Risk Index for Initiating Events (BRIIE)—an industry-level estimate of change in core damage frequency (expressed on a per plant basis) resulting from changes in initiating event frequency performance relative to established industry-average baseline performance. The BRIIE is quantified using Equations (4-2), (4-3), and (4-4).

Birnbaum importance measure—for initiating events, the Birnbaum importance measure is the derivative with respect to the initiating event of interest of the standardized plant analysis risk (SPAR) core damage frequency from internal events. The Birnbaum is calculated by evaluating the SPAR core damage frequency with the initiating event frequency set to 1.0/rcry and 0.0/rcry. The difference in core damage frequency (divided by the difference in frequency) is the Birnbaum. In this context, the Birnbaum has no units.

Calendar year (CY)—the calendar year starts on January 1 and ends on December 31.

Fiscal year (FY)—for the U.S. Nuclear Regulatory Commission, the fiscal year starts on October 1 of the prior calendar year and ends on September 30.

Initiating event—an unplanned event that occurs while a nuclear power plant is in critical operation and requires that plant to shut down to achieve a stable state. Definitions for individual initiating events used in this report are found in NUREG/CR-5750, with modifications as explained in NUREG/CR-6928.

Initiating event baseline frequency—the established industry-average baseline frequency documented in NUREG/CR-6928. These frequencies were established using industry data over baseline periods ending in 2002 (with start years ranging from 1988 to 1998, depending whether trends existed) and are considered to represent up-to-date industry performance.

Initiating event current frequency—the frequency estimate based on industry data for a given year. The current frequency is estimated using a Bayesian update with the prior gamma distribution (a constrained noninformative distribution or CNID) characterized by the mean frequency from the baseline distribution and $\alpha = 0.5$., as indicated in Equation (4-3). Industry data for the given year are collected by plant type (boiling water reactor or pressurized water reactor), and the current frequency is then evaluated for each plant type. The current frequency estimate is then compared with the baseline frequency to determine the change in plant-type performance for that year, as indicated in Equation (4-2).

Initiating event historical frequency—the historical frequency is the frequency estimate based on industry data for a past (historical) year. This frequency is quantified similar to the "current" frequency but using data from a past year.

Prediction limit—an upper bound limit for the number of industry-wide or plant-type initiating events occurring within a year that, if reached or exceeded, indicates a potential degradation in initiating event performance. The Tier 1 portion of the BRIIE compares industry or plant-type yearly data with established prediction limits for the initiating events covered under the program. The prediction limits used in the BRIIE represent the 95% limits, indicating that given baseline performance, there is a 0.05 probability that the prediction limit will be reached or exceeded for a given year. These prediction limits incorporate both uncertainty in the baseline frequency (epistemic uncertainty) and randomness of the event count in a future year (aleatory uncertainty).

Tier 1—that portion of the BRIIE involving performance monitoring of individual initiating events at the industry or plant-group level (depending upon the initiator). Yearly event counts for each initiating event covered within the program are compared with established prediction limits. If an initiating event meets or exceeds its prediction limit, then performance is declared to be degraded, and an engineering analysis is performed to identify potential causes.

Tier 2—that portion of the BRIIE involving integration of individual initiating event performance into a risk index [the BRIIE, Equations (4-2), (4-3), and (4-4)] and comparison with a risk-significant threshold. If the threshold is reached or exceeded, then the degradation in initiating event performance for the year in question is declared to be risk significant and this is reported to Congress. In such cases, engineering analyses will be performed to identify causes and potential remedies.

Appendix A

Initiating Event Data and Baselines

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Figures

Appendix A

Initiating Event Data and Baselines

This appendix presents graphs for each initiating event covered under the Baseline Risk Index for Initiating Events (BRIIE). Each graph presents fiscal year (FY) data, the baseline period chosen to estimate current plant-group or industry-average performance, the baseline performance, and the 95% prediction limit. The initiating event data are based on operating experience at U.S. commercial nuclear power plants from FY 1988 through FY 2005, as reported in licensee event reports (LERs).

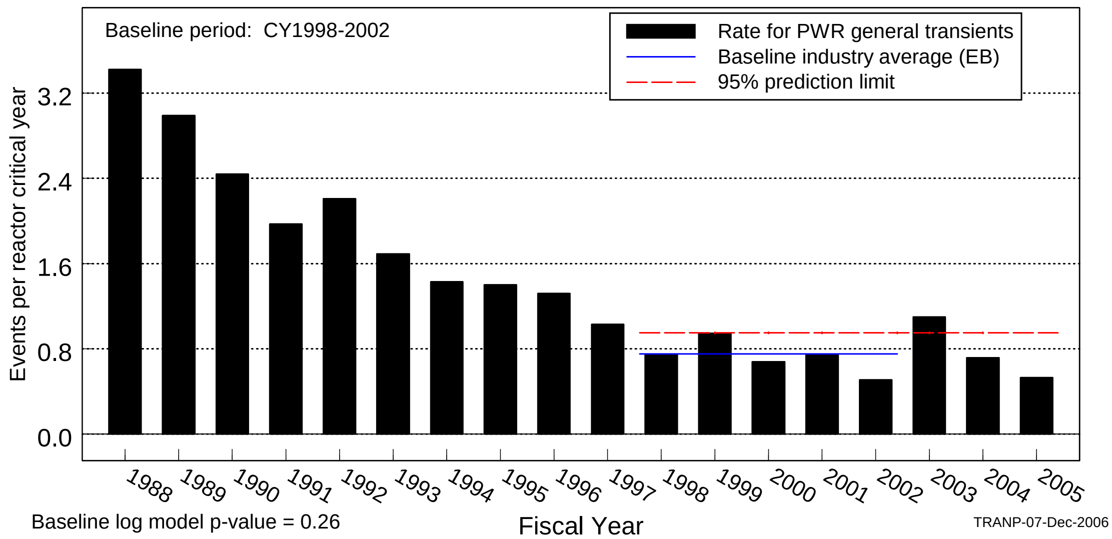

Figure A-1. PWR general transient—TRAN (PWR).

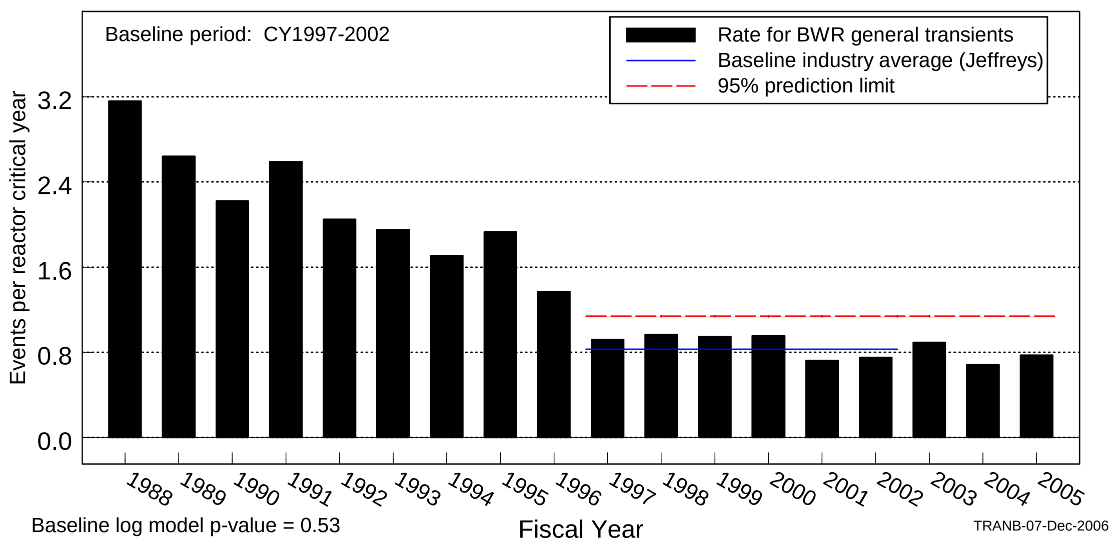

Figure A-2. BWR general transient—TRAN (BWR).

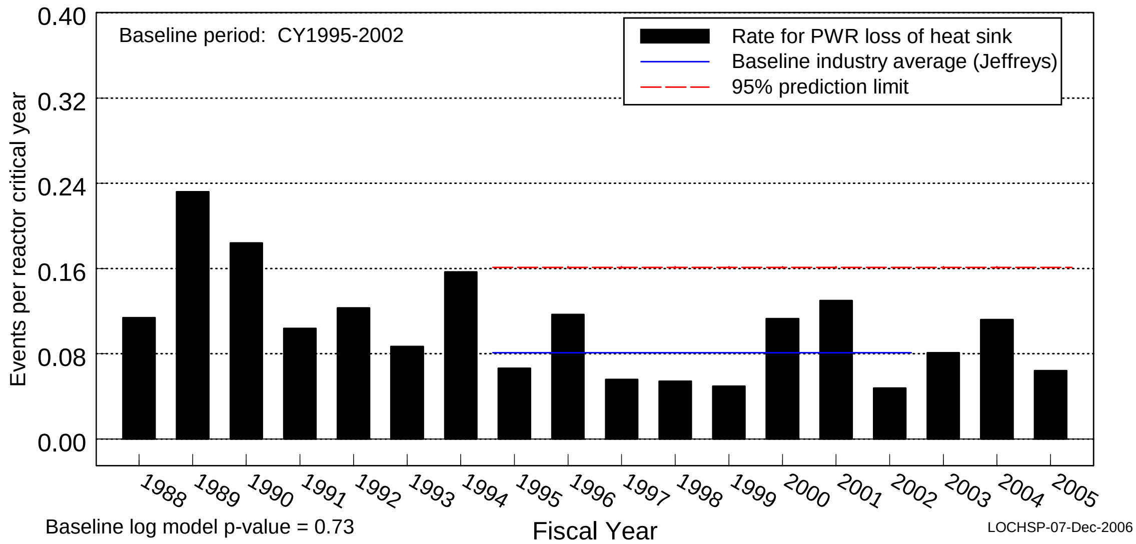

Figure A-3. PWR loss of condenser heat sink—LOCHS (PWR).

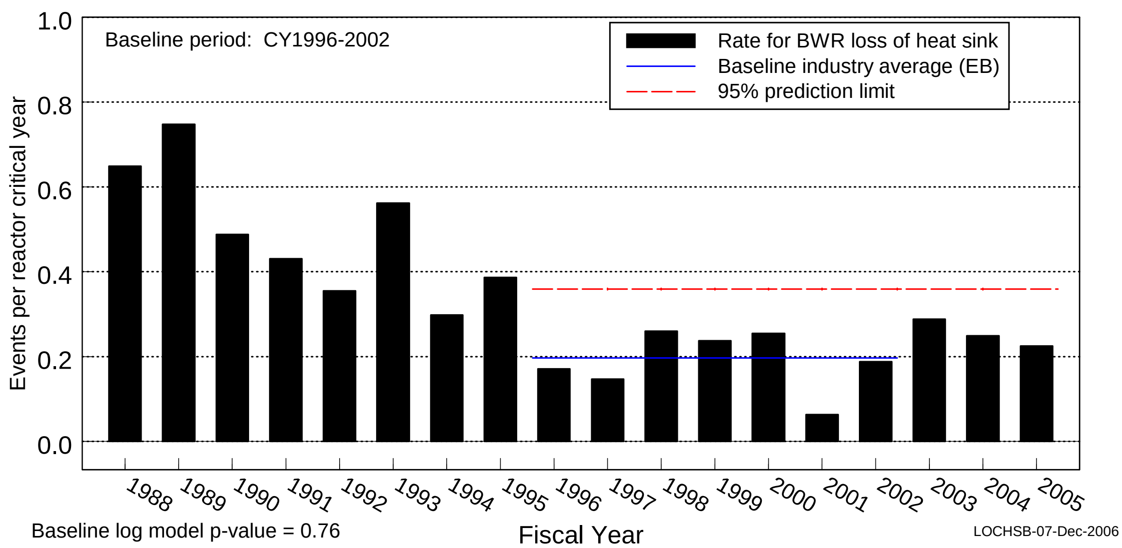

Figure A-4. BWR loss of condenser heat sink—LOCHS (BWR).

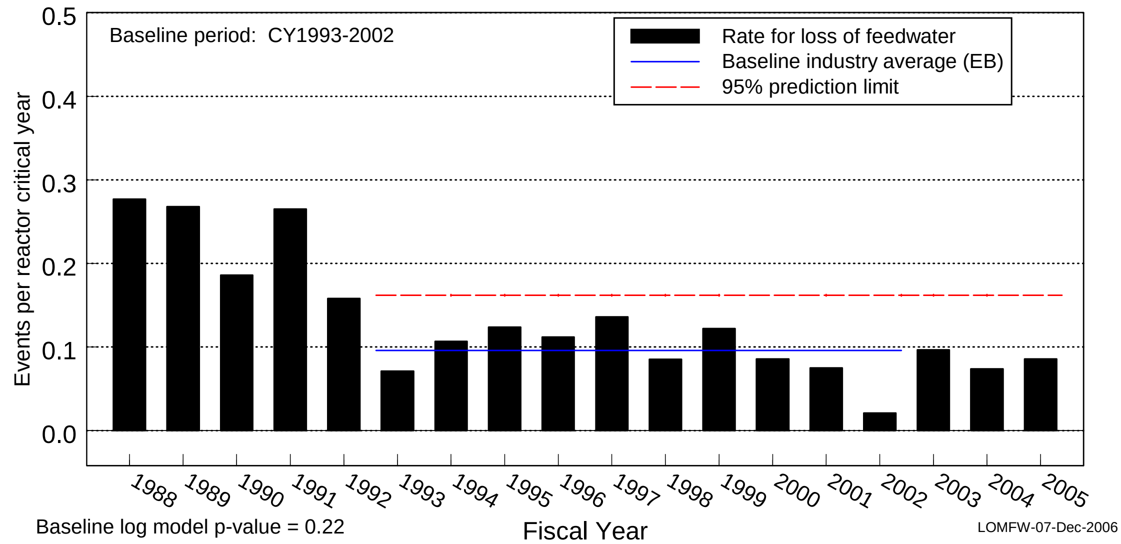

Figure A-5. Loss of main feedwater—LOMFW.

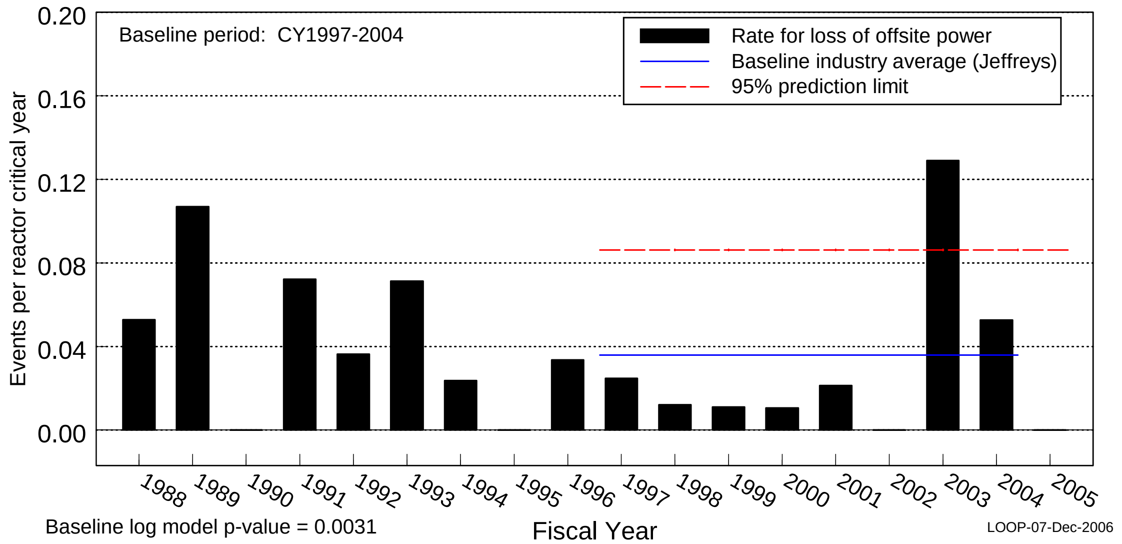

Figure A-6. Loss of offsite power—LOOP.

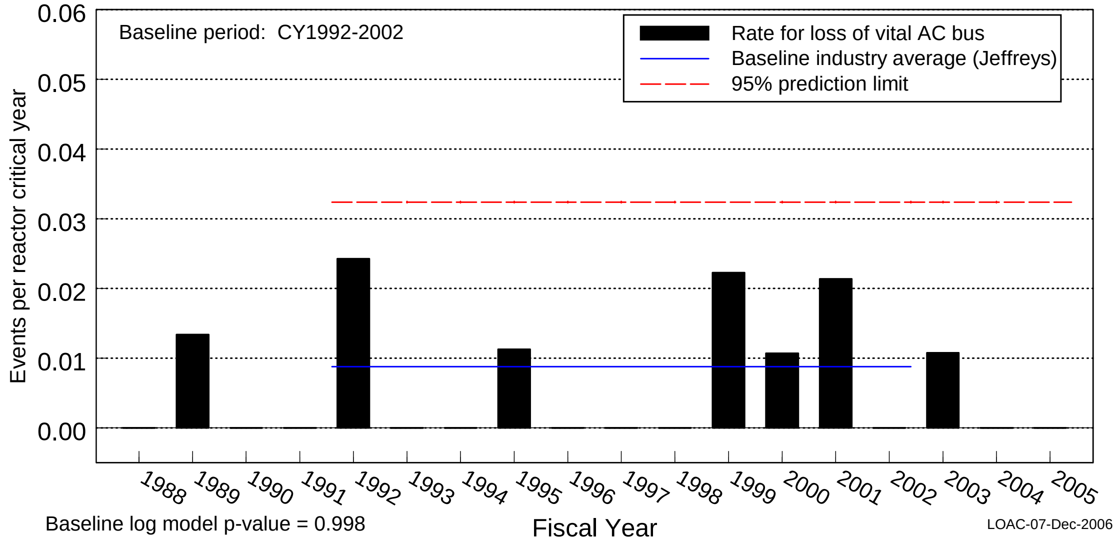

Figure A-7. Loss of vital ac bus—LOAC.

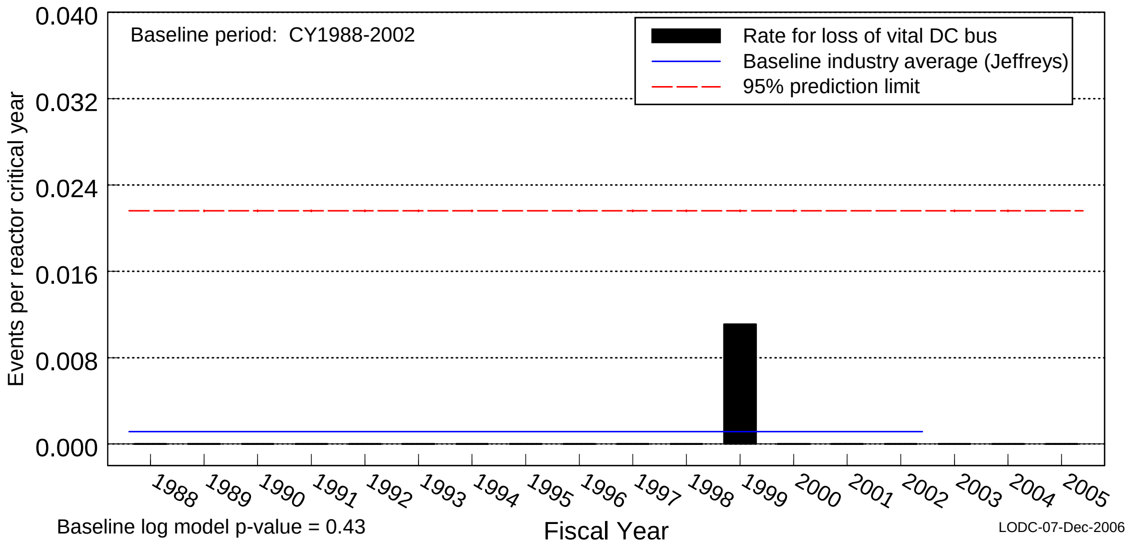

Figure A-8. Loss of vital dc bus—LODC.

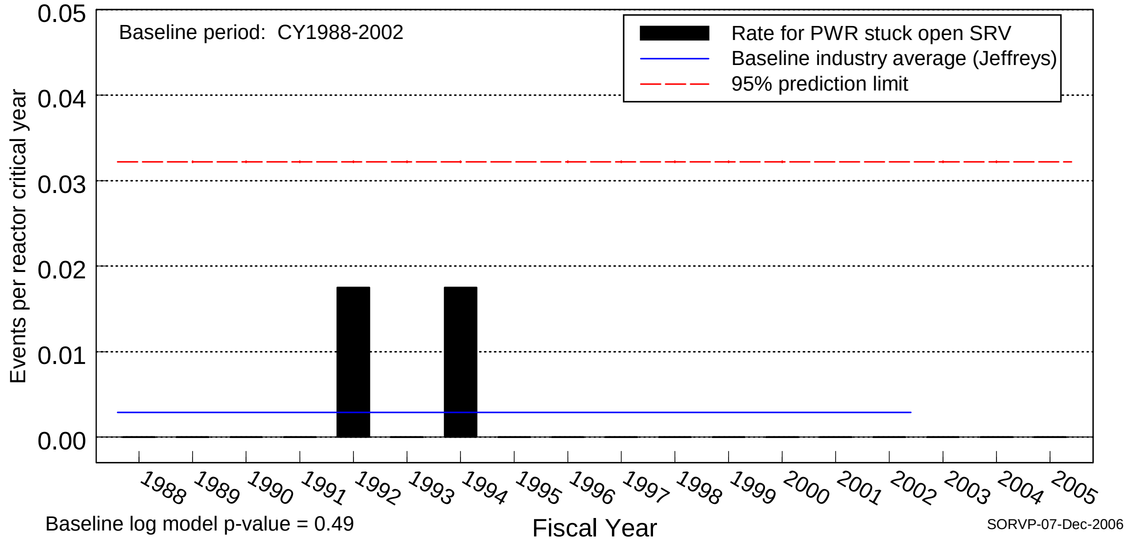

Figure A-9. PWR stuck open SRV—SORV (PWR).

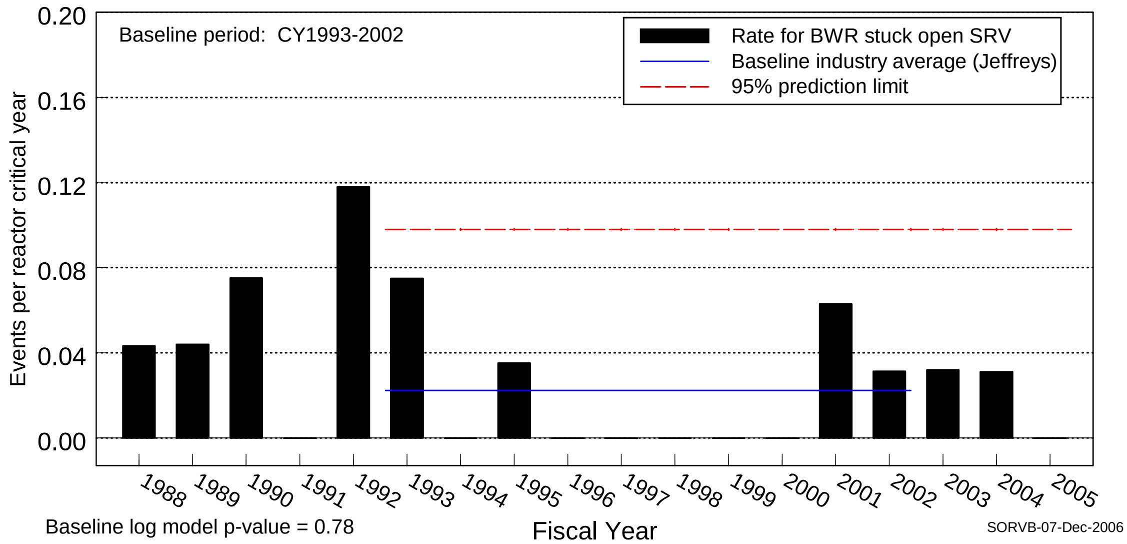

Figure A-10. BWR stuck open SRV—SORV (BWR).

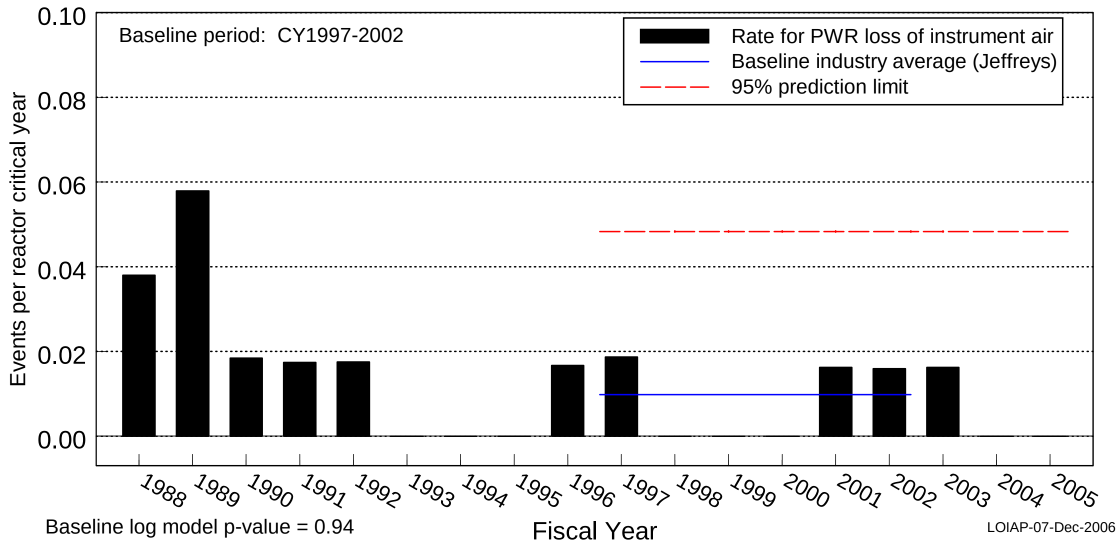

Figure A-11. PWR loss of instrument air—LOIA (PWR).

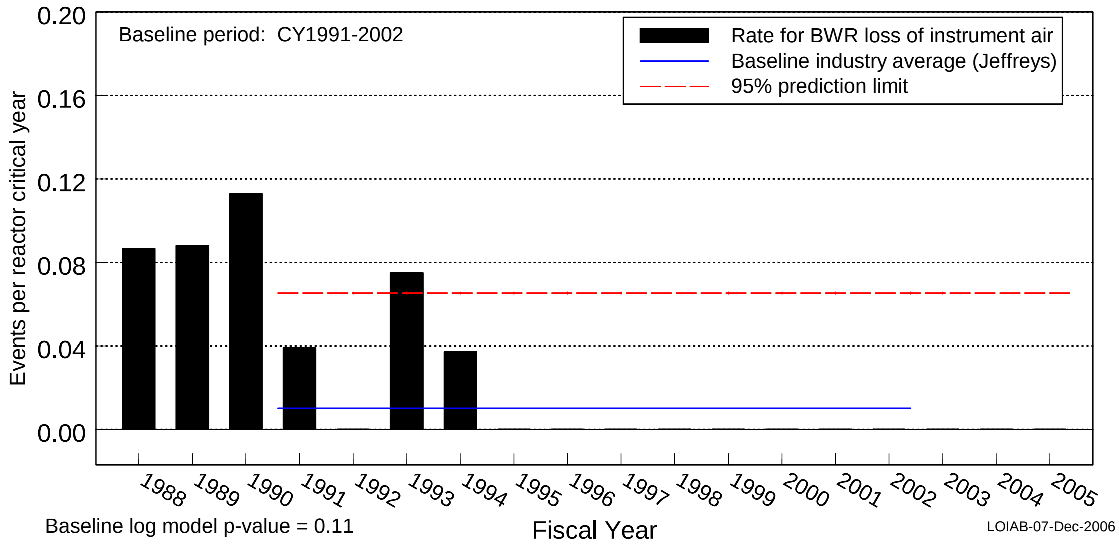

Figure A-12. BWR loss of instrument air—LOIA (BWR).

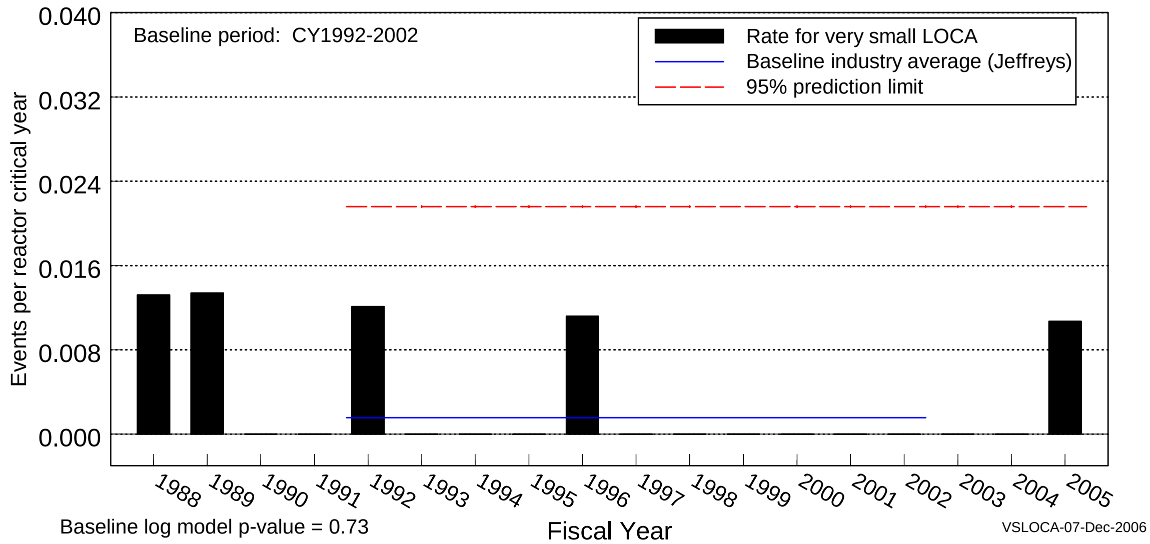

Figure A-13. Very small LOCA—VSLOCA.

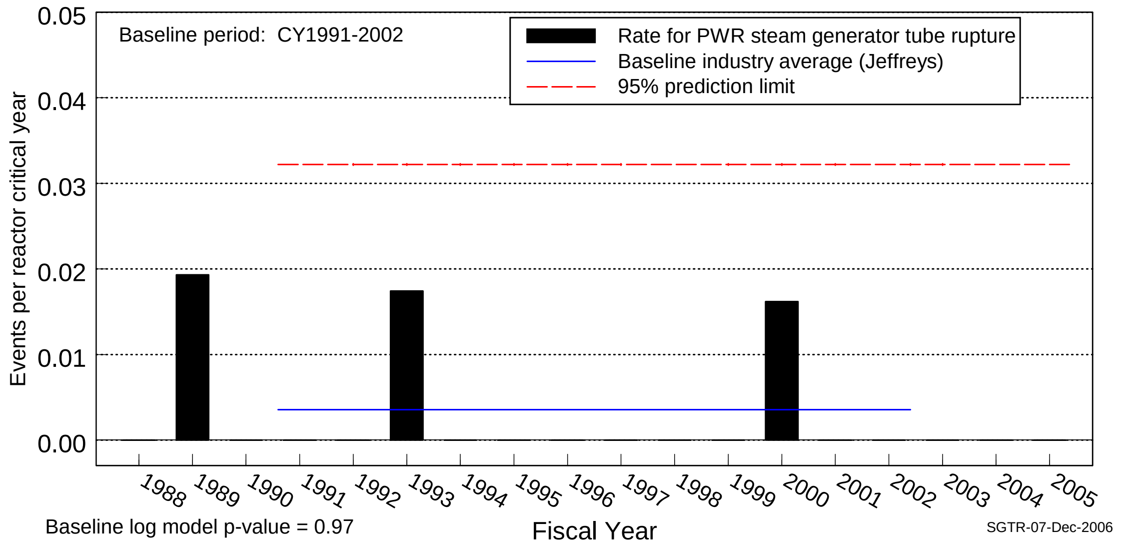

Figure A-14. PWR steam generator tube rupture—SGTR (PWR).

Appendix B

Initiating Event Prediction Limits

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Tables

Appendix B

Initiating Event Prediction Limits

B.1 Introduction

The initiating event baseline frequency distributions used in the Baseline Risk Index for Initiating Events (BRIIE) are presented in Table B-1. These baseline frequency distributions are identical to those presented in NUREG/CR-6928 (Ref. B-1). The distributions were generated in several ways, but in general they are interpreted as representing the plant-to-plant variation in initiating event frequency. The following general principles were used to estimate the amount of plant-to-plant variation:

1. For several cases—TRAN [pressurized water reactor (PWR)], LOCHS [boiling water reactor (BWR)], and LOMFW—the plant-to-plant variation was quantified using the empirical Bayes (EB) method with the Kass-Steffey adjustment. Both the mean of the gamma distribution and the α parameter were obtained from the EB results. These three cases all contained many events over their baseline periods. Using the EB method with the Kass-Steffey adjustment, the resulting distribution reflects both plant-to-plant variation and uncertainty in the mean frequency.
2. At the other extreme, cases with very few events (two or fewer over the baseline period)—LODC, SORV (PWR), VSLOCA, and SGTR—cannot possibly result in quantitative estimates of the plant-to-plant variation because of the limited data. These initiating events are rare and the plant-to-plant variation is believed to be large, although the data are insufficient to validate this belief. For these initiating events, the constrained noninformative distribution (CNID) was chosen. The CNID assumes $\alpha = 0.5$ (indicating a wide distribution) and uses a mean obtained from the data. In this case, the mean was determined using a Bayesian update of the Jeffreys noninformative prior [adding 0.5 to the number of events and dividing by the reactor critical year (rcry) exposure].
3. Other cases—TRAN (BWR), LOCHS (PWR), LOAC, SORV (BWR), and LOIA (BWR)—have enough data to indicate that the plant-to-plant variation is small but not quantifiable using the EB method. For those cases, the baseline data were pooled and used to update the Jeffreys noninformative prior. (Baseline period data presented in Table B-1 represent the pooled data.) However, even for these cases, the resulting distribution was interpreted as reflecting plant-to-plant variation as well as uncertainty about the mean value.

Among the initiating events listed in Table B-1, there are two special cases that do not explicitly follow the general principles listed above. For LOIA (PWR) there were three events in the baseline period. However, in that case, one plant experienced two of the three events. This indicated more plant-to-plant variability than is assumed from the third principle listed above. Therefore, the CNID was used in that case. In addition, for LOOP the distribution was obtained directly from NUREG/CR-6890 (Ref. B-2).

The following sections describe possible methods for determining 95% prediction limits given these baseline frequency estimates and assumptions concerning plant-to-plant variation.

Table B-1. BRIIE initiating event baseline data and frequency distributions.

Initiating Event	Identifier	Baseline Period	Baseline Data (note a)		Gamma Frequency Distribution (note a)		
			Events	Exposure (rcry)	Mean (1/rcry)	α	β (rcry)
General Transient —PWR	TRAN (PWR)	1998–2002	228	304.0	7.51E–01	17.77	23.66
General Transient —BWR	TRAN (BWR)	1997–2002	149	180.2	8.30E–01	149.5	180.2
Loss of Condenser Heat Sink—PWR	LOCHS (PWR)	1995–2002	38	475.0	8.11E–02	38.50	475.0
Loss of Condenser Heat Sink—BWR	LOCHS (BWR)	1996–2002	41	208.6	1.97E–01	11.08	56.38
Loss of Main Feedwater	LOMFW	1993–2002	84	881.9	9.59E–02	1.326	13.83
Loss of Offsite Power	LOOP	1997–2004	24	724.3	3.59E–02	1.580	44.02
Loss of Vital AC Bus	LOAC	1992–2002	8	965.8	8.80E–03	8.500	965.8
Loss of Vital DC Bus	LODC	1988–2002	1	1282.4	1.17E–03	0.500	427.5
Stuck Open SRV —PWR	SORV (PWR)	1988–2002	2	866.6	2.88E–03	0.500	173.3
Stuck Open SRV —BWR	SORV (BWR)	1993–2002	6	291.7	2.23E–02	6.500	291.7
Loss of Instrument Air —PWR	LOIA (PWR)	1997–2002	3	356.9	9.81E–03	0.500	50.99
Loss of Instrument Air —BWR	LOIA (BWR)	1991–2002	3	343.3	1.02E–02	3.500	343.3
Very Small LOCA	VSLOCA	1992–2002	1	965.8	1.55E–03	0.500	321.9
Steam Generator Tube Rupture —PWR	SGTR (PWR)	1991–2002	2	706.4	3.54E–03	0.500	141.3

Note a – Rcry is reactor critical year.

B.2 Basics

If an event rate λ has a gamma(α, β) distribution, and if X given λ has a Poisson(λt) distribution, for some known t, then the unconditional gamma-Poisson distribution of X is negative binomial:

$$\Pr(X = x) = \binom{\alpha + x - 1}{\alpha - 1} p^{\alpha}(1-p)^{x} = \frac{\Gamma(\alpha + x)}{\Gamma(\alpha)x!} p^{\alpha}(1-p)^{x}, \quad x = 0, 1, 2, \ldots \tag{B-1}$$

where $p = \beta/(\beta+t)$. Denote this as negative binomial(p, α). The mean of the negative binomial is

$E(X) = \alpha(1 - p)/p$

and the variance is

$\mathrm{var}(X) = E(X)/p$.

When we have many values X_i, such as the counts from many plants, each X_i has an unconditional negative binomial(p_i, α) distribution, where $p_i = \beta/(\beta+t_i)$. However, the distribution of the sum of event counts, $X = \Sigma X_i$, depends on the model, which may have a common λ for all the X_is or a distinct value of λ for each X_i.

The Bayesian predictive distribution of X is defined as follows. Suppose that X has a distribution that depends on a parameter that we denote generically as θ. In the simplest model, θ is just the event rate λ, but in a hierarchical model θ is the two-dimensional pair (α, β). Let θ have a Bayesian distribution g that is evaluated using baseline data. Then the predictive distribution of X is defined as

$$\Pr(X = x) = \int \Pr(X = x \mid \theta) g(\theta) d\theta \ .$$

Simple Model Assuming λ Is the Same for All Plants

In the simple model, λ is assumed to be the same for all plants. Conditional on λ, $X = \Sigma X_i$ has a Poisson(λt) distribution, where $t = \Sigma t_i$. If the Jeffreys prior is used and updated with x_{base} events in the baseline period of t_{base} reactor critical years, the posterior distribution of λ is gamma(α, β), where $\alpha = x_{base} + 0.5$ and $\beta = t_{base}$. Use this distribution of λ, and let t be the number of rcry in some future prediction period. The predictive distribution of X is negative binomial(p, α), where $p = \beta/(\beta+t)$. The mean is

$$E(X) = \alpha(1 - p)/p = t\alpha/\beta = t(x_{base} + 0.5)/t_{base}. \tag{B-2}$$

The variance is

$$\mathrm{var}(X) = \alpha(1 - p)/p^2 = E(X)(\beta + t)/\beta = E(X)(1 + t/t_{base}). \tag{B-3}$$

A Poisson count would have variance equal to the mean. X has a variance somewhat larger than a Poisson random variable with the same mean.

Complex Model Assuming λ Is Different for Each Plant

In the hierarchical model, each plant has a different event rate, with the rate for the i^{th} plant generated randomly from a gamma(α, β) distribution. Then the X_is are independent negative binomial random variables. For the prediction period, we "shuffle the deck," that is, we assume that the same gamma distribution applies, but the high plants during the baseline period are not necessarily the high plants during the prediction period. Also, we assume the same value of t_i for every plant in the prediction period, denoted as t_1, and let m denote the number of plants. It is shown below that the unconditional distribution of X is negative binomial(p_1, $m\alpha$), with $p_1 = \beta/(\beta+t_1)$. This can be used to obtain a prediction limit.

The moment-generating function of X_i is

$$m_{X_i}(s) \equiv E[\exp(sX_i)] = \left[\frac{p_i}{1-(1-p_i)e^s}\right]^{\alpha} \quad \text{(B-4)}$$

with $p_i = \beta/(\beta+t_i)$. This fact is relatively easy to derive from the distribution in Equation (B-1). The moment-generating function of X is the product of the individual moment-generating functions. When the t_is are all equal to the same value, t_1, we have

$$m_X(s) \equiv E[\exp(s\Sigma X_i)] = \prod_{i=1}^{m} E[\exp(sX_i)] = \left[\frac{p_1}{1-(1-p_1)e^s}\right]^{m\alpha} \quad \text{(B-5)}$$

This shows that the unconditional distribution of X is negative binomial(p_1, $m\alpha$).]

It is interesting to work directly with the moments. Suppose, for any values α^* and β^*, that the count at plant i, X_i, has a negative binomial(p, α^*) distribution, where $p = \beta^*/(t_1 + \beta^*)$. In the present application, α^* and β^* are the EB estimates. By the formula for the mean of a negative binomial, the predictive mean count in a future time t_1 is

$$E(X_i) = \alpha^*(1 - p)/p = t_1\alpha^*/\beta^*. \quad \text{(B-6)}$$

Therefore, the predictive mean of ΣX_i is $t\alpha^*/\beta^*$. In practice the values of α^* and β^* are highly correlated, and it turns out that the predictive mean of ΣX_i is almost exactly equal to the observed baseline count multiplied by t/t_{base}, where t is the rcry for all the plants in the prediction period, and t_{base} is the rcry of all the plants in the baseline period. This is very close to Equation (B-2)

By the formula for the variance of a negative binomial,

$$\text{var}(X_i) = t_1(1-p)/p^2 = E(X_i)[(\beta^* + t_1)/\beta^*] = E(X_i)[1 + t_1/\beta^*] . \quad \text{(B-7)}$$

Therefore, we have

$$\text{var}(\Sigma X_i) = E(\Sigma X_i)[1 + t_1/\beta^*] . \quad \text{(B-8)}$$

As before, t_1 is the rcry for one plant in the prediction period. If t_1 is small compared to β^*, then we do not need an accurate estimate of β^*. The variance is only slightly larger than the mean. Therefore, when t_1 is small compared to β^*, the predictive distribution is only slightly wider than the distribution of a Poisson random variable with mean equal to $x_{base}\times t/t_{base}$. This result may be compared with Equation (B-3) for the non-hierarchical case.

B.3 Method of Choice

Given the assumption that there is plant-to-plant variation for initiating event frequencies, the complex model approach discussed above was used. Results are summarized in Table B-2.

Table B-2. BRIIE Tier 1 performance-based prediction limits.

Initiating Event	Identifier	Mean (1/rcry)	Estimated rcry Per Year for Plant Group (note a)	Expected Number of Events Per Year (note b)	95% Prediction Limit
General Transient—PWR	TRAN (PWR)	7.51E-01	62.1	46.6	59
General Transient—BWR	TRAN (BWR)	8.30E-01	30.6	25.4	35
Loss of Condenser Heat Sink—PWR	LOCHS (PWR)	8.11E-02	62.1	5.0	10
Loss of Condenser Heat Sink—BWR	LOCHS (BWR)	1.97E-01	30.6	6.0	11
Loss of Main Feedwater	LOMFW	9.59E-02	92.7	8.9	15
Loss of Offsite Power	LOOP	3.59E-02	92.7	3.3	8
Loss of Vital AC Bus	LOAC	8.80E-03	92.7	0.8	3
Loss of Vital DC Bus	LODC	1.17E-03	92.7	0.1	2
Stuck Open SRV—PWR	SORV (PWR)	2.88E-03	62.1	0.2	2
Stuck Open SRV—BWR	SORV (BWR)	2.23E-02	30.6	0.7	3
Loss of Instrument Air —PWR	LOIA (PWR)	9.81E-03	62.1	0.6	3
Loss of Instrument Air —BWR	LOIA (BWR)	1.02E-02	30.6	0.3	2
Very Small LOCA	VSLOCA	1.55E-03	92.7	0.1	2
Steam Generator Tube Rupture—PWR	SGTR (PWR)	3.54E-03	62.1	0.2	2

Note a – There are 34 BWRs and 69 PWRs (total of 103) in the U.S. commercial nuclear power plant industry. The rcry estimates represent 90% critical operation during a calendar year. Rcry is reactor critical year.
Note b – The expected number of events is the mean frequency multiplied by the plant group rcry.

B.4 References

B-1. Eide, S.A. et al., *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG/CR-6928, February 2007.

B-2. Eide, S.A. et al., *Reevaluation of Station Blackout Risk at Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG/CR-6890, December 2005.

Appendix C

Initiating Event Birnbaum Importance Measures

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Initiating Event Birnbaum Importance Measures

The Baseline Risk Index for Initiating Events (BRIIE) requires Birnbaum importance measures for each of ten types of initiating events. Birnbaum estimates were obtained from the standardized plant analysis risk (SPAR) models of U.S. commercial nuclear power plants. SPAR models cover at power, internal event core damage frequency (CDF). Contributions to CDF from shutdown and from external events are not included at this time. There are 72 SPAR models covering the 103 operating plants [34 boiling water reactors (BWRs), and 69 pressurized water reactors (PWRs)].

The SPAR Rev. 3i models have been updated to SPAR Rev. 3 models. Results from plant visits have been incorporated into all SPAR Rev. 3 models. Birnbaum estimates are based on the SPAR Rev. 3.21 models released in December 2005.

The BRIIE measures the change in CDF, or ΔCDF, resulting from changes in individual initiating event frequencies. For a given initiator, the ΔCDF is the Birnbaum times the change in initiator frequency (current value minus baseline value). Initiating event frequencies are presented as events per reactor critical year (rcry), and the associated Birnbaums have no units. Table C-1 shows the Birnbaum importance measures for each initiator.

Table C-1. Plant-group average Birnbaum importance measures.

Initiating Event	Birnbaum Importance (note a)		Initiator Modeled Explicitly in SPAR?	Birnbaum Importance Obtained How?	Comments
	BWRs	PWRs			
General Transient —TRAN	5.51E-07	7.97E-07	Yes (note b)	BWR: SPAR output PWR: cut set slicing	All BWR models explicitly model general transients, loss of condenser heat sink, and loss of main feedwater. About half of the PWR models do this; the others must be determined by cut set slicing.
Loss of Condenser Heat Sink—LOCHS	4.31E-06	2.32E-05	Yes/No (note b)		
Loss of Main Feedwater —LOMFW	2.32E-06	2.01E-06	Yes/No (note b)		
Loss of Offsite Power —LOOP	6.15E-05	1.12E-04	Yes	Directly from SPAR output	
Loss of Vital AC Bus —LOAC	6.85E-05	4.22E-05	Yes	Directly from SPAR output	SPAR models include this initiator if it is risk significant at the plant in question. Thirty four plant models include this initiator.
Loss of Vital DC Bus —LODC	2.61E-04	9.39E-04	Yes	Directly from SPAR output	PWR results dominated by 4 plants (out of 66 PWRs with LODC included in the SPAR models)
Stuck Open SRV —SORV	4.59E-06	7.14E-04	No	BWR: SPAR output PWR: cut set slicing	
Loss of Instrument Air —LOIA	3.40E-05	6.57E-05	Yes	Directly from SPAR output	
Very Small LOCA —VSLOCA	5.51E-07	7.97E-07	Yes	Directly from SPAR output	
Steam Generator Tube Rupture—SGTR	Not applicable	3.89E-04	Yes	Directly from SPAR output	SPAR models for this initiator are thought to be conservative (result in high CDF estimates).

Note a – Per plant
Note b – In some of the PWR general transient event trees, top events also cover loss of main feedwater, loss of condenser heat sink, and stuck open SRV. Therefore, the Birnbaum obtained directly from the SPAR output for the general transient initiator reflects importances from four types of initiating events. To obtain the correct Birnbaum for the general transient initiator, cut set slicing was used.

Appendix D
BRIIE Tier 2 Formulations

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BRIIE Tier 2 Formulations

The Baseline Risk Index for Initiating Events (BRIIE) Tier 2 (or BRIIE for short) measures the change in core damage frequency (CDF), or ΔCDF, resulting from changes in individual initiating event frequencies. For a given initiator, the ΔCDF is the Birnbaum importance measure times the change in initiator frequency (current value minus baseline value). If initiating event frequencies are presented as events per reactor critical year (rcry), then the BRIIE has units of ΔCDF (per rcry) for the average plant.

This appendix explores the various potential methods for quantifying the BRIIE. In addition, two methods used to calculate the initiating event current frequency are explored: Bayesian update and maximum likelihood estimate (MLE). Therefore, this appendix investigates the sensitivity of the BRIIE to various modeling assumptions (or formulations).

Finally, a variation of the BRIIE calculation that does not compare the current frequency to the baseline frequency is investigated for illustrative purposes.

D.1 BRIIE Calculations Using Group and Plant-Specific Methods

The BRIIE can be calculated for groups of plants, depending on which group the Birnbaum and initiating event frequency are based on. The most obvious groups are

- Industry – the BRIIE represents an average of all plants
- Plant type – the BRIIE represents an average boiling water reactor (BWR) or pressurized water reactor (PWR) plant.

The recommended BRIIE methodology is to calculate results at the plant-group (BWR or PWR) level and then combine those results into an industry average result. Given a specific group, the BRIIE is calculated using a group-specific average Birnbaum and group current frequency for each initiating event. However, the BRIIE could be calculated by averaging plant-specific results (using plant-specific Birnbaums and plant-specific current frequencies) within the group. Both calculation approaches are listed in Table D-1.

Table D-1. Matrix of grouping and calculation methods.

Group	Calculation Method	Designation
Plant Group	Type-Average	BWR-BRIIE-A PWR-BRIIE-A
Individual Plant	Plant-Specific	BWR-BRIIE-P PWR-BRIIE-P

The group-average BRIIE (ΔCDF) is given by the following equation:

$$BRIIE_A = \sum_{i=1}^{m} \overline{B_i}\left(\lambda_{ic}^{*} - \lambda_{ib}\right), \qquad \text{(D-1)}$$

where

$m =$ number of initiating events covered in the BRIIE

$\overline{B_i} =$ group-average Birnbaum for initiating event *i*

$\lambda_{ic}^{*} =$ group current frequency for initiating event *i*

$\lambda_{ib} =$ baseline frequency for initiating event *i*.

The plant-specific BRIIE (ΔCDF) is given by the following equation:

$$BRIIE_P = \frac{\sum_{j=1}^{n}\sum_{i=1}^{m} B_{i,j}\left(\lambda_{ip,j} - \lambda_{ib}\right)}{n}, \qquad \text{(D-2)}$$

where

$n =$ number of plants in the group

$B_{i,j} =$ plant-specific Birnbaum for initiating event *i*, plant *j*

$\lambda_{ip,j} =$ plant-specific current frequency for initiating event *i*, plant *j*.

Equation (D-1) uses initiating event Birnbaums averaged across the plants within the group (e.g., BWRs) and the group current frequency for each initiating event. The products of the Birnbaum and change in initiating event frequency (current minus baseline) are summed to obtain the BRIIE.

Equation (D-2) uses the plant-specific Birnbaum and plant-specific current frequency of the initiating event compared to the baseline frequency. The sum of these products is the BRIIE for that plant for that year. The sum over all plants gives the integrated ΔCDF for that year and this divided by the number of plants gives the per plant ΔCDF for that year. The results of Equations (D-1) and (D-2) would be equal if the Birnbaums and initiating event frequencies were equal for all plants. However, Equation (D-2) emphasizes the coincidence of the Birnbaum importance and the occurrence of an initiating event at each individual plant as compared with Equation (D-1).

D.1.1 Comparison of BRIIE Averaging Method

Figure D-1 and Figure D-2 show the comparison between Equations (D-1) and (D-2) for BWRs and PWRs. There are significant differences between the two equation variations. In some cases, the yearly results flip from negative to positive (or vice-versa). This generally occurs only when the calculation results are close to zero.

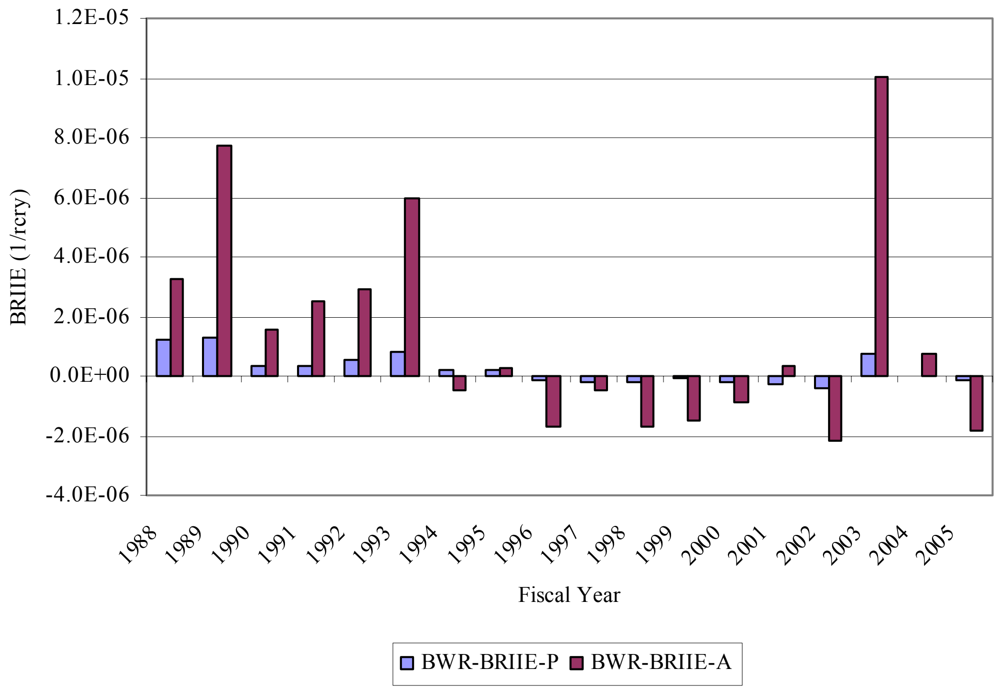

Figure D-1. Comparison of BWR BRIIE results using plant-specific and group-average BRIIE calculations.

The average BRIIE method generally results in a larger prediction of the average plant ΔCDF. The average BRIIE calculation effectively applies observed initiating events to plants that did not actually observe them. In addition, the average initiating event Birnbaum is also applied, giving less credit to those plants that have lower Birnbaums and minimizing the impact of the plants with high Birnbaums. The combined effect is to predict larger results for the average BRIIE versus the plant-specific BRIIE.

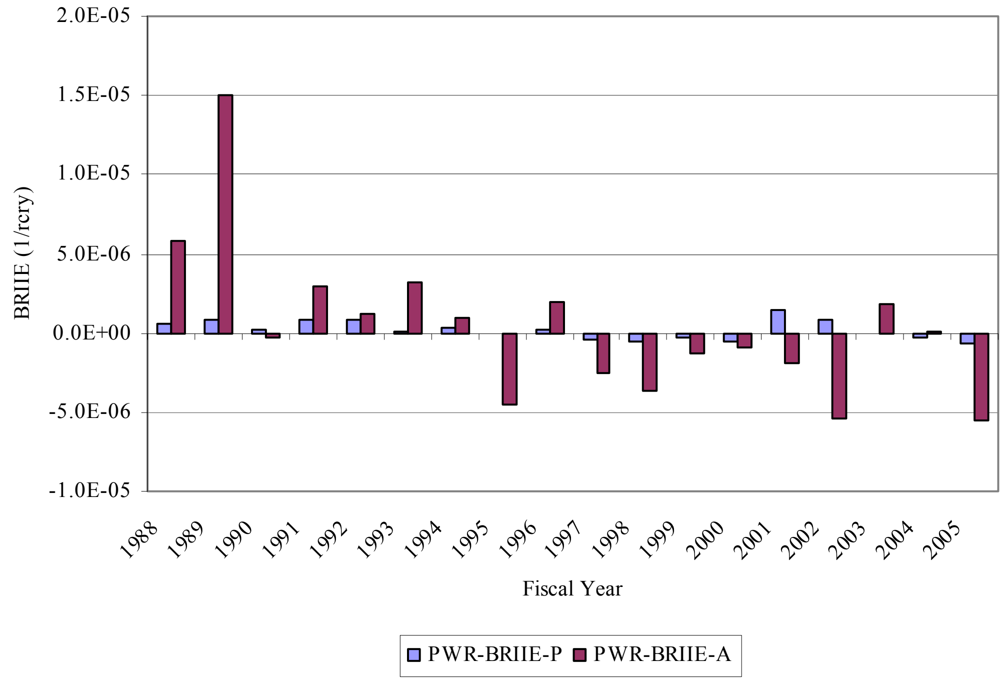

Figure D-2. Comparison of PWR BRIIE results using plant-specific and group-average BRIIE calculations.

In FY 2003, Figure D-1 shows a significant difference (approximately a factor of 14) in the calculated BWR BRIIE between the group-average and the plant-specific methods. In FY 2003, there were eight BWR loss of offsite power (LOOP) events. These are the major contributors to the increase of the BRIIE over the baseline. We will investigate the LOOP calculation.

The group-average LOOP Birnbaum for a BWR plant is 6.15E–05. The plant-specific average Birnbaum for the eight BWR plants that recorded a LOOP is 3.8E–05. In addition, only one of those eight plants has a Birnbaum larger than the group-average Birnbaum. The Birnbaum difference only accounts for a factor of approximately 1.6 in the FY 2003 LOOP BRIIE calculation between plant-specific and type average methods.

In the plant-type average method, the Bayesian update of the LOOP frequency is performed over the plant type. The plant-type average LOOP frequency for FY 2003 is 1.9E–01/rcry, which is 1.6E–01/rcry greater than the LOOP baseline.

In the plant-specific method, the Bayesian update of the LOOP frequency is performed for each plant. The plants that did not experience a LOOP event that year evaluate to approximately 3.37E–02/rcry current LOOP frequency, which is 2.2E–03/rcry less than the baseline (making the BRIIE contribution from these plants negligible). The plants that do experience LOOPS evaluate to 1.0E–01/rcry current LOOP frequency, which is 6.5E–02/rcry greater than the baseline (a factor of 2.5 less than the plant-type average frequency).

Therefore, the difference in the LOOP frequency calculation and Birnbaum accounts for about 4 of the factor of 14 ΔCDF difference in FY 2003. The rest of the difference is because the plant-specific result is divided by the number of plants in the group (34 BWRs) to get the average BWR result.

D.1.2 Comparison of Bayesian and MLE Frequency Estimates

Previous BRIIE summaries used a Bayesian update to calculate the current frequency for the initiating event. The Bayesian update is calculated using the following equation:

$$\lambda_i^* = \frac{(\alpha_i + c_i)}{(\beta_i + t)}, \qquad \text{(D-3)}$$

where

$\alpha_i =$ alpha parameter of the baseline gamma distribution for initiating event *i*

$c_i =$ the plant count(s) for initiating event *i* in the current year

$\beta_i =$ beta parameter of the baseline gamma distribution for initiating event *i*

$t =$ critical time (rcry) for current year at the plant(s).

In Equation (D-3), the quantities c_i and *t* refer to either an entire plant group or to a single plant, depending upon the BRIIE quantification approach being used.

We decided to investigate the use of another way of expressing the current frequency at a plant in the current year, the MLE:

$$\lambda_i^* = \frac{c_i}{t}. \qquad \text{(D-4)}$$

Similar to Equation (D-3), the quantities c_i and *t* in Equation (D-4) refer to either an entire plant group or to a single plant, depending upon the BRIIE quantification approach being used.

The MLE is calculated using the current year's initiating event counts for the plant (or group of plants) and that plant's (or group of plants') critical operating history for the year. Essentially, the occurrence of no particular initiating event would result in a zero current frequency and one observed event would result in a greater than 1.0/rcry current frequency (plants rarely have a full 1.0 rcry during a year). The MLE BRIIE (ΔCDF) calculation variation would in effect credit a plant for the lack of observed initiating events (negative BRIIE contribution) and strongly penalize a plant for any observed initiating events (positive BRIIE contribution). This should give the maximum sensitivity to the importance of initiating events occurring over time at various plants.

The following charts show comparisons of the calculation results (MLE versus Bayesian) for the cases of Birnbaums and initiating events averaged over the plant type and calculation method as shown in Table D-2.

Table D-2. Matrix of Birnbaum and IE count average figures.

Plant Type	Group-Average Birnbaum and IE Count	Plant-Specific Birnbaum and IE Count
BWR	Figure D-3	Figure D-5
PWR	Figure D-4	Figure D-6

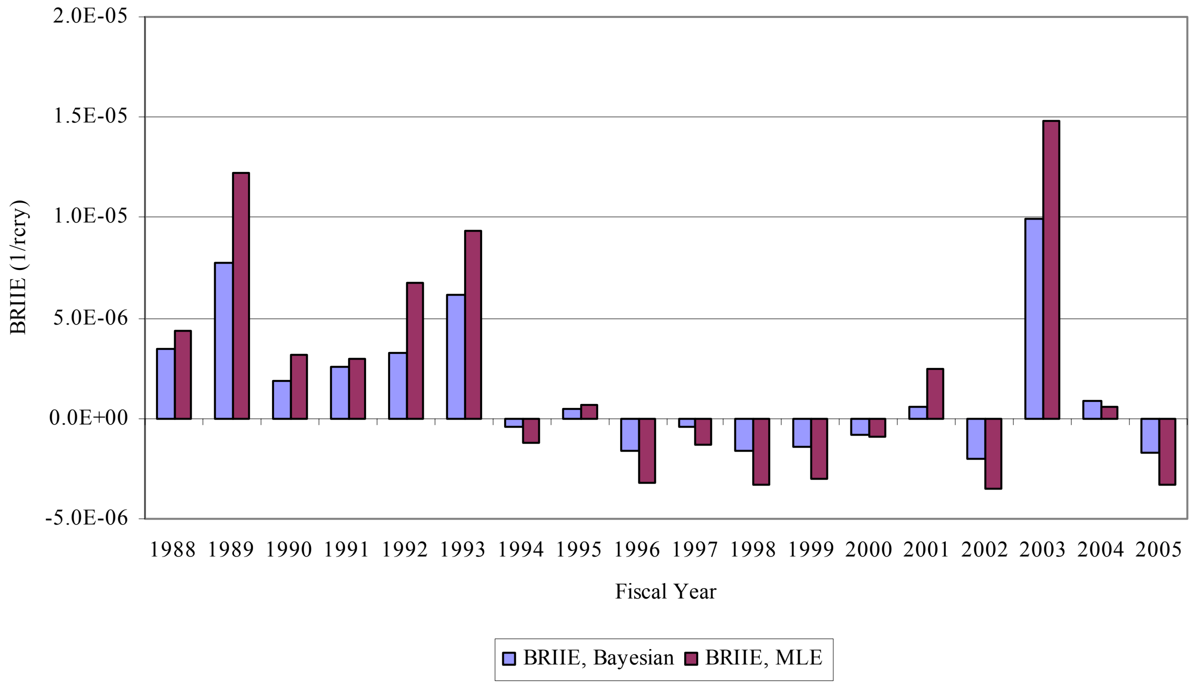

Figure D-3. BWR group-average calculation showing Bayesian and MLE results.

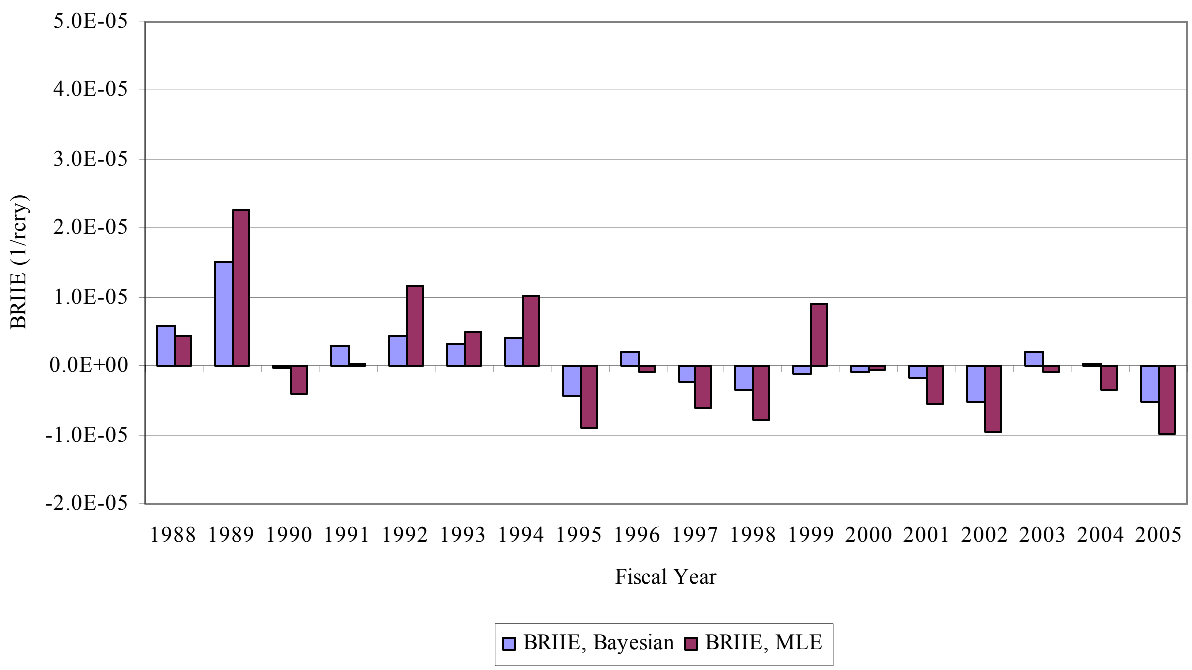

Figure D-4. PWR group-average calculation showing Bayesian and MLE results.

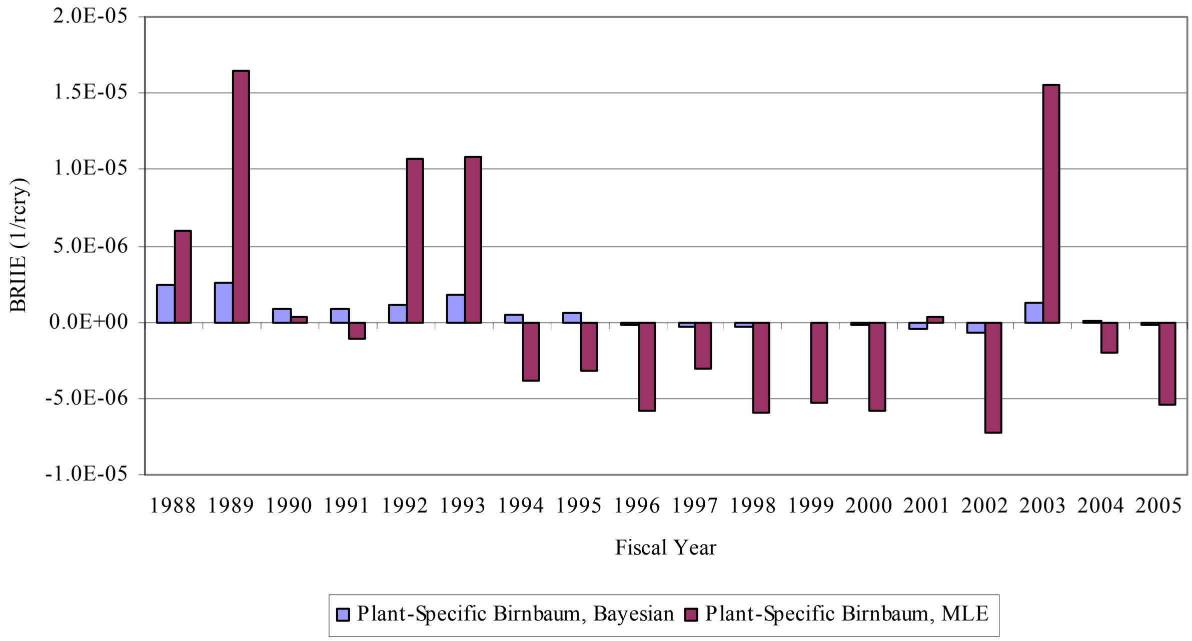

Figure D-5. BWR plant-specific calculation showing Bayesian and MLE results.

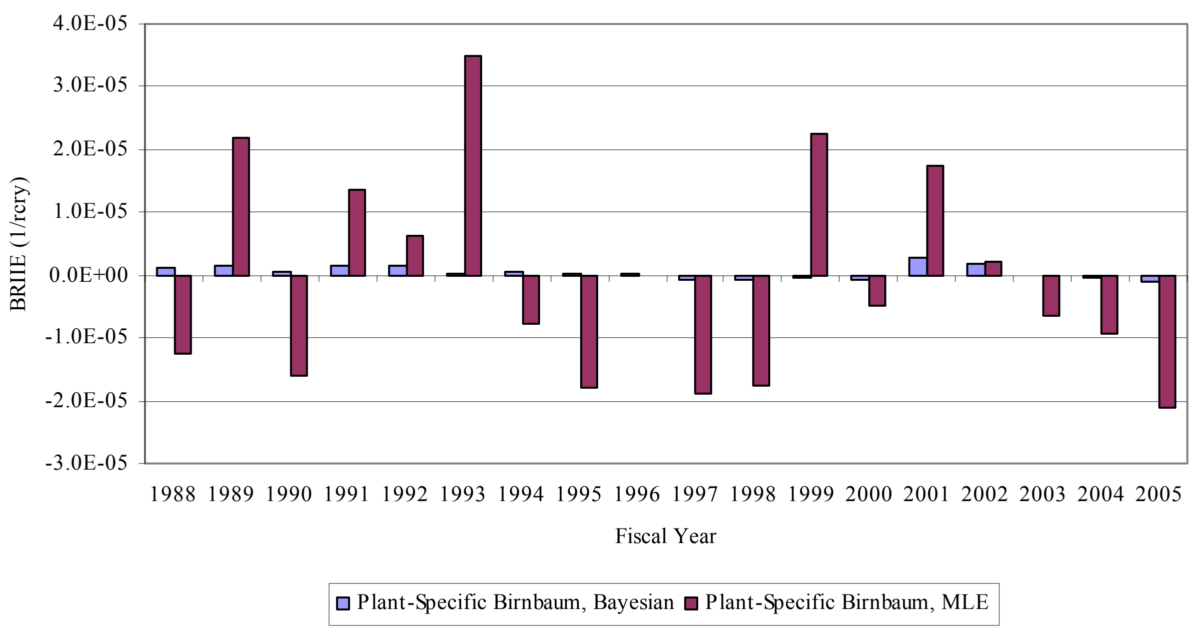

Figure D-6. PWR plant-specific calculation showing Bayesian and MLE results.

The MLE method shows larger results than the Bayesian method. In the MLE calculation when no events occur, the difference between the observed frequency (MLE) and the baseline frequency is the negative of the baseline frequency. This decreases the total BRIIE significantly. When initiating events occur, the MLE is ≥ 1.0/rcry. The difference between the observed frequency (MLE) and the baseline frequency in those cases is large. This increases the total BRIIE significantly. The net effect, in general, is that the calculated BRIIE (absolute value) is larger for the MLE method.

D.2 Industry Total Calculations

The previous discussions have shown plant-type calculations using group-average and plant-specific calculations. The true average plant in the US is not PWR or BWR, but a weighted average of the two. This section will display results for the industry, comparing the same types of calculations.

D.2.1 Comparison of BRIIE Averaging Method

Figure D-7 shows BRIIE results at an industry level using industry-average and plant-specific averaging methods. The phenomena shown in Figure D-1 and Figure D-2 generally are dampened in Figure D-7. The large peak in FY 2003 in Figure D-1 is no longer dominant. The large peak in FY 1989 from Figure D-2 is still dominant.

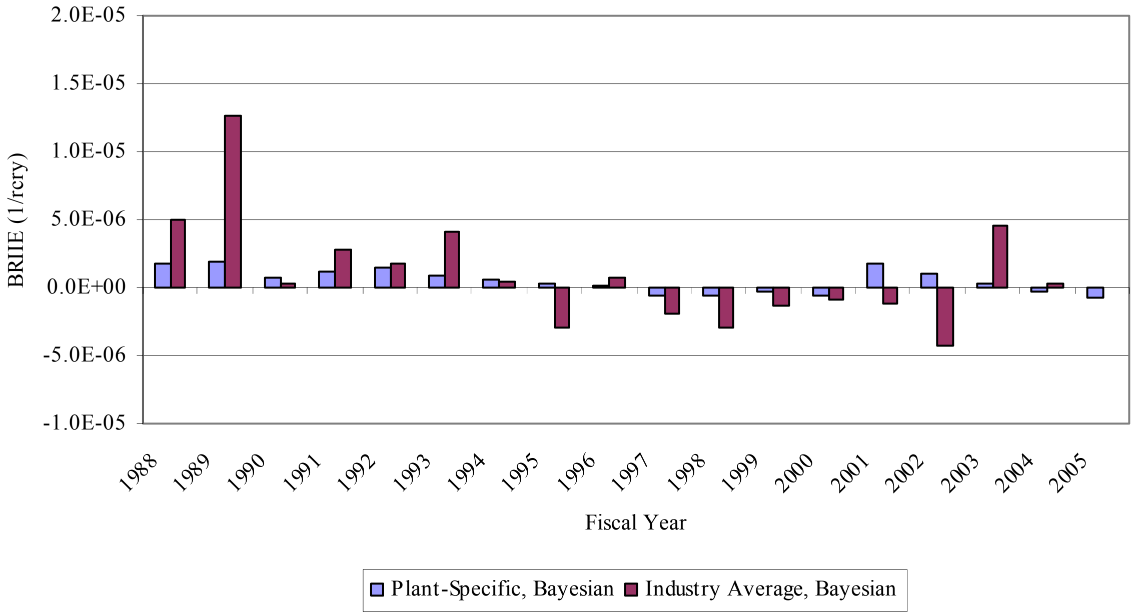

Figure D-7. Comparison of industry BRIIE results using industry-average and plant-specific BRIIE calculations.

D.2.2 Comparison of Bayesian and MLE Frequency Estimates

Figure D-8 and Figure D-9 show comparisons of the calculation results (MLE versus Bayesian) for the cases of Birnbaums and initiating events averaged over the industry or plant-specific groups.

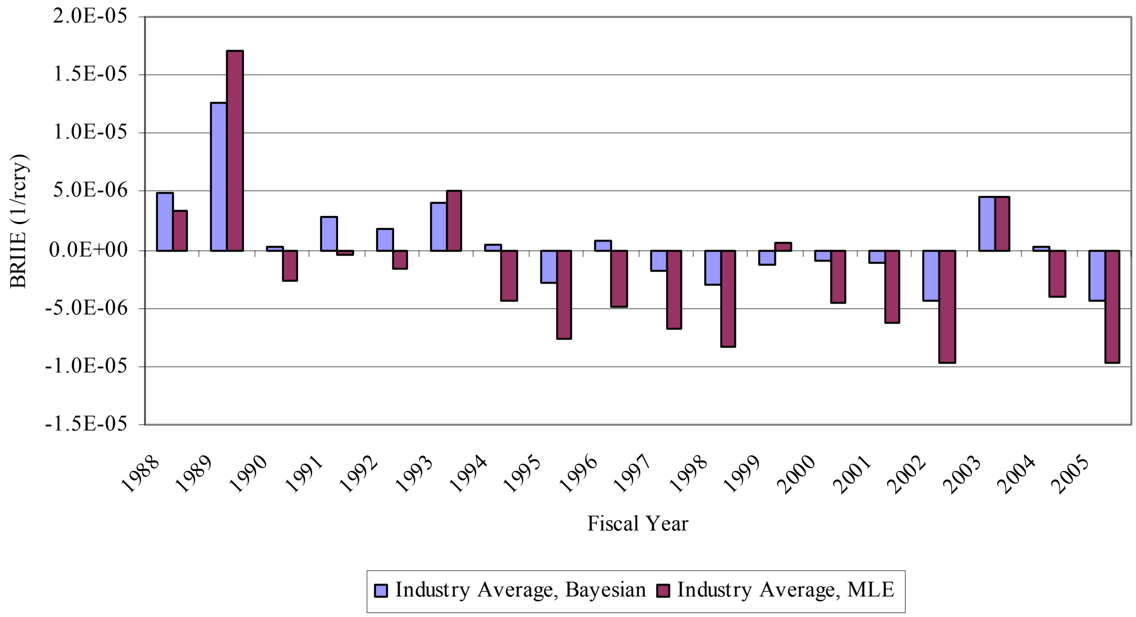

Figure D-8. Industry average calculation using industry-average method showing Bayesian and MLE results.

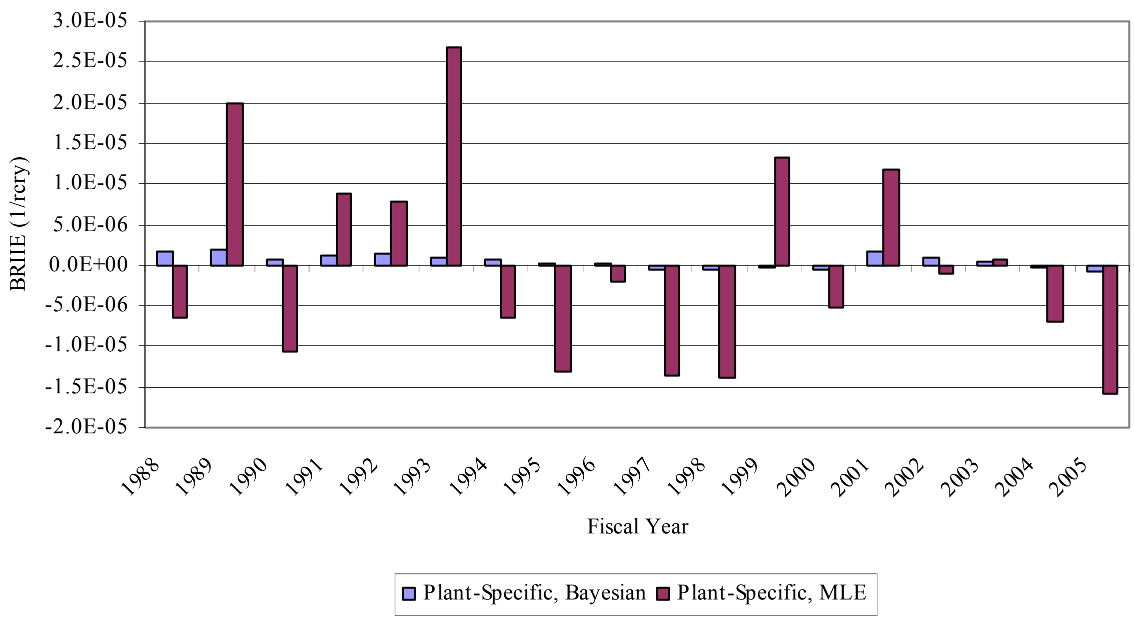

Figure D-9. Industry calculation using plant-specific method showing Bayesian and MLE results.

D.3 Comparison of Bayesian and MLE Frequency Estimates Using Core Damage Frequency

Several different quantification methods were considered for evaluating the BRIIE. One method related to CDF represents an absolute measure of CDF for the selected initiating events. This section presents the results of Sections D.1 and D.2 using CDF rather than ΔCDF.

To keep the different calculation types straight, this measure will be called the Risk Index for Initiating Events, or RIIE since there is no baseline term in the equations. These RIIE metrics can be calculated using varying levels of averages. All of the results represent CDF (per rcry) for the average plant.

Table D-3. Matrix of group-average calculation methods for CDF.

Group	Calculation Method	Designation
Plant Group	Group Average	BWR-RIIE-A PWR-RIIE-A
Individual Plant	Plant-Specific	BWR-RIIE-P PWR-RIIE-P

The average RIIE, related to CDF, is given by the following equation:

$$RIIE_A = \sum_{i=1}^{m} \overline{B_i}\left(\lambda_{ic}^{*}\right), \tag{D-5}$$

where

m = number of initiating events covered in the BRIIE

$\overline{B_i}$ = group-average Birnbaum for initiating event i

λ_{ic}^{*} = common group current frequency for initiating event i.

The plant-specific RIIE, related to CDF, is given by the following equation:

$$RIIE_P = \frac{\sum_{j=1}^{n}\sum_{i=1}^{m} B_{i,j}\left(\lambda_{ip,j}\right)}{n}, \tag{D-6}$$

where

n = number of plants in the group

$B_{i,j}$ = plant-specific Birnbaum for initiating event i, plant j

$\lambda_{ip,j}$ = plant-specific current frequency for initiating event i, plant j.

The following charts show the calculation of an absolute risk parameter (RIIE) using both the Bayesian and MLE methods. The absolute risk lends itself to comparisons of contributions of each initiator. Table D-4 shows the matrix of the calculations and the charts.

Table D-4. RIIE figure matrix.

Plant Type	Frequency Calculation Type	Average Birnbaum and IE Count	Plant-Specific Birnbaum and IE Count
BWR	Bayesian	Figure D-10	Figure D-14
PWR	Bayesian	Figure D-11	Figure D-15
BWR	MLE	Figure D-12	Figure D-16
PWR	MLE	Figure D-13	Figure D-17

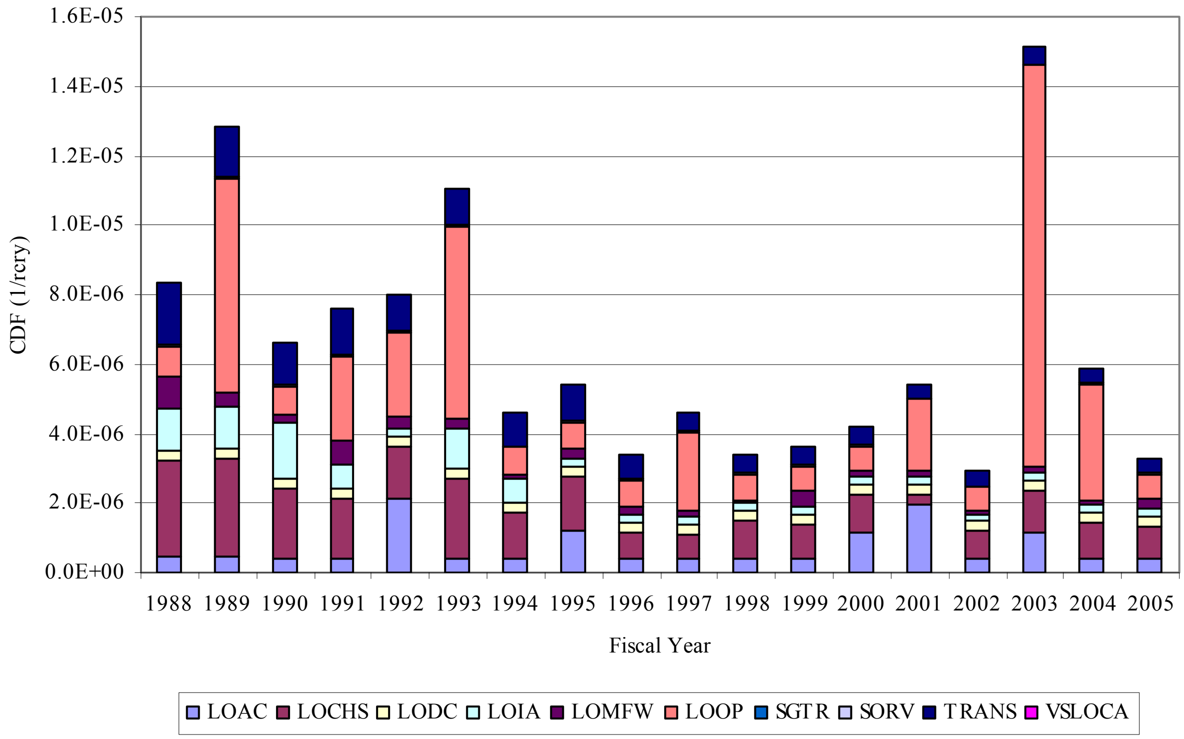

Figure D-10. BWR group-average CDF calculation showing Bayesian results by initiating event.

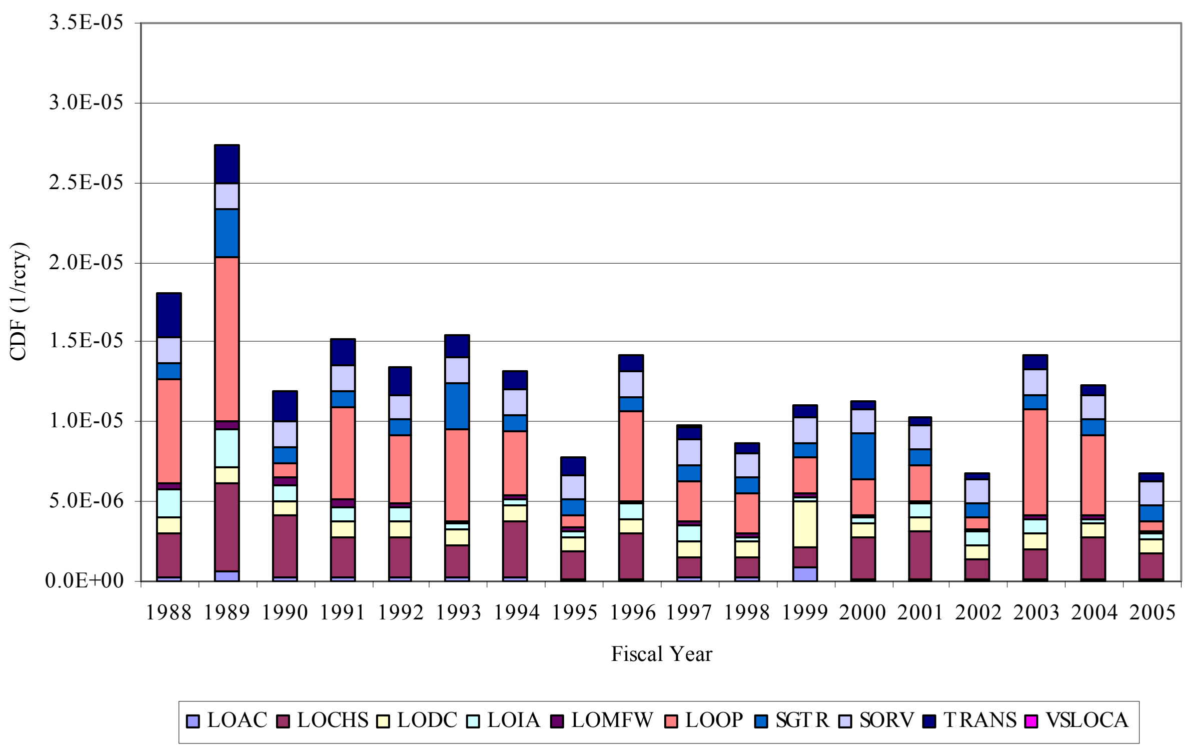

Figure D-11. PWR group-average CDF calculation showing Bayesian results by initiating event.

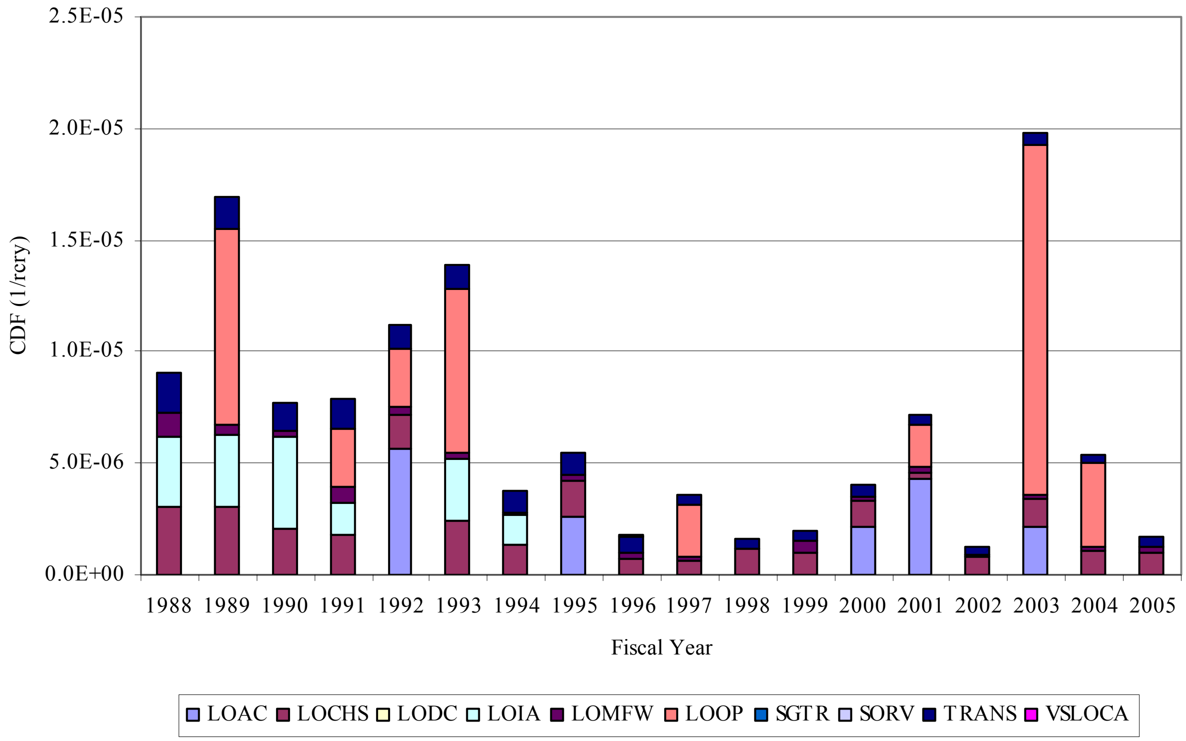

Figure D-12. BWR group-average CDF calculation showing MLE results by initiating event.

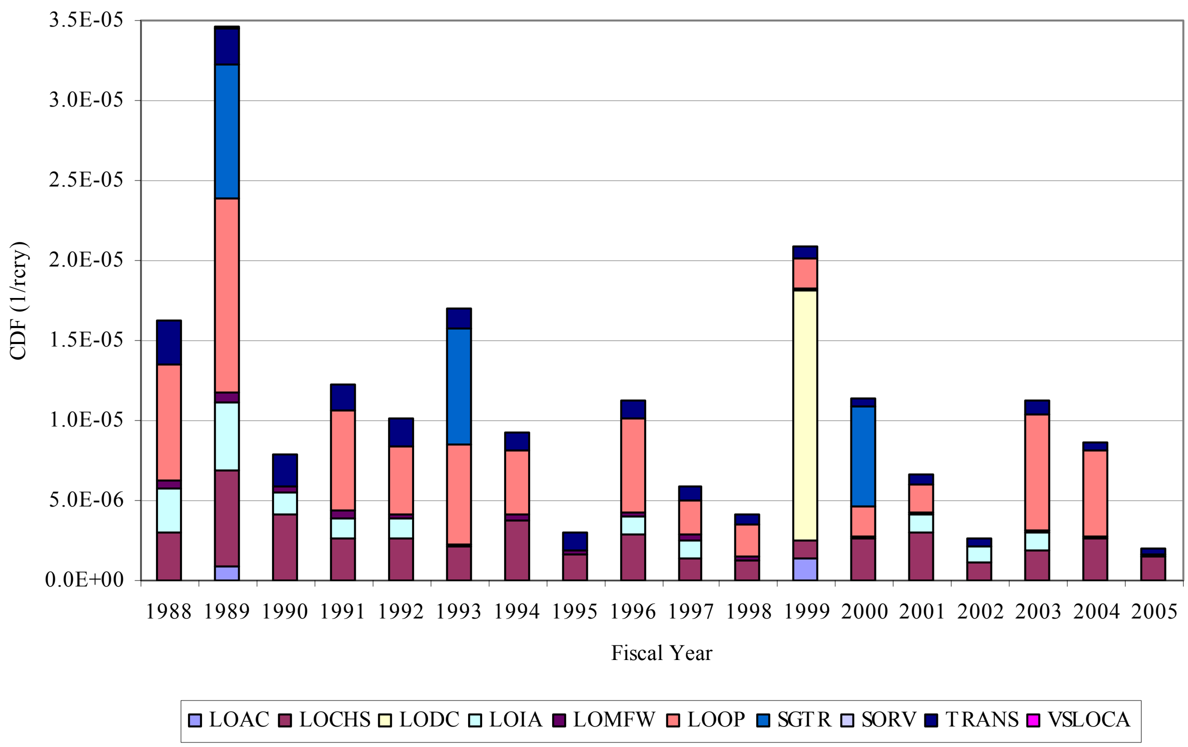

Figure D-13. PWR group-average CDF calculation showing MLE results by initiating event.

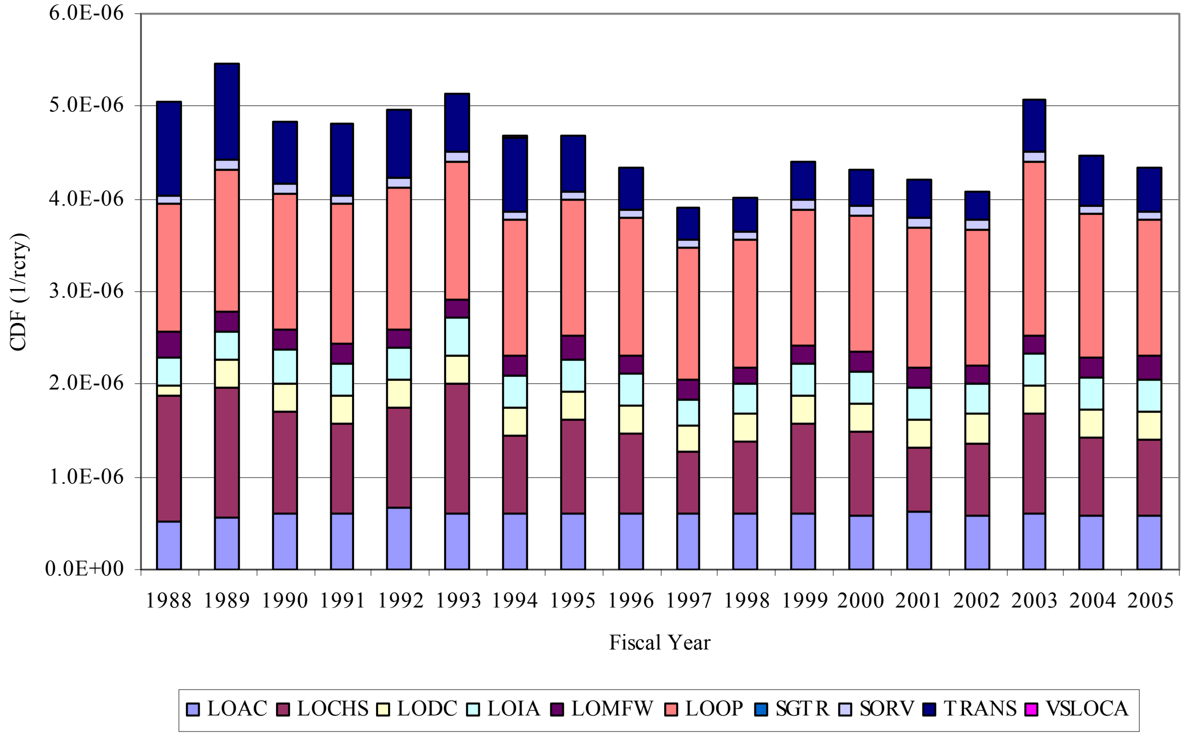

Figure D-14. BWR plant-specific CDF calculation showing Bayesian results by initiating event.

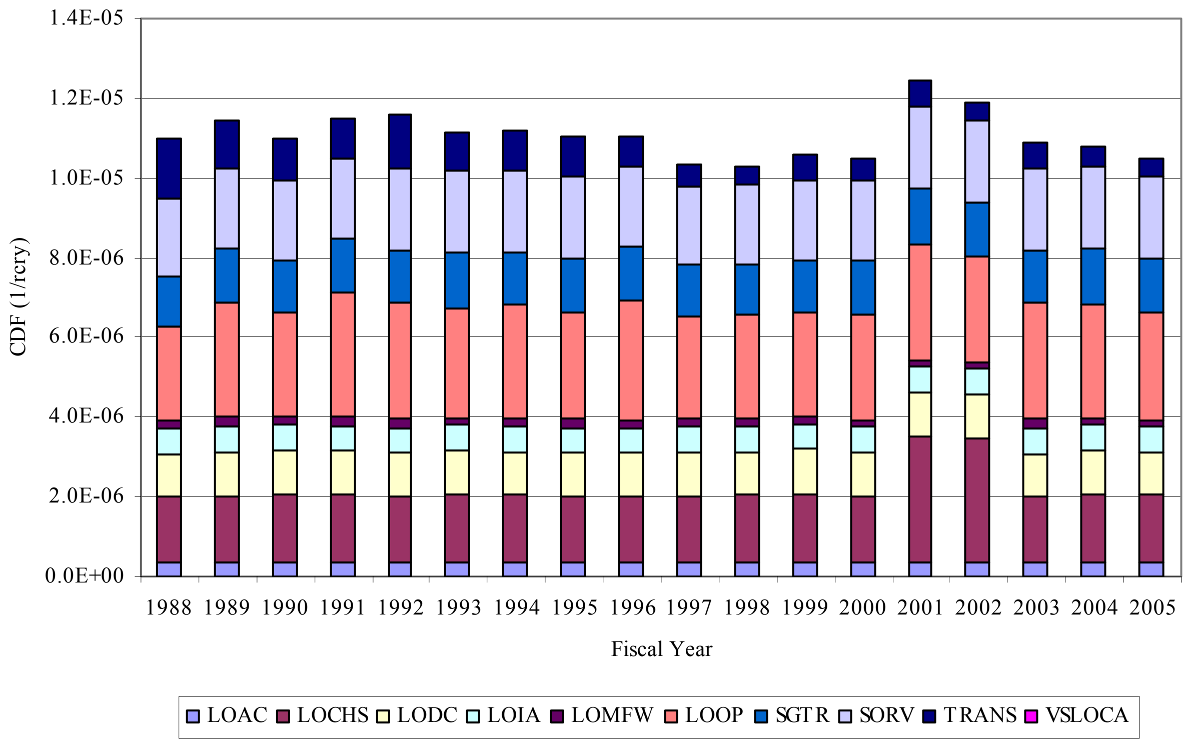

Figure D-15. PWR plant-specific CDF calculation showing Bayesian results by initiating event.

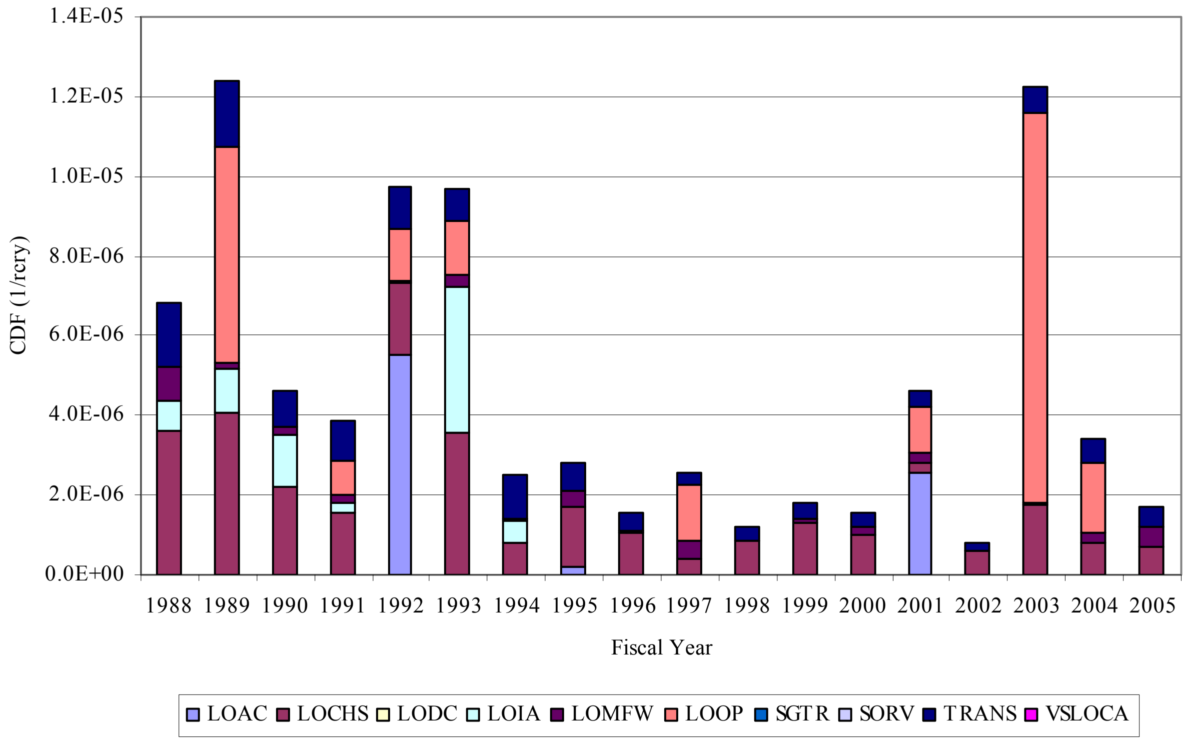

Figure D-16. BWR plant-specific CDF calculation showing MLE results by initiating event.

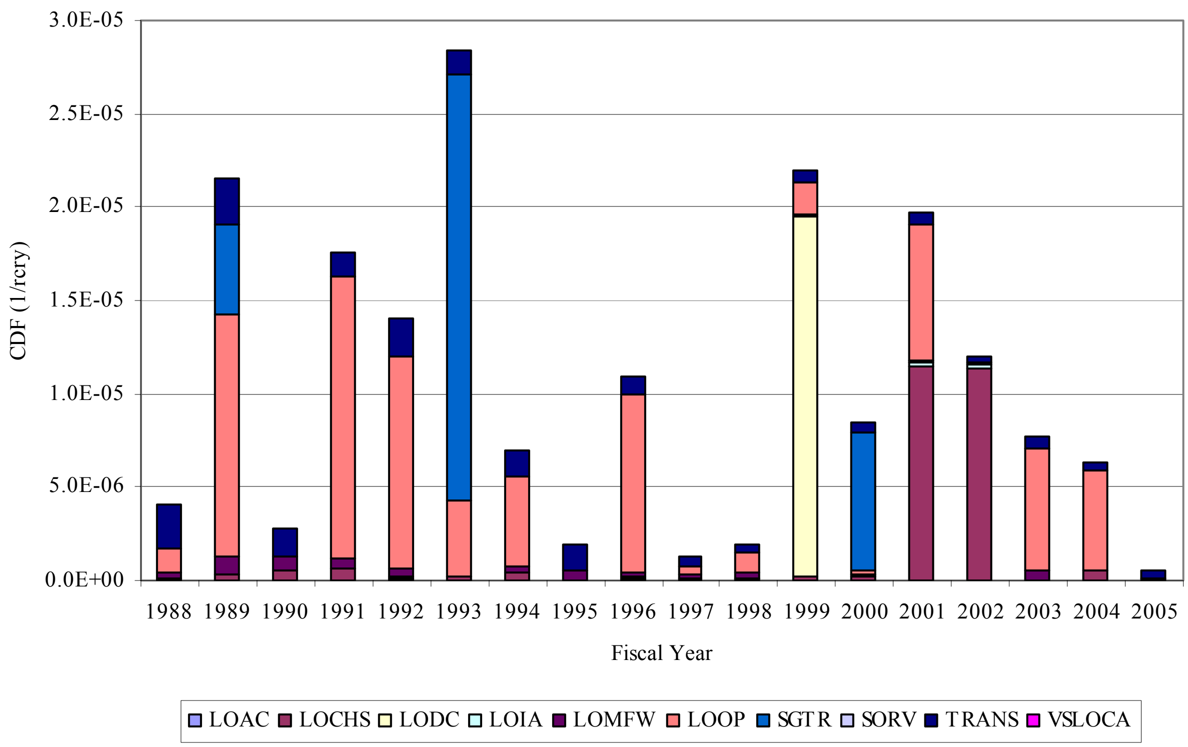

Figure D-17. PWR plant-specific CDF calculation showing MLE results by initiating event.

Table D-5 and Table D-6 show the counts of the initiating events for each plant type. The most important property to notice is that the MLE charts only show bar height for the initiating events that have occurred. The Bayesian update will always have a bar height whether there is an initiating event or not.

Table D-5. BWR initiating event counts.

Initiating Event (note a)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
LOAC					2			1					1	2		1		
LOCHS	15	15	12	10	9	14	8	10	5	4	7	7	8	2	6	9	8	7
LODC																		
LOIA	2	2	3	1		2	1											
LOMFW	10	4	3	8	4	3	1	3	3	2		6	3	3	1	2	2	4
LOOP		3		1	1	3				1				1		8	2	
SORV	1	1	2		3	2		1						2	1		1	
TRANS	70	56	56	61	48	48	44	51	38	24	26	28	30	23	24	28	22	24
VSLOCA									1									1

Note a –These event counts include only the 34 BWRs currently operating.

Table D-6. PWR initiating event counts.

Initiating Event (note a)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
LOAC		1										2						
LOCHS	6	12	9	6	6	5	9	4	7	3	3	3	7	8	3	5	7	4
LODC												1						
LOIA	2	3	1	1	1				1	1				1	1	1		
LOMFW	11	14	12	12	8	3	8	7	7	9	7	5	5	4	1	7	5	4
LOOP	3	5		3	2	3	2		3	1	1	1	1	1		4	3	
SGTR		1				1							1					
SORV					1		1											
TRANS	164	134	122	105	116	92	78	80	74	54	41	57	42	46	32	68	45	33
VSLOCA	1	1			1													

Note a – These event counts include only the 69 PWRs currently operating.

D.4 Conclusions

Two different calculations are helpful to explain the whole story. The BRIIE (ΔCDF) Figure D-7, industry average results, shows average plant risk on a yearly basis, but cannot show each initiating event contribution. Therefore, the RIIE is helpful in explaining what contributes to the BRIIE going up or down.

There are significant differences between the type-average and the plant-specific approaches. The type-average approach produces larger BRIIE values, but does not use all of the available information. The plant-specific approach matches up occurrences of initiating events and the appropriate Birnbaum values. Where the event was important (high Birnbaum value), it shows up as important. However, if the event is not important (low Birnbaum value), then the BRIIE contribution is small.

The use of Bayesian updating versus MLE for the current frequency was examined. The MLE method tends to produce larger results in the BRIIE when initiating events occur. To be consistent with the approach taken for the Mitigating Systems Performance Index (MSPI), the Bayesian update approach was chosen. This approach was also recommended in NUREG-1753 (Ref. D-1). However, MLE CDF results by plant type (BWR or PWR) are helpful in indicating the contributors to yearly BRIIE results.

D.5 References

D-1. Hamzehee, H.G. et al., *Risk-Based Performance Indicators Results of Phase-1 Development*, U.S. Nuclear Regulatory Commission, NUREG-1753, April 2002.

Appendix E

Summary of Expert Panel Meeting

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Appendix E

Summary of Expert Panel Meeting

A panel of experts was convened on July 18 and 19, 2006, in conformance with the completion plan for the Baseline Risk Index for Initiating Events (BRIIE) development effort. The panel consisted of senior managers and staff with extensive knowledge of probabilistic risk assessment (PRA) methods and U.S. Nuclear Regulatory Commission (NRC) policies. Panel members were the following:

- Richard Barrett – Office of Nuclear Regulatory Research (RES)
- Nilesh Chokshi – RES
- Thomas Boyce – Office of Nuclear Reactor Regulation (NRR)
- James Vail – NRR
- Robert Haag – Region II.

E.1 Specific Questions Addressed

The panel was convened with the objective of reviewing the BRIIE effort and establishing threshold values for BRIIE Tier 2 that would trigger an indication of risk-significant, degrading industry performance in initiating events. The specific questions directed to the panel to arrive at the threshold were the following:

1. What form of the BRIIE Tier 2 should be used—absolute core damage frequency (CDF) or ΔCDF?
2. Which form of the initiating event current frequency should be used—maximum likelihood estimator (MLE) or Bayesian update?
3. What initiating events should be included in the BRIIE—the current list, all those contained in the standardized plant analysis risk (SPAR) models, or a subset of all initiating events? (A constant would be added to the absolute form of BRIIE to account for those initiating events that would not be monitored, so that it is almost equal to the internal events estimated CDF. This would subtract out in the difference form of the BRIIE.)
4. Which initiating events should be monitored—those that occur frequently or occasionally (i.e., they have been observed in the past) or all initiating events?
5. Does it make sense to monitor initiating events that have not occurred [e.g., a loss-of-coolant accident (LOCA) event]? How should such an event be treated in the BRIIE if it did occur?
6. Given the characteristics of the BRIIE and the simulation results, what are appropriate CDF and ΔCDF thresholds?
7. What threshold values should be used for reporting to Congress?
8. How often should the initiating event baseline performance be updated? (An example is the LOOP initiating event. Years 2003 and 2004 were different from the years 1997-2002 and 2005.)
9. Does the two-tier BRIIE make sense?

E.2 Conclusions Reached

Discussions during the meeting addressed all these questions. After considerable collegial debate on the pros and cons of the proposed alternatives for each of these issues, the panel reached the following conclusions:

1. Maintain the two-tier process for the BRIIE. The panel felt that both tiers are required to provide an accurate and full picture of industry performance. The two-tiered process provides trending information and action levels for NRC engagement if the 95% prediction limit of Tier 1 is reached, as outlined in the *NRC Inspection Manual*, Manual Chapter 0313, "Industry Trends Program" (Ref. E-1). Tier 2 does not provide strict trending information but provides a risk perspective of industry performance as a deviation from a baseline value and the proximity of the deviation to a set threshold.
2. The presentation for BRIIE should be in a bar graph that provides three separate values for each year: one bar providing industry-wide results, one bar for boiling water reactor (BWR) results, and the third bar for pressurized water reactor (PWR) results. All three bars for each year should be presented on one graph. The panel indicated that this form of presentation provides more information than simply aggregating industry-wide results into one number or presenting BWR and PWR results individually.
3. The BRIIE should be in the form of ΔCDF with Bayesian updating. The absolute CDF form using MLE would be calculated and provided as a communication tool to stakeholders to provide additional insights. The panel preferred the ΔCDF form of BRIIE because the absolute CDF form of BRIIE would result in different levels for BWRs and PWRs. The ΔCDF form shows the change from the baseline for both types of reactors and hence is more understandable. The panel discussed and decided that infrequently occurring initiating events [loss of service water (LOSW), loss of component cooling water (LOCCW), small loss-of-coolant accident (SLOCA), medium loss-of-coolant accident (MLOCA), large loss-of-coolant accident (LLOCA), interfacing system loss-of-coolant accident (ISLOCA), reactor vessel rupture (RXVRUPT), excessive loss-of-coolant accident (X-LOCA), and others] would not be included in the calculation of BRIIE. These events, if they occur, would be captured in the calculation of absolute CDF with MLE.
4. The threshold for reporting to Congress should be set at 1.0E–05 per reactor critical year (rcry). It should be associated only with the ΔCDF BRIIE calculations. This threshold value was derived from considerations of the NRC safety goals, Regulatory Guide 1.174 (Ref. E-2), and consistency with the Reactor Oversight Process (Ref. E-3) and Accident Sequence Precursor (ASP) Program (Ref. E-4). The threshold was derived from coherency with current agency metrics and the surrogates for the safety goals discussed in Regulatory Guide 1.174. Two scenarios were discussed. The first was that a single event at 1.0E–03/rcry ΔCDF (e.g., the current ASP indicator threshold for reporting significant events to Congress) would make the aggregate industry performance about equal to 1.0E–05/rcry ΔCDF (1.0E–03/rcry divided by 100 plants). Also, if 10% of plants had a problem at about 1.0E–04/rcry ΔCDF, then this would also make industry performance about equal to 1.0E–05/rcry ΔCDF. The 10% number was chosen to provide a distinction between an industry problem and issues with individual plants.

The panel was concerned about the loss of offsite power (LOOP) grid-related events of August 2003. The panel felt that these August 2003 events were outliers and may not be representative of baseline industry performance. As a sensitivity study, the BRIIE Tier 2 results by fiscal year were recalculated using a LOOP baseline that excluded the August 2003 grid-related events. Excluding those events resulted in a LOOP baseline frequency of 2.49E–02/rcry, compared with the existing baseline of 3.59E–02/rcry. BRIIE results using the sensitivity case LOOP frequency were similar to those using the existing baseline frequency. Therefore, the panel felt that the BRIIE should use the existing baseline LOOP frequency to be consistent with NUREG/CR-6890 (Ref. E-5) and the SPAR models.

E.3 References

E-1. U.S. Nuclear Regulatory Commission, *NRC Inspection Manual*, Manual Chapter 0313, "Industry Trends Program," ML060320705, March 13, 2006.

E-2. U.S. Nuclear Regulatory Commission, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," Revision 1, Regulatory Guide 1.174, November 2002.

E-3. U.S. Nuclear Regulatory Commission, "Reactor Oversight Process," http://nrc.gov/reactors/operating/ oversight.html.

E-4. U.S. Nuclear Regulatory Commission, "Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk (SPAR) Models," SECY-06-0208, October 2006.

E-5. Eide, S.A. et al., *Reevaluation of Station Blackout Risk at Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG/CR-6890, December 2005.

Appendix F

Resolution of Comments

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Tables

Appendix F
Resolution of Comments

Various organizations were invited to comment on the draft report *Development of an Integrated Industry Initiating Event Indicator* (S. Eide et al., March 13, 2003). Comments were received in 2003 from the following organizations:

- U.S. Nuclear Regulatory Commission,
    - Division of Safety and Systems Analysis (NRR DSSA)
    - Region I
    - Region II
    - Probabilistic Safety Assessment Branch (NRR SPSB)
    - Inspection Program Branch (NRR IIPB)
    - Division of Systems Analysis and Regulatory Effectiveness (RES DSARE)
- Nuclear Energy Institute (NEI)
- Union of Concerned Scientists (UCS)

The questions and responses received were based on the March 13, 2003, draft report and comments received in response to the public meeting held on July 24, 2003. Since then, many things have transpired that have influenced the BRIIE development. Some of these are associated with the Mitigating Systems Performance Index (MSPI), such as improvements to the standardized plant analysis risk (SPAR) models. Thus, the final report differs significantly from the draft report. The final report's BRIIE was called industry integrated initiating event indicator (IIIEI) in the draft report, and the final report Equations (8-1) through (8-4) were numbered 2 through 5 in the draft report. In the discussion below, the comments and responses are rephrased to use the terminology of the final report.

In addition to general comments, reviewers were asked to respond specifically to 11 questions listed in Section 6 of the draft report. Those questions are listed below, along with a summary of the reviewers' responses. (It is important to note that many of the questions would not be asked today in light what we have learned since the draft report was written and issued for review.)

1. Is Equation (8-4) rather than Equation (8-1) or (8-2) most appropriate for quantifying the BRIIE?

   Most of the reviewers felt that Equation (8-1) (Equation 2 in the March 13, 2003, draft report), plant-specific calculations rolled up into a plant-group [boiling water reactor (BWR) or pressurized water reactor (PWR)] or industry average, was the best way to quantify the BRIIE. However, sample results using each of the different quantification methods were not presented in the March 13, 2003, draft report. Since then, the historical BRIIE was calculated for fiscal year (FY) 1988 through FY 2005 (Appendix D) using all four equations. Results indicate that the BRIIE is much more sensitive to yearly performance if Equation (8-4) were used, based on plant-group industry initiating event frequencies. (The same formula is obtained regardless of whether plant-specific Birnbaum importances or plant-group average importances are used.) Therefore, the final report recommends that this plant-group average approach be used.

The reviewers were not provided the results in Appendix D, which compare the recommended Bayesian update process for determining the current initiating event frequency with the alternative maximum likelihood estimate (MLE, events divided by reactor critical years or rcry). Those sensitivities were performed after the draft report was reviewed.

2. Is the method for determining baseline performance adequate (Sections 8.1 and 8.2)?

   One reviewer thought the justification for the baseline periods was not strong enough. Another reviewer thought the baseline periods were appropriate. The final report uses the methodology and baseline period results contained in NUREG/CR-6928. Those results are similar to the baseline performance estimates presented in the draft report, except for several initiating event categories that underwent a review of the individual event reports to ensure that only those events applicable to the standardized plant analysis risk (SPAR) modeling assumptions were included. Manual Chapter 0313 recommends using the baseline method and prediction limits.

3. Is the proposed method for calculating current frequencies for the initiating events (Bayes update with 3 years of data in the draft report) appropriate (Section 4.3, Equation 4 and Section 8.7)?

   Two reviewers indicated the method was appropriate, one said more than 3 years of data should be used, and one said not enough information was presented to answer this question. The final report suggests using a Bayes update with 1 year of data. One year of data is now recommended because this eliminates any dependencies between years when calculating the Tier 1 and Tier 2 performance indicators. Also, this approach maximizes the sensitivity of the indicators.

4. Should core damage frequency (CDF) or ΔCDF be used as the measure for the BRIIE (Section 4.3 and Appendix D)?

   Two reviewers favored ΔCDF, two were neutral, and one favored CDF. However, most agreed that ΔCDF may be more transparent. The final report presents BRIIE in terms of ΔCDF. The expert panel recommended that ΔCDF be used.

5. Given the characteristics of the BRIIE and the simulation results (Section 9), what might be appropriate CDF and ΔCDF action thresholds?

   Most reviewers felt that development of the Tier 2 BRIIE thresholds would be a challenge. One reviewer thought the thresholds should be developed at lower plant-group levels, rather than at the industry-wide level. Finally, one reviewer did not think thresholds would be appropriate given the high plant-to-plant variability in Birnbaum importance measures. The final report recommends the Tier 2 threshold that was developed by an expert panel process (Section 8.6 and Appendix E), which was the process recommended in the March 13, 2003, draft report.

6. Should the plant-group average Birnbaum importances be obtained from the SPAR models or from industry risk models?

   Three reviewers said use the SPAR models, while a fourth said use both. The final report uses Birnbaum importances that were obtained from updated SPAR models.

7. If the Birnbaum importance measures are obtained from the industry, how will the differences between the two models (industry and SPAR) be addressed?

Most reviewers felt the SPAR models should be used to determine Birnbaum importance measures. However, several thought that comparisons should be made with plant probabilistic risk assessment (PRA) results and differences addressed. The final report uses Birnbaum importances obtained from updated SPAR models. The updated SPAR models are expected to agree reasonably well with plant PRA models, especially at the plant-group level.

8. How often should initiating event baseline performance be updated?

   One reviewer thought the baseline, if reflecting current industry performance that is deemed acceptable to NRC, should not need to be updated. Another thought that the baseline should be reviewed every 3 years. The final report does not address this implementation issue. However, a comprehensive review of industry performance (both initiating event frequencies and component unreliability and unavailability) should be performed periodically, and results from such a review could be used to determine whether the baselines still reflect industry performance.

9. How often should the Birnbaum importance measures be updated?

   Most reviewers indicated that the Birnbaum importance measures should be kept up to date. One reviewer thought the Birnbaums should be reevaluated whenever plant conditions change significantly, while another suggested reviewing the Birnbaums every 3 years. The final report does not address this implementation issue.

10. Is the treatment of uncertainties adequate in Section 9 (Appendix E of March 13, 2003, report)?

    Few reviewers commented on this question. Those who did indicated that the treatment of uncertainties is inadequate, and modeling uncertainties should be addressed. Additional uncertainty analyses performed since the draft report was issued for review indicate that incorporating uncertainty in the Birnbaums (representing plant-to-plant variation) did not significantly increase the uncertainty in the BRIIE. Also, because the BRIIE is meant to measure the risk impacts of changes in plant-group current initiating event frequencies, the plant-group average Birnbaums and the baseline initiating event frequencies are treated as known and constant.

11. Should the thresholds be set so that no one event in a 3-year period would cause the threshold to be exceeded?

    Two reviewers felt a single event should not result in exceeding a threshold. Two others thought that selecting thresholds should not be influenced by whether a single event could reach or exceed the threshold. The Tier 1 prediction limits in Section 4, Table 4-4 are all two events or greater, so no single event can trigger a Tier 1 response. Also, the sensitivity results in Section 9 indicate that if a given initiating event is at its prediction limit, the BRIIE (assuming all other initiating events are at their baseline performance) will not exceed the threshold of 1.0E–05/rcry (per reactor) recommended by the expert panel.

Specific comments from these groups and the comment resolutions are presented in Table F-1. Note that in some cases the comments are paraphrased and in many cases the listed comment was extracted from longer commentary. Also, comments from RES DSARE were generated after the public meeting on the proposed enhancements to the Industry Trends Program (ITP) coverage of the Initiating Events

Cornerstone of Safety (held on July 30, 2003). The DSARE comments cover both the March 13, 2003, draft report and additional information presented at the public meeting.

The comments that answer each question listed previously are grouped together, by question, at the end of the table. The comments on other topics are so diverse that no grouping by topic was helpful. Instead, those comments are presented in the order given by the reviewers.

Table F-1. Comment resolution.

Comment	Source	Comment Resolution	Report Section
General Comments 1. It would seem to me that tracking individual initiating events is likely to be more fruitful for internal agency uses.	NRR DSSA	We agree with the reviewer. That is the reason the Tier 1 activities under the enhanced ITP (not documented in the March 13 draft report) were developed. They involve trending of individual initiating events and comparison of yearly industry performance with prediction limits. This is the method currently used in the ITP to assess short term trends. It is documented in the NRC Inspection Manual Chapter 0313.	Section 4
General Comments 1. In other words, we would have to wait till we got a lot of events for this [integrated] indicator to change significantly.	NRR DSSA	Sensitivity analyses summarized in Section 9 of the final report indicate that the PWR BRIIE is sensitive to loss of offsite power (LOOP), stuck open safety relief valve (SORV), loss of dc bus (LODC), and steam generator tube rupture (SGTR). The BWR BRIIE is most sensitive to LOOP. However, the reviewer is correct in that these initiating events would need to significantly exceed their prediction limits (Section 4) in order for the BRIIE to exceed the threshold of 1.0E–05/rcry (or several different events would need to occur).	Section 9
General Comments 1. If it [the integrated indicator] is used to provide information to Congress, it must be very carefully qualified as not representing the estimate of the risk (in terms of core damage), since a potentially significant contribution from external events, particularly fires, and from other modes of operation (low power and shutdown) are not addressed.	NRR DSSA	Agreed. The scope of the BRIIE is explicitly stated in the Executive Summary. The BRIIE estimates change in that portion of the CDF corresponding to an explicit list of kinds of initiating events. Words have been added to the final report to explain this.	Executive Summary, Section 4
General Comments 2. Would it not be better to calculate the changes in CDF given all the changes, including those in the conditional core damage probabilities (CCDPs) [representing changes in mitigating system performance]? This is in fact a more natural match to the original Safety Goal policy statement and its subsidiary objective.	NRR DSSA	The ITP enhancement effort has focused first on the Initiating Events Cornerstone of Safety. Follow-on work (not currently being pursued) may also address the Mitigating Systems Cornerstone of Safety. (The mitigating systems impact the CCDPs mentioned in the comment.) At present, there is no plan to integrate ITP performance indicators above the cornerstone of safety level. However, the proposed higher-level integration could be performed if desired.	N/A
General Comments 3. The report needs to be thoroughly edited.	NRR DSSA	The proposed technical editing was performed.	Entire report
General Comments 4. The report should be cleaned up with respect to its use of statistical jargon. Examples include "predictive distribution" and "p-value".	NRR DSSA	More information is provided in the report concerning predictive distributions. A definition of p-value was added to the report. Statistically significant is defined in terms of the 'p-value.' A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.)	Sections 4, 8.3. and Appendix B
General Comments 5. As a note of clarification, Regulatory Guide 1.174 does not provide goals for ΔCDF, it provides guidelines.	NRR DSSA	The sentence in question was removed from the report.	Executive Summary

Comment	Source	Comment Resolution	Report Section
General Comments 6. Given that the CDF is a linear function of the initiating event frequencies, the first part of Appendix A, through Equation A-3, is superfluous.	NRR DSSA	The March 2003 draft's Appendix A was removed from the report.	N/A
Recommendations. It appears to me that this indicator can, at best, only be a lagging indicator. A more pro-active approach is one based on identifying significant events on a plant-specific basis and then assessing whether those events have a potential for affecting other plants.	NRR DSSA	This is true. However, an indicator that lags by only one year still has worth. The existing historical downward trends are of interest, and any start of an upward trend would be of great interest. Also, preliminary results can be calculated as the data come in, reducing the lag further. The suggested pro-active approach is not precluded by the use of industry trending.	N/A
Recommendations. This indicator should be exhaustively exercised to understand what sort of changes in trends would actually trip the threshold, or result in an increasing trend. This can then be played out against realistic expectations (admittedly very subjective) to test the value of the indicator.	NRR DSSA	The final report presents both Tier 1 prediction limits and a Tier 2 industry-level threshold for the BRIIE. The Tier 2 threshold was established by an expert panel process. Section 9 presents the impacts on the BRIIE Tier 2 if each initiating event reaches its Tier 1 prediction limit. Simulations and sensitivity studies were conducted to evaluate the behavior of the BRIIE. These may not have been as exhaustive as suggested by the reviewer, but we feel they were adequate to provide the necessary insights for BRIIE Tier 2 behavior.	Sections 4 and 9
The document title should be changed to "Development of an Industry Aggregate Risk Indicator"	Region II	The title of the final report is "Baseline Risk Index for Initiating Events (BRIIE)." Because the revised report addresses both Tier 1 (individual initiating events) and Tier 2 (aggregation of initiators into a single risk-informed performance indicator) activities, the suggested title change might appear too limited in scope.	Title
Instead of using average risk, don't divide by the number of plants, and show the aggregate risk.	Region II	This is a question of taste, because either value can be calculated from the other. This report uses risk per plant because most analysts are familiar with acceptable values of risk per plant.	N/A
The index inputs can be used to derive a companion indicator that reflects industry aggregate large early release frequency (LERF). Work on a similar approach is underway in the Significance Determination Process (SDP) Program to provide LERF output from the SDP sheets.	Region II	The scope of the effort was to focus on initiating events and CDF for at-power operation. Thus, LERF is not addressed. Follow-on work (not currently being pursued) could expand the BRIIE to include LERF.	
When determining the Birnbaums, be aware of potential truncation effects of the risk models.	RII	The Birnbaum importances were determined using a truncation level of 1.0E-12/rcry in the SPAR rev. 3.21 models. That truncation level is believed to be appropriate for determining initiating event Birnbaums. The Birnbaum importances, listed in Appendix C, are all at least five orders of magnitude larger that the truncation level. This should provide sufficient accuracy. During the implementation phase of BRIIE, the Birnbaums will be reevaluated.	N/A
Some plants have fault trees, instead of a single basic event with a frequency for their initiating event in the model. For those calculated initiating events (IEs), Birnbaum does not work. Use CCDP/IE frequency.	Region II	None of the SPAR models at present use fault trees for initiating events. In the future, fault trees may be used for certain IEs. We will evaluate this issue at that time.	N/A

Comment	Source	Comment Resolution	Report Section
For charts and tables that use simulation versus actual, indicate simulation on the chart, so it is not taken out of context accidentally by the reader.	Region II	This has been done in the final report in the figure titles.	Section 9
In Appendix A, page 35, include some language explaining what Birnbaum represents in nonmathematical language.	Region II	The Birnbaum descriptions were modified to characterize them both in simple terms and by evaluation method within SAPHIRE.	Sections 4 and 8.4
As information becomes available, modify the Birnbaums to include internal flooding and fire and external event importance.	Region II	The current scope of BRIIE focuses at power, internal events only This recommendation could be incorporated into follow-on efforts. Most SPAR models do not now include external events, but fire, flood, and seismic events may be added within a few years.	N/A
Overall, a well written paper on a new approach to an industry health indicator. In this reviewer's opinion this is well worth additional funding.	Region II	No comment necessary.	N/A
General Comment 1. The subject report seems to be predominantly focused on developing the technical and mathematical structure for addressing the third objective [communicate industry-level information to Congress...] without establishing the first two objectives [collect and monitor industry-wide data..., and assess the safety significance and causes of any statistically significant adverse industry trends...].	NRR SPSB	The March 13, 2003, draft report primarily addressed development of the BRIIE Tier 2. BRIIE results that reach or exceed a Tier 2 threshold will be reported to Congress. The revised report provides equal coverage to the Tier 1 activities, monitoring individual IEs. The Tier 1 process clearly involves data collection, monitoring, and trending.	Sections 4 and 6
General Comment 2. The subject report does not address limitations of this concept or limitations of the developed methodology and its associated uncertainties, which should be presented. These limitations include: 1. Not all initiating events are addressed 2. Not all of the initiating events considered in the report may be the result of deficient licensee performance (e.g., grid-related LOOP events) 3. External events are excluded 4. Industry averages may conceal information about groups of plants 5. The current SPAR models may not reflect changes and improvements in plant design and operational procedures 6. No strong justification is provided for using predictive distributions rather than historical trending.	NRR SPSB	All these comments are addressed elsewhere in this table: 1. See NRR DSSA General Comment 1 and NRR SPSB Implementation Comment 1. 2. See NRR SPSB Implementation Comment 2. 3. See NRR SPSB Implementation Comment 3. 4. See NRR SPSB Implementation Comment 4. 5. See NRR SPSB Implementation Comment 5. 6. See NRR SPSB Implementation Comment 6.	Various
General Comment 3 does not exist because it was omitted in the comments.			

Comment	Source	Comment Resolution	Report Section
General Comment 4. Thresholds should be developed to be applicable on a lower industry level in addition to the overall industry-wide level (e.g., reactor type or vendor).	NRR SPSB	The expert panel considered this suggestion. They decided to recommend a single BRIIE Tier 2 threshold of 1.0E–05/rcry for the Industry. This threshold is used only for reporting to Congress. The panel also recommended that BRIIE results for PWRs and BWRs be presented, but that the threshold should not be applied to them. Follow-on work (not currently being pursued) could be performed to identify the characteristics of BRIIE results for subsets of plants, to be used internally by NRC. A sentence was added to Section 1 to warn the reader that the BRIIE as presently characterized is not designed to detect trends or deviations from normal performance at plant group levels below those used in the BRIIE (industry, BWR, and PWR).	Sections 1 and 8.6
General Comment 5. Because of significantly decreasing initiating event frequencies over the years, it may not be appropriate to try to determine a predictive distribution on the industry-average based solely on the last few years.	NRR SPSB	The methods used to determine baseline periods (ending in calendar year 2002) for the initiating events is believed to be appropriate. Manual Chapter 0313 outlines the use of the baseline method in the Industry Trends Program. It is also described in detail in NUREG/CR-6928 and is focused on determining a baseline frequency that most appropriately represents current industry performance. (These baselines will be reviewed periodically to determine if industry performance has changed.) The predictive distribution is simulated from the statistics of this baseline frequency, addressing both aleatory and epistemic uncertainty. We believe that the baseline frequency statistics are appropriate for simulating the predictive distributions.	Sections 4 and 8.3 and Appendix B
Detailed Comment 1. Baseline periods short and long seem to be the same (1988 - 2001). (Executive summary, p. x in the draft report)	NRR SPSB	This was a typo in the draft report. That sentence is not in the final report.	N/A
Detailed Comment 2. We recommend that the same data be used in all four equations for the BRIIE in order to determine the magnitude of the differences. This information can then be used to decide on which formula to use for estimating the BRIIE. (Section 3.3, p. 9 in the draft report)	NRR SPSB	In the final report, all four equations were used to determine the historical performance of the BRIIE. The recommended choice is the industry average approach, Equation (8-4). This equation provides the most sensitivity to the occurrence of less frequent initiating events with high Birnbaum importances.	Sections 4 and 8.5 and Appendix D
Detailed Comment 3. In the equation defining the average industry Birnbaum, the summation should be about u and not i. (Section 3.3, p. 9 in the draft report)	NRR SPSB	This was corrected in the final report.	Section 8.5
Detailed Comment 4. Need to define the p-value. (Section 3.4, p. 11 in the draft report)	NRR SPSB	The final report uses initiating event baseline periods determined in NUREG/CR-6928. The baseline period determination and p-value information are discussed in detail in that document. The report no longer uses the term “p-value”.	N/A
Implementation Comment 1. The report should address how new IEs of significance will be identified and integrated into the program, even if their current importance ranking is relatively low.	NRR SPSB	If new IEs of significance occur, the issue of including them in the SPAR models may need to be addressed. When new IEs are added to the SPAR models, then they can be evaluated as potential candidates for inclusion in the BRIIE, based on the steps used to identify the existing BRIIE Program IEs (as listed in Section 8.1). A paragraph was added to explain the process by which new IEs might be added.	Section 8.1

Comment	Source	Comment Resolution	Report Section
Implementation Comment 2. The report needs to address how it will address events and trends that are not directly related to the performance or authority of the licensee (e.g., grid-related LOOP events).	NRR SPSB	As presently described, the Tier 1 and Tier 2 performance indicators do not distinguish events not directly related to licensee performance. For example, grid-related LOOP events are not distinguished from other causes of LOOP. However, if the prediction limits or the threshold are exceeded, then follow-on evaluations would identify whether the increased number of events was the result of events not directly related to licensee performance. Examples of potential NRC responses are presented in Section 7 of the final report.	Section 7
Implementation Comment 3. The report does not address external events, which for some plants are the overwhelmingly dominant contributor to plant risk.	NRR SPSB	The BRIIE was developed as an at power Level 1 indicator. This could be addressed as potential follow-on work (not currently being pursued). Most of the SPAR models do not now include external events. Fire, flood, and seismic event risk models are being developed. Fires and floods may occur frequently enough to allow trending at the industry level.	Section 1
Implementation Comment 4. The integrated data (industry averages) may conceal information about groups of plants contribution to changes in the BRIIE.	NRR SPSB	As presently formulated, if the Tier 1 prediction limits or the Tier 2 threshold are not exceeded, then no further examination is required. If a subset of the industry (at a level lower than BWRs and PWRs) exhibits a change in performance, but the rest of the industry masks this change, then the industry-wide performance indicators will indicate no significant industry-wide change in performance. This balancing of performance is believed to be appropriate at the industry level. Follow-on work (not currently being pursued) could investigate whether performance indicators should also be formulated at a lower, group-of-plants level. If a Tier 1 prediction limit or the Tier 2 threshold is exceeded, analysis of the data, based on groups of plants, could be performed to determine the causes.	N/A
Implementation Comment 4. If a good or bad performer is shut down for a long period of time (e.g., six months or a year) to address an issue, will the calculated industry average consider the repercussions of the issue on the BRIIE results?	NRR SPSB	Periods of shutdown would be automatically incorporated in the calculation of the industry-wide (or BWR or PWR) critical years of operation for the fiscal year in question and fewer initiating events from the plant in question. Hypothetically, if a poorly performing plant had been the source for several less frequent initiating event occurrences (e.g., loss of DC bus) that substantially increased the BRIIE, and that plant was then shut down for an extended length of time, the BRIIE would show an improvement. (In this case, the improvement in the BRIIE would have been the result of the poorly performing plant being shut down, rather than the result of improving its performance. If that plant then came back on line without an improvement in performance, then the BRIIE would show a subsequent degradation.) Issues such as this will be addressed as they arise during implementation of the BRIIE.	N/A
Implementation Comment 5. The report needs to present how PRA quality, SPAR modeling conservatisms, and uncertainties in results and model/plant fidelity will be addressed within the program to ensure that the results are representative of the existing plant designs and conditions.	NRR SPSB	Work associated with implementation of the Mitigating Systems Performance Index (MSPI) Program included the issue of PRA quality and SPAR modeling versus licensee risk models. That led to a comprehensive effort to update the SPAR models based on a cut set level comparison with licensee risk models (with this comparison leading to both SPAR model and licensee model changes). During the implementation phase of BRIIE, the Birnbaums will be reevaluated using the most up-to-date SPAR models and parameter estimates.	N/A

Comment	Source	Comment Resolution	Report Section
Implementation Comment 6. There is not a strong justification provided for using predictive analyses with simulations instead of using historical performance, and the uncertainties in the parameters used in these analyses are not presented.	NRR SPSB	The predictive distribution gives a comparison of current performance with baseline performance, accounting correctly for uncertainties. Historical performance was considered a valuable input to the expert panel process to determine thresholds for the BRIIE. However, the approach of simulating a predictive distribution also provides valuable insight into the characteristics of the BRIIE. (Inputs for these simulations are summarized in Section 9 of the final report. Uncertainties in these inputs are also discussed.) Both types of information were provided to the expert panel.	Section 8.6
Implementation Comment 6. It is not even justified why the baseline period is what it is for each IE.	NRR SPSB	The draft report did not present sufficient information in this area. Since issuing the draft report in 2003, the NRC is using the baseline concept. This concept is documented in the ITP Inspection Manual Chapter 0313. BRIIE uses the initiating event baseline periods and frequencies presented in NUREG/CR-6928. Those baselines have been reviewed by NRC.	Sections 4 and 8.2 and Appendix A
Implementation Comment 6. The trending should also be both long term (over the past 15 years) and short term (over the past few years).	NRR SPSB	In the final report, Appendix A presents initiating event frequency data over the period FY 1988 through FY 2005, even though the baseline periods chosen may be much shorter. These plots show both the long-term and short-term trends (or lack thereof). The ITP manual chapter suggests using a 10-year window. If the ITP chooses to add BRIIE IEs and BRIIE to its trending effort, a 10-year window may be appropriate for these additional performance indicators. Words were added to Section 1 to indicate that the BRIIE is not focused on trending, but on comparing yearly results against either prediction limits or a threshold. The ITP will make a decision whether to also trend the BRIIE IEs and the BRIIE Tier 2 results.	Section 1 and Appendix A
Implementation Comment 6. A slight increase in some IEs over the next couple of years should not be considered a negative trend, as it may just be that the initiating event frequency is leveling out. The criteria for determining and addressing these conditions need to be presented.	NRR SPSB	Trending methods already used by the ITP, and documented in the ITP manual chapter, can be used to determine whether adverse trends exist in the individual initiating events. However, BRIIE focuses on whether the individual initiating events reach their prediction limits within a year and whether the BRIIE reaches its risk threshold.	N/A
Concept Comment 1. Do we want to include data that are not related to a licensee performance deficiency?	NRR IIPB	Yearly initiating event data collection will not include a determination whether each event was related to licensee performance. However, if Tier 1 or Tier 2 thresholds are reached, then the follow-on review should identify which events were outside the control of the licensees.	N/A
Concept Comment 1. Where does LERF factor in this high level look at the industry's performance?	NRR IIPB	At present, LERF is not considered in BRIIE. [The same is true of the existing ITP performance indicators, except perhaps for more recent Accident Sequence Precursor (ASP) evaluations.] However, LERF could be considered in follow-on work (not currently being pursued). The final report states that the BRIIE as outlined does not include LERF considerations.	Executive Summary and Section 4

Comment	Source	Comment Resolution	Report Section
Relationship Comment 1. The relationship is clear between the ROP and the BRIIE, but it is not as clear between the ITP and the BRIIE.	NRR IIPB	BRIIE is part of the ITP. The Tier 1 portion of BRIIE is perhaps more typical of the existing ITP (monitoring of individual performance indicators using performance-based prediction limits), while the BRIIE Tier 2 is probably more like the ROP Mitigating Systems Performance Index (MSPI). Sections 1 through 4 more clearly discuss the existing ITP and how BRIIE fits into the ITP. The BRIIE development efforts have been reported in the annual ITP Commission paper for the last several years.	Sections 1 through 4
Summary Comment 1. The proposed indicator is inconsistent with the guidelines [in the Commission's White Paper on "Risk-Informed and Performance-Based Regulation"] because no threshold has been proposed that demonstrates the ability to preserve safety margins, while providing time to take corrective action, if the threshold is tripped.	RES DSARE	The ITP is intended to complement the present ROP. Because it looks at historical industry-wide data, its primary role is not to detect specific problems, but rather to provide assurance that the industry as a whole remains safe. BRIIE with its Tier 1 prediction limits is designed to detect performance degradation at the industry (or BWR or PWR) level. The prediction limits are tripped significantly before the BRIIE Tier 2 ΔCDF threshold of 1.0E–05/rcry is reached. Therefore, to a certain extent the Tier 1 portion of BRIIE provides time to take corrective action before the Tier 2 threshold is reached (assuming a gradual degradation rather than an abrupt, large degradation occurs). See Section 7.	Sections 4 and 9
Summary Comment 2. It appears that uncertainty is significantly underestimated in the report [compared with Regulatory Guide (RG) 1.174 (Ref. F-3) direction to include both aleatory, epistemic, and completeness uncertainties].	RES DSARE	The final report presents an uncertainty analysis result in Section 9 that addresses only the uncertainty in the baseline initiating event frequencies. That analysis is not meant to indicate the overall uncertainty in the BRIIE Tier 2 CDF. The BRIIE Tier 2 treats the Birnbaum importance measures and baseline initiating event frequencies as constants. Therefore, including additional uncertainties would be misleading in terms of the BRIIE. The uncertainty analysis is presented mainly for comparisons purposes with the BRIIE Tier 2 predictive distribution, which is believed to be the most representative of future BRIIE Tier 2 results (assuming future industry performance remains at its baseline performance).	Section 9
Summary Comment 3. The subject report does not clearly indicate how the safety goal policy (as amended) will apply for the performance indicator.	RES DSARE	The safety goals and other guidelines (e.g., RG 1.174) were used by the expert panel as guidance in setting the BRIIE Tier 2 threshold of 1.0E–05/rcry.	
General Comment 1. It is not clear to all concerned that what is being monitored is the variability of a statistic and not safety of the operating fleet of power reactors.	RES DSARE	In the final report, the BRIIE Tier 1 comparison with performance-based prediction limits associated with the individual initiating events monitors variability. The Tier 2 BRIIE then interprets the Tier 1 results in terms of safety of the operating fleet (with respect to the Initiating Events Cornerstone of Safety).	Section 4
General Comment 2. It should be recognized that this hierarchical structure [aggregation of plant-level information into industry-wide results] is quite different from the hierarchy of the regulatory framework associated with the ROP, which dis-aggregates the safety mission of the NRC into the cornerstones.	RES DSARE	The ITP aggregates plant-level information into industry-wide results. The purpose of the BRIIE is to address only the Initiating Events Cornerstone of Safety. Aggregation above this cornerstone of safety is not being addressed at this time.	N/A

Comment	Source	Comment Resolution	Report Section
General Comment 3. It is not clear how inspection results will be factored into the ITP.	RES DSARE	As structured, BRIIE does not directly include inspection results. However, if Tier 1 prediction limits or the Tier 2 ΔCDF threshold are reached or exceeded, then engineering analyses will be performed to attempt to determine the causes. These engineering analyses would involve applicable inspection results. The ITP is to complement the ROP, not just summarize data from the ROP.	N/A
Summary Comment 1. We believe the concept of the BRIIE—assessing initiating events based on their risk worth (or Birnbaum in the draft report)—is appropriate and believe that this approach should be applied in developing a plant specific performance indicator to replace the current "Scrams with Loss of Normal Heat Removal."	NEI	The ITP work does not consider plant-specific risk. The suggested work is possible, but it is not in the scope of this project.	N/A
Summary Comment 2. We believe the use of this approach [BRIIE approach] for assessing industry performance is not appropriate. It is not clear what the BRIIE result really represents and it is clearly not an "actionable" measure.	NEI	The BRIIE is like a report card for the industry as a whole. The resulting action, if required, would be to tell Congress that last year the industry had a worse report card than we wanted. Any corrective or preventive actions would be based not on the BRIIE, but on engineering analyses or on plant-specific or event-specific investigations.	N/A
Summary Comment 3. Thus the BRIIE seems to merely add an additional level of assessment which appears to be of relatively low value, and may be difficult to explain to stakeholders. We believe that the current body of indicators and inspection findings provide a very robust measure of industry performance.	NEI	The Tier 1 results are more useful than the BRIIE Tier 2, in terms of discovering, understanding, and correcting problems. However, some tool is needed for determining when the NRC tells Congress that problems are risk significant—a tool that encompasses the industry and that does not raise many false alarms. For this, BRIIE seems appropriate.	N/A
Summary Comments 1. We do not believe that the BRIIE will add much value to the Industry Trends Program for the simple reason that it fails to monitor sufficiently meaningful data. Its focus seems almost completely decoupled from the reality of the NRC's oversight program and thus, if used, will not assist the agency fulfill its mission. Since September 1984, 24 nuclear power reactors have been shut down for longer than a year. [A list of those reactors and their shutdown periods was provided.] These outages are *prima facie* evidence of unacceptable safety levels—it took extensive efforts lasting over a year to restore the safety levels at these reactors. However, none of these extended shutdowns were precipitated by the occurrence of one of the initiating events to be covered by the BRIIE. Therefore, the BRIIE would not have enabled the agency to avoid any of these costly safety shutdowns.	UCS	The ITP is intended to complement the present ROP. Because it looks at historical industry-wide data, its primary role is not to detect specific problems, but rather to provide assurance that the industry as a whole remains safe, and (less frequently) to provide an indication of any adverse trends that are starting to develop. Since the review of the 2003 draft report, the Tier 1 concept has been further developed. The Tier 1 indicators are likely to discover such adverse trends before they affect the BRIIE strongly. Both Tier 1 and Tier 2 use industry-wide data, and therefore are less focused on particular problems than are existing oversight programs.	N/A

Comment	Source	Comment Resolution	Report Section
Summary Comments 2. Setting aside, for the moment, the fact that the BRIIE is monitoring the wrong things, we believe it is monitoring the wrong things in the wrong way. It attempts to allow comparisons between events using importance factors. That might work on a plant-specific basis, but it cannot work on a reactor type basis (e.g., BWR or PWR). This “one size fits all” approach is wrong because it will downplay certain events at some plants and overplay those events elsewhere.	UCS	The objection seems to be that the industry mean is presented instead of the individual plant-specific ΔCDF values. The BRIIE Tier 2 was calculated using several approaches in the development stage. One approach was to calculate the BRIIE Tier 2 for each individual plant and then average those results. That approach was not as sensitive as the proposed approach, in terms of predicting the largest variations from the baselines. Therefore, the plant-type average approach was selected. The comment is correct in that this approach has the potential to downplay certain events and overplay others, but at least for the historical data analyzed (covering 1988–2005) the plant-type average approach resulted in higher ΔCDF peaks that the plant-specific approach.	Appendix D
Summary Comments 3. In addition, this indicator is way too convoluted for public consumption.	UCS	The BRIIE Tier 2 indicator is similar to the MSPI, which has been implemented as an enhancement to the ROP. In fact, it is simpler than the MSPI because it does not have front stops and backstops. The ITP Commission paper as provided information and summaries of the BRIIE develop efforts.	N/A
Question 1: Is Equation (8-4) rather than Equation (8-1) or (8-2) most appropriate for quantifying the BRIIE?			
I cannot see why the Equation (8-1) would not be used rather than Equation (8-2) or (8-4).	NRR DSSA	The BRIIE Tier 2 was calculated using several approaches in the development stage. One approach was to calculate the BRIIE Tier 2 for each individual plant and then average those results [Equation (8-1) approach]. That approach was not as sensitive as the proposed approach [Equation 8-4)], in terms of predicting the largest variations from the baselines. Therefore, the plant-type average approach [Equation (8-4)] was selected. See Appendix D.	Section 4 and Appendix D
The sensitivity to the method of calculating the baseline and annual values of the BRIIE needs to be investigated. It may be more appropriate to use the plant-specific method [Equation (8-1)], to better account for the differences between plants. Using the industry mean values could minimize the effects of plants that may be in the tails of the plant by plant initiating event distributions of frequency or Birnbaum importance measure.	Region I		
All of the various equations have meaning. Equation (8-1) would be closest to true industry aggregate risk. Equation (8-2) is an indicator that should represent the average state of industry design, and the adequacy of the average design to respond to the challenges of the particular location. Equation (8-3) represents what we currently see nationwide for rare events’ treatment in PRAs. Finally, Equation (8-4) can be useful as an indicator, but evaluations need to be made comparing the results with the output from Equation (8-1).	Region II		
The average values may not identify the importance of the extremes. Consider using more plant specific data and let the outliers be revealed.	NRR IIPB		
The basis for responding to this question has not been sufficiently established in the report.	RES DSARE		

Comment	Source	Comment Resolution	Report Section
Equation (8-1) is sufficient for quantifying the BRIIE. More complex formulations would have limited value for the generation of an industry average performance indicator.	NEI		
Question 2. Is the method for determining baseline performance adequate (Section 8.2)?			
However, it would be preferable to see the [baseline] period hypothesized on the basis of stability of industry/regulatory practice, with statistical tests used to test the validity rather than have the statistical tests drive the approach without any discussion of reasons why the observed effects are to be expected.	NRR DSSA	What is suggested is probably the ideal way to identify appropriate baseline periods for determining up-to-date baseline frequencies. However, the review of industry/regulatory practices and their impact on initiating event frequency trends is beyond the scope of the present effort. The statistical approach to identifying appropriate baseline periods is believed to be adequate for our purposes. The baseline approach is discussed in the ITP Manual Chapter 0313.	N/A
In calculating the annual BRIIE, using the individual SPAR Birnbaum importance measure at the time of each initiating event may more closely represent the actual consequence of events and provide more information relative to actual industry performance trends.	Region I	What is suggested would more accurately reflect the plant-specific risk of individual initiating event occurrences. However, if SPAR Birnbaums were to be re-evaluated to reflect plant-specific conditions at the time of each initiating event occurrence, this would require on average over 100 such evaluations each year. One goal of BRIIE is to use data already being collected each year with minimal extra effort. Therefore, the final report suggests that a set of SPAR plant-specific baseline Birnbaums be established and then used year after year. These plant-specific Birnbaum importances end up influencing the BRIIE only through the industry average, as seen by comparing Equations (8-3) and (8-4). (The implementation issue concerning possible periodic updates to these baseline Birnbaums is not addressed in the final report.)	Section 4
Coincide the minimum period of data collection with refueling outages. Also, 4 years (subjectively) as a minimum may be premature for Bayesian updating.	NRR IIPB	This response appears to be addressing Question 3, rather than Question 2. If not (and this response addresses the minimum number of years to use to establish a baseline period), then the final report uses 5 years as a minimum baseline period. Longer periods are used whenever the frequency appears constant during that longer period.	Section 8.2
The method is not adequate because the focus appears to be on assuring stability of the indicator when the underlying data are (or could be) highly variable, rather than focusing on the safety significance.	RES DSARE	This comment appears to be addressing Question 3 rather than Question 2.	N/A
The method described appears to satisfy the desirable characteristics outlined in Section 3.4 (draft report). The decision rules in section 3.4 do take some time to understand and may not be transparent enough to allow them to be easily understood by the public.	NEI	The baseline periods and baseline frequency distributions in the final repot are those presented in NUREG/CR-6928. A summary of the methods used in that report is presented in the final report.	Section 8.2
Question 3: Is the proposed method for calculating current frequencies for the initiating events (Bayes update with 3 years of data) appropriate?			

Comment	Source	Comment Resolution	Report Section
The method for calculating the initiating event frequencies is as good as any, particularly for the rare events, e.g., loss of instrument air.	NRR DSSA	The final report suggests that a Bayes update with 1 year of industry data be used to calculate initiating event current frequencies. One year, rather than 2 or 3 years, was chosen. The use of a 1-year period eliminates data dependencies between yearly results and provides increased sensitivity to industry performance during the year in question. Note that the baseline is used to estimate the mean industry initiating event frequency. The use of 1 year is for the actual initiating event contribution to BRIIE for that year.	Sections 4 and 8.7
If all the underlying assumptions and premises are considered acceptable, then this method appears to be acceptable.	RES DSARE		
There were not enough sensitivity studies performed to determine the answer to this question.	NEI		
Three years does not appear to represent an adequate data collection period, especially considering the cyclic nature of performance that some licenses have demonstrated.	NRR IIPB	See the above response, which applies here as well. In addition, if a plant exhibits cyclic performance, then the rolling, 1-year data collection period would reflect poor performance during the “bad” portion of the cycle and good performance during the “good” portion of the cycle. Since a yearly measure of performance is desired, this characteristic is appropriate. The mean industry initiating event frequency is estimated using the baseline method and includes several years.	N/A
Question 4: Should CDF or ΔCDF be used as the measure for the BRIIE?			
I’m not sure it matters whether CDF or ΔCDF is used, though the variation from year to year may show up more clearly in the ΔCDF plot.	NRR DSSA	The final report presents BRIIE Tier 2 results in terms of ΔCDF, which was the recommendation of the expert panel. Both approaches are discussed in the report, and either approach could have been used.	N/A
Use delta CDF because it is consistent with the ROP.	NRR IIPB		
The delta CDF is the preferred metric because it is consistent with the guidance in RG 1.174. Besides, delta CDF is a more transparent metric than CDF.	RES DSARE		
It does not appear to matter if CDF or delta CDF is used.	Region I		
CDF should be used for the measure for the BRIIE.	NEI		
Question 5: Given the characteristics of the BRIIE and the simulation results, what might be appropriate CDF and ΔCDF action thresholds?			
It’s not clear how you would establish action thresholds. If they are to be established by an expert panel, one useful source of information would be a set of sensitivity studies that demonstrate how the indicator would change given postulated occurrences of initiating events of various types.	NRR DSSA	The final report used an expert panel process for the establishment of the BRIIE Tier 2 ΔCDF threshold of 1.0E–05/rcry applied at the industry level. The expert panel was supplied sensitivity study and uncertainty results to aid in its determinations. This information is contained in the report.	Sections 5, 8.6, and 9
The development of a threshold will be a challenge.	Region I		

Comment	Source	Comment Resolution	Report Section
Proposed action thresholds should include site specific Birnbaum times site specific initiating event frequency compared to the industry average result as a measure. This will measure the impact of high Birnbaum and high initiating event at the same plant, and its impact on industry risk.	Region II	The sensitivity results comparing a plant-specific approach [Equation (8-1)] to the recommended plant-group average approach [Equation (8-4)] were supplied to the expert panel.	N/A
Given the extremely high variability in the Birnbaum importance measure, the concept of an action threshold is not applicable.	NRR DSARE	The expert panel felt that a threshold of 1.0E–05/rcry applied at the industry level was appropriate for reporting to Congress.	N/A
It is difficult to discuss industry wide action thresholds without any context that defines what the actions may be. This question cannot be adequately addressed without this context. A simplistic response is that the surrogate safety goal of 1.0E–04 is the appropriate action limit. It is generally recognized that this goal is a conservative reflection of the actual safety goals.	NEI	Actions to be taken given that BRIIE Tier 1 prediction limits are exceeded or BRIIE Tier 2 threshold is exceeded are summarized in Section 7. Note that if the BRIIE Tier 2 threshold is exceeded, the NRC will already have taken some type of action.	Section 7
No comment.	NRR IIPB	No response necessary.	N/A
Question 6: Should the industry-average Birnbaum importances be obtained from the SPAR models or from industry risk models?			
The Birnbaum importance measures should be obtained from the SPAR3 models. The SPAR models are performed to a consistent standard even if they are less detailed than the licensee PRAs. Licensee PRAs vary in the level of detail and style of modeling and would introduce an additional source of variability that might mask the significance of some initiating events.	NRR DSSA	The final report uses Birnbaum importance measures obtained from the SPAR Rev. 3.21 models. Before the BRIIE is officially implemented, final Birnbaum values should be obtained from the most up-to-date SPAR models. As part of the SPAR model program and the implementation of the MSPI, importance measures from the SPAR models are being compared to corresponding importance measures from licensee models. As part of the implementation phase, it may be possible to perform comparisons using a subset of the plant risk models.	Sections 4 and 8.4
Industry average Birnbaum importances should be obtained from both the SPAR models and industry risk models. The results should be compared and then a decision should be made as to which set to use.	NRR IIPB		

Comment	Source	Comment Resolution	Report Section
The industry average Birnbaum importance values should be obtained from the SPAR models. However, benchmarks performed for the MSPI pilot plants demonstrated that additional benchmarks are necessary before the SPAR models could produce Birnbaum importance values that are representative of the actual plant configurations.	NEI		
Section 6 Questions 6, 7, and 9. The use of the SPAR models is preferred, since this will be an NRC indicator. As time passes there will be a need to ensure that the SPAR models remain consistent with changes in plant design and operation.	Region I		
It is premature to obtain an answer to this question. It would appear that the variations within the industry risk models are likely to be so large that treating them as a monolithic group may not be appropriate.	RES DSARE	The expert panel felt that a BRIIE tier 2 threshold of 1.0E–05/rcry applied at the industry level was appropriate for the report to Congress.	N/A
Question 7: If the Birnbaum importance measures are obtained from the industry, how will the differences between the two models (industry and SPAR) be addressed?			
In light of the answer to the previous question, this question is moot.	NRR DSSA	No further response necessary.	N/A
See the response to Question 6. That is, use both and compare them to ensure consistency.	NRR IIPB		
The use of the SPAR models is preferred, since this will be an NRC indicator. As time passes there will be a need to ensure that the SPAR models remain consistent with changes in plant design and operation. .	Region I		
Differences in the models must be addressed for the indicator to have any integrity no matter which set of models is used to supply the importance measures.	NEI	Differences in the models were addressed as part of the MSPI implementation process. That process led to changes in both the licensee and SPAR models.	N/A
See the response to Question 6. That is, variations within industry risk models mean that treating the industry as a whole is probably inappropriate.	RES DSARE		
Question 8: How often should initiating event baseline performance be updated?			
It's not clear that the baseline performance would ever need to be updated if we, NRC, believe that the current performance is acceptable.	NRR DSSA	The final report does not provide recommendations concerning whether to periodically update the initiating event baseline frequencies. This question is more of an implementation issue rather than a basis issue. One possibility might be to reinvestigate	NA

Comment	Source	Comment Resolution	Report Section
Once the final method of calculating the BRIIE baseline, annual value, and the threshold is developed, a sensitivity study should be conducted on the methods of updating the baseline.	Region I	industry performance every 5 years to decide if new baselines are appropriate.	
The baselines should be updated every two refueling outage cycles (36 months).	NRR IIPB		
It would appear that having a predictable period, such as a year, should be preferable to having any other criterion that may increase the variability.	RES DSARE		
If CDF is used as the metric (as opposed to ΔCDF), it is not clear what the purpose of the baseline is. The answer to this question should be reflective of the purpose of the baseline. If the baseline is used to provide the early warning threshold, then it should be updated as often as necessary to be reflective of current industry performance.	NEI		
Question 9: How often should the Birnbaum importance measures be updated?			
If the Birnbaum measures are obtained from the SPAR models, will they be updated? What is the plan for updating the SPAR models? How would trending be performed if Birnbaum measures are changed?	NRR DSSA	The final report uses Birnbaum importance measures obtained from the SPAR models. Before the official implementation of the BRIIE, final Birnbaum values should be obtained from the most up-to-date SPAR models. The final report does not make a recommendation about updating the Birnbaum importances. This is more of an implementation issue than a basis issue. The SPAR models are being updated and improved in a systematic and controlled manner. One possibility might be to revisit the SPAR Birnbaums every 5 years to decide whether the baseline Birnbaums should be changed. Another possibility would be to review the baseline Birnbaums at the same time that the baseline initiating event frequencies are reviewed. If changes are made, then succeeding yearly BRIIE results would use the updated baseline Birnbaums, and the yearly BRIIE results that had been previously calculated (using an older set of baseline Birnbaums) would remain unchanged.	NA
The Birnbaums should be updated coincidently with the baselines.	NRR IIPB		
See the response to Question 8, i.e. keep the update times predictable.	NRR DSARE		
When the plant designs and operating methods change, on a continuous basis.	NEI		
The use of the SPAR models is preferred, since this will be an NRC indicator. As time passes there will be a need to ensure that the SPAR models remain consistent with changes in plant design and operation.	Region I		
Question 10: Is the treatment of uncertainties adequate?			

Comment	Source	Comment Resolution	Report Section
In this report, uncertainty is fed in through the generation of the various distributions. What will be more interesting is how the authors propose to use this information to both set, and provide the approach for comparison with, the thresholds.	NRR DSSA	The expert panel was provided the uncertainty and sensitivity information presented in the final report. The expert panel used these insights, along with other information, to help them set the Tier 2 threshold.	Section 9 and Appendix D
Once a final method of determining the baseline and the annual BRIIE is developed, the related uncertainties in the SPAR models and the BRIIE calculations need to be reviewed and understood as the threshold is developed.	Region I		
Because only uncertainties in the initiating event frequencies have been included, the treatment of uncertainties is inadequate.	RES DSARE	In the final report, the BRIIE Tier 2 is regarded as an index, similar to the MSPI. Its purpose is to detect degradation in industry initiating event performance and characterize the risk significance in terms of ΔCDF. Therefore, we ask what varies from year to year, and consider only those uncertainties. The baseline data, the Birnbaum importances, and the SPAR models are (virtually) constant from year to year, and therefore regarded as known. When examining whether a high value of the BRIIE Tier 2 is risk significant, the only relevant uncertainty is the uncertainty in the corresponding initiating event frequencies, because the initiating event frequencies are the only quantities that change in the calculation of BRIIE from year to year.	N/A
No. Modeling uncertainties must be addressed.	NEI		
No comment.	NRR IIPB	No response necessary	N/A
Question 11: Should the thresholds be set so that no one event in a three year period would cause the threshold to be exceeded?			
It makes no sense for one event at one plant to trip an industry wide threshold. It makes more sense to investigate the one event first to see if it reflects a plant specific problem or one that could have generic implications.	NRR DSSA	The sensitivity studies in the final report indicate that no single event can trip either the Tier 1 prediction limits or the Tier 2 ΔCDF threshold. Therefore, no artificial restraint is needed.	Section 9
No. Any event of sufficient importance (i.e., delta CDF of 1E-3) should trigger the threshold.	NRR IIPB		
Such an artificial constraint would do disservice to the cause of regulation and damage to public confidence.	RES DSARE		
If one event in a 3-year period could cause a threshold to be exceeded, then the method is fundamentally flawed. It would indicate the 3-year period [for data collection] is not sufficient.	NEI		
Section 6 Questions 10 and 11. Once a final method of determining the baseline and the annual BRIIE is developed, the related uncertainties in the SPAR models and the BRIIE calculations need to be reviewed and understood as the threshold is developed.	Region I		