POLICY ISSUE
INFORMATION

October 4, 2013 SECY-13-0107

FOR: The Commissioners

FROM: Brian W. Sheron, Director
Office of Nuclear Regulatory Research

SUBJECT: STATUS OF THE ACCIDENT SEQUENCE PRECURSOR PROGRAM AND THE STANDARDIZED PLANT ANALYSIS RISK MODELS

PURPOSE:

To inform the Commission of the status of the Accident Sequence Precursor (ASP) Program, including quantitative ASP results, and communicate the status of the development and maintenance of the standardized plant analysis risk (SPAR) models. This paper does not address any new commitments or resource implications.

BACKGROUND:

In a memorandum to the Chairman dated April 24, 1992, the staff of the U.S. Nuclear Regulatory Commission (NRC) committed to report periodically to the Commission on the status of the ASP Program. In SECY-02-0041, “Status of Accident Sequence Precursor and SPAR Model Development Programs,” the staff expanded the annual ASP SECY paper to include: (1) the evaluation of precursor data trends and (2) the development of associated risk models (e.g., SPAR models). The ASP Program systematically evaluates U.S. nuclear power plant (NPP) operating experience to identify, document, and rank the operating events that have a conditional core damage probability (CCDP) or an increase in core damage probability (ΔCDP) greater than or equal to 1×10^{-6}. The ASP Program provides insights into the NRC’s risk-informed and performance-based regulatory programs and monitors performance against safety measures established in the agency’s Congressional Budget Justification (see NUREG-1100, Volume 29, “Congressional Budget Justification: Fiscal Year 2014,” issued April 2013).

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Under the SPAR Model Program, the staff develops and maintains independent risk-analysis tools and capabilities to support NPP-related risk-informed regulatory activities. The staff uses SPAR models to support the Reactor Oversight Process (ROP) Significance Determination Process (SDP); the ASP Program; the Management Directive (MD) 8.3, "NRC Incident Investigation Program," event assessment process; and the MD 6.4, "Generic Issues Program," resolution process. In addition, the staff uses SPAR models to risk-inform inspection activities.

DISCUSSION:

This section summarizes the status, accomplishments, and results of the ASP Program and SPAR Model Program since the previous status report, SECY-12-0133, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models," dated October 4, 2012.

ASP Program

The staff continues to review plant events from licensee event reports and inspection reports to identify potential precursors. Precursors are events with a CCDP for initiating event analyses or a ΔCDP that are greater than or equal to 1×10^{-6} for equipment deemed unavailable or degraded. *Significant* precursors have a CCDP or ΔCDP greater than or equal to 1×10^{-3}. The staff has identified eight precursor events for fiscal year (FY) 2012. The staff did not identify any *significant* precursors for FY 2012, and has not identified any potentially *significant* precursors for FY 2013, to date, although evaluation of some FY2013 events is still in progress.

The ASP Program evaluates the trend for all precursors (i.e. those greater than 1×10^{-6}) as an input to the Industry Trends Program (ITP), which provides an input to the agency's safety performance measure of no significant adverse trend in industry safety performance. For the period of FY 2003 through FY 2012, the staff found no statistically significant trend when looking at the total population of all precursors.

In addition to the trend analysis of all precursors required for the ITP, the staff performs trend analyses on precursor subgroups for additional insights. These subgroups include important precursors with high safety significance (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-4}). The staff found a statistically significant increasing trend in the subgroup of precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4}. This increasing trend is due to occurrence of seven precursors in this subgroup in the past three years after no events were identified in the previous six years. The staff reviewed these events for risk-informed insights, looking at the systems causing the events, the dominant risk sequences, and the plant types affected by the events. The most common similarity was that six of the seven events were caused by multiple electrical-related failures. These electrical failures varied from electrical equipment such as circuit breakers failing to losses of offsite power. Regulatory actions taken as a result of these events include plant-specific SDP evaluations of the risk significance of the performance deficiencies associated with the events, information notices, and a bulletin.

Enclosure 1, "Results, Trends, and Insights of the Accident Sequence Precursor Program," provides additional details on results and trends of the ASP Program.

SPAR Model Program

The staff continued to maintain and update the 80 SPAR models representing 104 commercial nuclear power reactors. Additionally, the staff has also developed new reactor SPAR models for the AP1000, Advanced Boiling Water Reactor (BWR) (for both the Toshiba and General Electric-Hitachi designs), U.S. Advanced Pressurized Water Reactor (PWR), and the U.S. Evolutionary Power Reactor. The scope of every SPAR model includes internal events, at-power, through core damage (i.e., Level 1 model). In addition, the staff continued to expand SPAR model capability beyond internal events at full-power operation. Currently, a total of 19 operating reactor SPAR All-HaZard (SPAR-AHZ) models include hazards such as fires, floods, and seismic events based on the results from the Generic Letter 88-20, Supplement 5, "Individual Plant Examination of External Events for Severe Accident Vulnerabilities," assessments and other readily available information. The staff has completed incorporation of internal fire scenarios from the National Fire Protection Association (NFPA) 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants," fire probabilistic risk assessments (PRAs) for the Shearon Harris Nuclear Power Plant and the Donald C. Cook Nuclear Power Plant. The staff is also leveraging the ongoing Level 3 PRA project for the Vogtle Electric Generating Plant, Units 1 and 2, to develop improved external hazard and fire modeling for the Vogtle SPAR model. In addition, the staff is expanding the capability of the AP1000 SPAR models to include hazards such as seismic, fire, and flooding events. The Office of Nuclear Regulatory Research staff continues to work with the Office of Nuclear Reactor Regulation (NRR) and the Office of New Reactors to identify future enhancements to the SPAR-AHZ models, including accelerating the development of new all-hazard SPAR models.

In FY 2010, the staff completed peer [1]reviews of a representative BWR SPAR model and PWR SPAR model. These peer reviews were performed in accordance with American Society of Mechanical Engineers (ASME)/ American Nuclear Society (ANS) RA-S-2008, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," and Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities." The peer review teams concluded that, within the constraints of the program, the SPAR models provide an appropriate tool to conduct an independent check on the technical adequacy of utility PRAs. The teams also identified a number of facts and observations (F&Os) related to areas where enhancements could be implemented on the SPAR models and supporting documentation. The staff has reviewed the peer review comments and has prioritized them into high, medium, and low bins.

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[1] In this context, the term "peer review" refers to a formal review done in accordance with Regulatory Guide 1.200, "An Approach For Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," intended to determine the technical adequacy of a PRA. When implemented in accordance with RG 1.200, this peer review process obviates the need for the NRC staff to conduct in-depth reviews of a base PRA in order to allow the staff to focus on key assumptions and areas identified by peer reviewers as being of most concern and relevant to the application under consideration. Normally, peer reviews of licensee developed PRAs are conducted by a team of utility and contractor personal who are independent of the PRA being reviewed and, collectively, are experts in all phases of PRA and experienced in performance of PRAs. In order for the SPAR model peer reviews to be conducted in the same manner as industry peer reviews, the staff used review teams composed of a combination of industry and NRC experts that were led by experienced industry peer review leaders. This approach ensured that all SPAR peer review team members met the basic qualification requirements endorsed by RG 1.200 and that the SPAR peer review approach and conduct was consistent with what is normally done for industry peer reviews.

The staff has initiated projects to address the high-priority comments, as available resources permit. Major activities undertaken to address these peer review items in FY 2013 include the following:

- Structuring the SPAR model documentation to more closely align with the structure of ASME/ANS PRA standard.
- Incorporating improved loss of offsite power modeling and support system initiating events modeling (e.g., loss of service water or component cooling water).
- Addressing the high-priority F&Os for the BWR SPAR models.

Due to sequestration, the staff reduced the pace of work on these activities during FY 2013. However, pending the availability of sufficient resources in FY 2014, the staff plans to continue to address high-priority BWR peer review items, including documentation enhancements and model updates. The staff has deferred resolution of high-priority PWR peer review comments and all low- and medium-priority comments due to funding limitations. In addition to this effort, the staff has also completed a comprehensive update to the SPAR quality assurance program in FY 2013.

The staff continues to maintain and improve the SAPHIRE software to support the SPAR Model Program. SAPHIRE is a personal computer-based software application used to develop PRA models and to perform analyses with SPAR Models. During FY 2013, significant SAPHIRE activities included the following:

- Oversight of the SAPHIRE software quality assurance program, including performance of an annual audit of software quality assurance activities, tools, and documents in accordance with NUREG/BR-0167, "Software Quality Assurance Program and Guidelines."
- Transitioning legacy SAPHIRE source code to a newer programming language for the purpose of improving long-term maintenance and support.
- Continued research on advanced quantification methods to improve accuracy and calculation speeds.

Enclosure 2, "Status of the Standardized Plant Analysis Risk Models," provides a detailed status of SPAR models and related activities.

Planned Activities

- The staff will continue the screening, review, and analysis (preliminary and final) of potential precursors for FY 2013 and FY 2014 events to support the agency's safety measures.
- The staff will continue to implement enhancements to the internal event SPAR models for full-power operations. Enhancements include incorporating new models for support-system initiators and revised success criteria based on insights from ongoing thermal-hydraulic analyses.

- The staff will continue quality assurance activities for both the agency SPAR models and the SAPHIRE code. This will ensure that agency risk tools continue to be of sufficient quality for performing SDP, ASP, and MD 8.3 event assessments in support of the staff's risk-informed regulatory activities.

- The staff will continue to evaluate the need for additional SPAR model capability (beyond full-power internal events) based on experience gained from SDP, ASP, and MD 8.3 event assessments and feedback from user offices.

- The staff will continue development of new SPAR-AHZ models, including incorporation of modeling derived from the NFPA 805 application process. The staff will continue to work to identify approaches that can accelerate the pace of external hazard model development for operating reactors.

- The staff is reviewing precursor events from the past five years to determine if there is any trend of concern. The staff will document any conclusions or recommendations resulting from this review in the FY 2013 Industry Trends annual report. In addition, the staff will evaluate the conclusions and recommendations to determine if changes to the ROP are warranted as part of the ROP Self-Assessment Process.

<u>SUMMARY</u>:

Under the ASP Program, the staff continues to evaluate the safety significance of operating events at NPPs and to provide insights into the NRC's risk-informed and performance-based regulatory programs. The staff identified no *significant* precursors in FY 2013 for events evaluated to date. A statistically significant increasing trend in precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4} was observed. This was largely due to an increase of precursors in this subgroup with seven events in the past three years after no events were identified in the previous six years. Six of the seven events were caused by multiple electrical-related failures which varied from electrical equipment such as circuit breakers failing to losses of offsite power. These events were evaluated within the ROP and generic communications programs and are being reviewed by NRR to determine if there is any trend of concern that the NRC will need to address. The SPAR Model Program is continuing to develop and improve independent risk analysis tools and capabilities to support the use of PRA in the agency's risk-informed regulatory activities.

<u>COORDINATION</u>:

The Office of the General Counsel reviewed this Commission paper and has no legal objection.

/RA/ K. Steven West for

Brian W. Sheron, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Results, Trends, and Insights of the ASP Program
2. Status of the SPAR Models

Results, Trends, and Insights of the Accident Sequence Precursor Program

1.0 Introduction

This enclosure discusses the results of accident sequence precursor (ASP) analyses conducted by the staff as they relate to events that occurred during fiscal years (FYs) 2012 and 2013. Based on those results, this document also discusses the staff's analysis of historical ASP trends and the evaluation of the related insights.

2.0 Background

The U.S. Nuclear Regulatory Commission (NRC) established the ASP Program in 1979 in response to recommendations made in NUREG/CR-0400, "Risk Assessment Review Group Report," issued September 1978. The ASP Program systematically evaluates U.S. nuclear power plant (NPP) operating experience to identify, document, and rank the operating events most likely to lead to inadequate core cooling and severe core damage (i.e., precursors).

To identify potential precursors, the staff reviews plant events, including the impact of external events (e.g., fires, floods, and seismic events) from licensee event reports (LERs) and inspection reports (IRs) on a unit basis (i.e., a single event that affects a multiunit site is counted as a precursor for each unit). The staff then analyzes any identified potential precursors by calculating the probability of an event leading to a core damage state. A plant event can be one of two types—either (1) an occurrence of an initiating event, such as a reactor trip or a loss of offsite power (LOOP), with or without any subsequent equipment unavailability or degradation, or (2) a degraded plant condition depicted by the unavailability or degradation of equipment without the occurrence of an initiating event.

For the first type, the staff calculates a conditional core damage probability (CCDP). This metric represents a conditional probability that a core damage state is reached given an occurrence of an initiating event (and any subsequent equipment failure or degradation).

For the second type, the staff calculates an increase in core damage probability (ΔCDP). This metric represents the increase in core damage probability for a time period that a component or multiple components are deemed unavailable or degraded.

The ASP Program considers an event with a CCDP or a ΔCDP greater than or equal to 1×10^{-6} to be a precursor.[1] The ASP Program defines a *significant* precursor as an event with a CCDP or ΔCDP greater than or equal to 1×10^{-3}.

Figure 1 provides a flowchart showing the complete ASP analysis process.

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[1] For initiating event analyses, the precursor threshold is a CCDP greater than or equal to 1×10^{-6} or the plant-specific CCDP for a non-recoverable loss of balance-of-plant systems, whichever is greater. This initiating event precursor threshold prevents reactor trips, with no losses of safety system equipment, from being precursors.

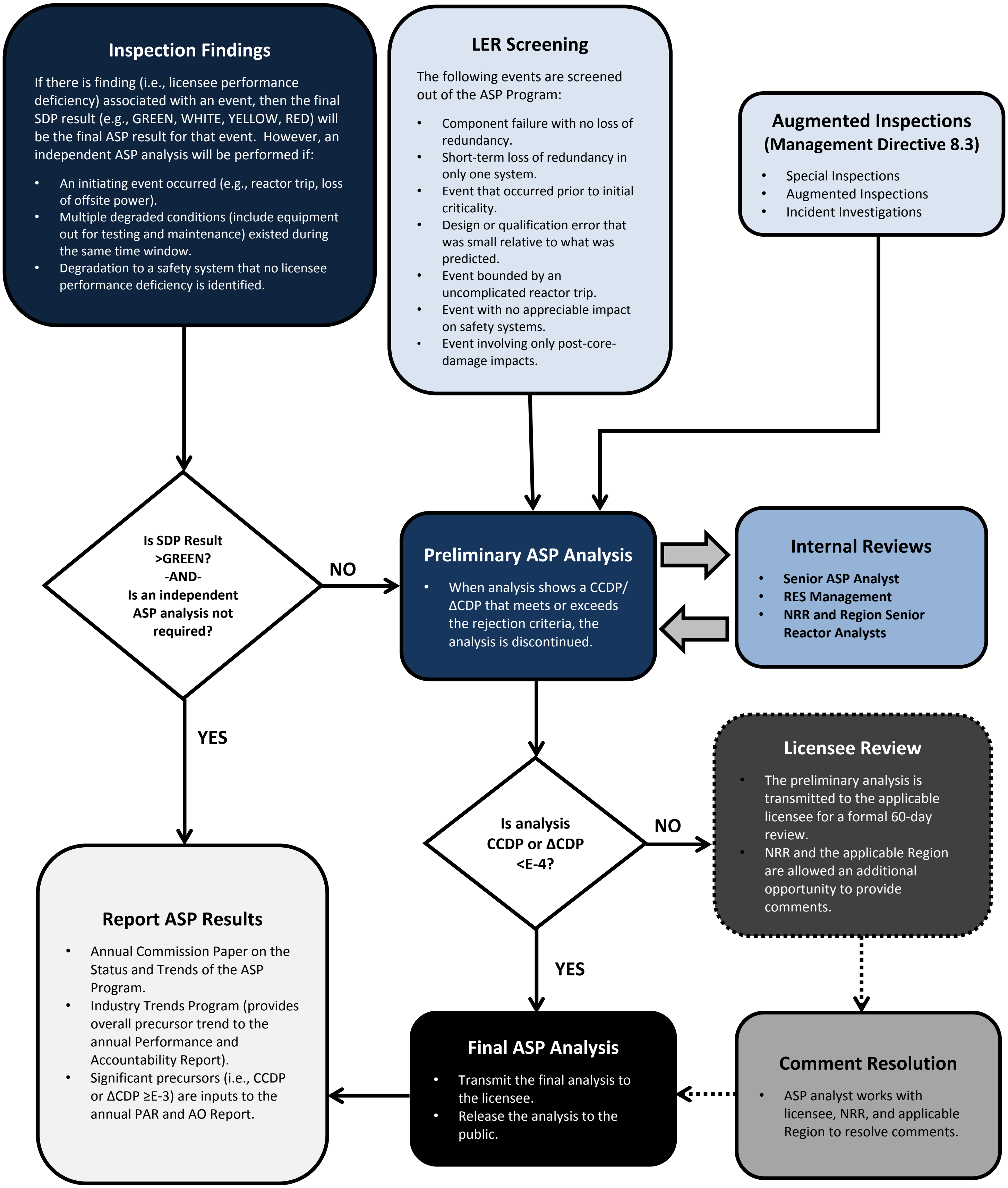

Figure 1. ASP process diagram

Program Objectives. The ASP Program has the following objectives:

- Provide a comprehensive, risk-informed view of NPP operating experience and a measure for trending core damage risk.
- Provide a partial validation of the current state of practice in risk assessment.
- Provide feedback to regulatory activities.

The NRC also uses the ASP Program as a means to monitor performance against the safety measures established in the agency's Congressional Budget Justification (Ref. 1), which was formulated to support the agency's safety and security strategic goals and objectives.[2] Specifically, the program provides input to the following safety measures:

- Zero events per year identified as a *significant* precursor of a nuclear reactor accident.
- No more than one significant adverse trend in industry safety performance (determination principally made from the Industry Trends Program (ITP) but partially supported by ASP results).

Program Scope. The ASP Program is one of three agency programs that assess the risk significance of events. The other two programs are the Significance Determination Process (SDP) and the event response evaluation process, as defined in Management Directive (MD) 8.3, "NRC Incident Investigation Program" or Inspection Manual Chapter (IMC) 309, "Reactive Inspection Decision Basis for Reactors." The SDP evaluates the risk significance of licensee performance deficiencies, while assessments performed under MD 8.3 or IMC 309 are used to determine the appropriate level of reactive inspection in response to a significant event. Compared to the other two programs, the ASP Program assesses an additional scope of operating experience at U.S. NPPs. For example, the ASP Program analyzes initiating events as well as degraded conditions where no identified deficiency occurred in the licensee's performance. The ASP Program scope also includes events with concurrent, multiple degraded conditions.

3.0 ASP Program Status

The following subsections summarize the status and results of the ASP Program as of September 30, 2013.

FY 2012 Analyses. The ASP analyses for FY 2012 identified eight precursors (six initiating events and two degraded conditions). All eight precursors occurred while the plants were at power. For two of the eight precursors, the performance deficiency identified under the Reactor Oversight Process (ROP) fully captured the risk-significant aspects of the event. In these cases, the SDP significance category (i.e., the "color" of the finding) is reported in the ASP Program. For the remaining six events an independent ASP analysis was performed to gain an accurate understanding of the increase in risk during the event. In these events it may be that there was no performance deficiency identified, or that there were multiple performance deficiencies that contributed to the overall significance of the event.

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[2] The performance measures involving precursor data (i.e., number of *significant* precursors and trend of all precursors) are the same for FYs 2005–2013.

The CCDP for three FY 2012 ASP analyses exceeded 1×10^{-4} (Wolf Creek precursor event that occurred on January 13, 2012; Byron, Unit 2, precursor event that occurred on January 30, 2012; and River Bend precursor event that occurred on May 24, 2012); therefore, the analyses were sent for a formal 60-day review to the licensees, Regions IV, III, and IV, respectively, and the Office of Nuclear Reactor Regulation (NRR).[3] All of the other ASP analyses were issued as final after completion of internal reviews in accordance with the ASP review process (see Ref. 2 and Figure 1).

Table 1 presents the results of the staff's ASP analyses for FY 2012 precursors that involved initiating events. Table 2 presents the analysis results for FY 2012 precursors that involved degraded conditions.

Table 1. FY 2012 Precursors Involving Initiating Events

Event Date	Plant	Description	CCDP
1/13/12	Wolf Creek	Multiple switchyard faults cause reactor trip and subsequent loss of offsite power. ***LER 482/12-001***	5×10^{-4}
1/30/12	Byron 2	Transformer and breaker failures cause loss of offsite power, reactor trip, and de-energized safety buses. ***LER 454/12-001***	1×10^{-4}
4/4/12	Catawba 1	Reactor trip caused by faulted reactor coolant pump cable and an error in protective relay. ***LER 413/12-001***	9×10^{-6}
5/22/12	Browns Ferry 3	Reactor trip and subsequent loss of offsite power caused by failure of unit station system transformer differential relay. ***LER 296/12-003***	2×10^{-5}
5/24/12	River Bend	Loss of normal service water, circulating water, and feedwater caused by electrical fault. ***LER 458/12-003***	3×10^{-4}
7/23/12	Oyster Creek	Turbine-generator trip and reactor scram following a transmission line trip causing a loss of offsite power. ***LER 219/12-001***	5×10^{-5}

Table 2. FY 2012 Precursors Involving Degraded Conditions

Condition Duration	Plant	Description	ΔCDP/ SDP Color
6 months	San Onofre 3	Steam generator tube integrity. ***Enforcement Action (EA)-13-083***	WHITE[4]
194 days	Point Beach	Inadequate maintenance leads to failure of turbine-driven auxiliary feedwater pump. ***EA-12-220***	WHITE

FY 2013 Analyses. The staff immediately performs an initial review of events to determine if they have the potential to be *significant* precursors. Specifically, the staff reviews a combination of LERs (per Title 10 of the *Code of Federal Regulations* (10 CFR) 50.73, "Licensee Event Report System," and daily event notification reports (per 10 CFR 50.72, "Immediate Notification Requirements for Operating Nuclear Power Reactors") to identify potential *significant* precursors. The staff has completed the initial review of FY 2013 events and identified no potentially *significant* precursors. The staff will inform the Commission if *significant* precursors are identified during the more detailed evaluations of events. The staff will perform full ASP

3 The preliminary ASP analysis for River Bend is currently undergoing the 60-day review by the licensee, NRR, and Region IV. The analysis results may change prior to the analysis being finalized.

4 A WHITE finding corresponds to a licensee performance deficiency of low-to-moderate safety significance and has an increase in core damage frequency in the range of greater than 10^{-6} to 10^{-5} per reactor year.

analyses of applicable events after the licensee and the NRC complete their follow-up actions, such as inspection and condition reporting.

4.0 Industry Trends

This section discusses the results of trending analyses for all precursors and *significant* precursors.

Statistically Significant Trend. 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 no trend exists in the data. P-values of less than or equal to 0.05 indicate that there is 95 percent confidence that a trend exists in the data (i.e., reject the null hypothesis of no trend).

Data Coverage. The data period for the ASP trending analyses is a rolling 10-year period in alignment with the ITP. The following caution applies to the data coverage of *significant* precursors.

- The data for *significant* precursors includes events that occurred during FY 2013. The results for FY 2013 are based on the staff's screening and review of a combination of LERs and daily event notification reports (as of September 30, 2013). The staff analyzes all potential *significant* precursors immediately.

- The ITP monitors a significant events indicator, which includes precursors with CCDP or ΔCDP greater than or equal to 1×10^{-5}. The ITP and ASP Program are not two independent indicators of industry performance, but are two separate programs that make use of some of the same data.

4.1 Occurrence Rate of All Precursors

The NRC's ITP provides the basis for addressing the agency's safety-performance measure on the "number of statistically significant adverse trends in industry safety performance" (one measure associated with the safety goal established in the NRC's Strategic Plan). The mean occurrence rate of all precursors identified by the ASP Program is one indicator used by the ITP to assess industry performance.[5]

Results. A review of the data for the rolling 10-year period reveals the following insights:

- The mean occurrence rate of all precursors does not exhibit a trend that is statistically significant (p-value = 0.32) for the period from FY 2003–2012 (see Figure 2).

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5 The occurrence rate is calculated by dividing the number of precursors by the number of reactor years.

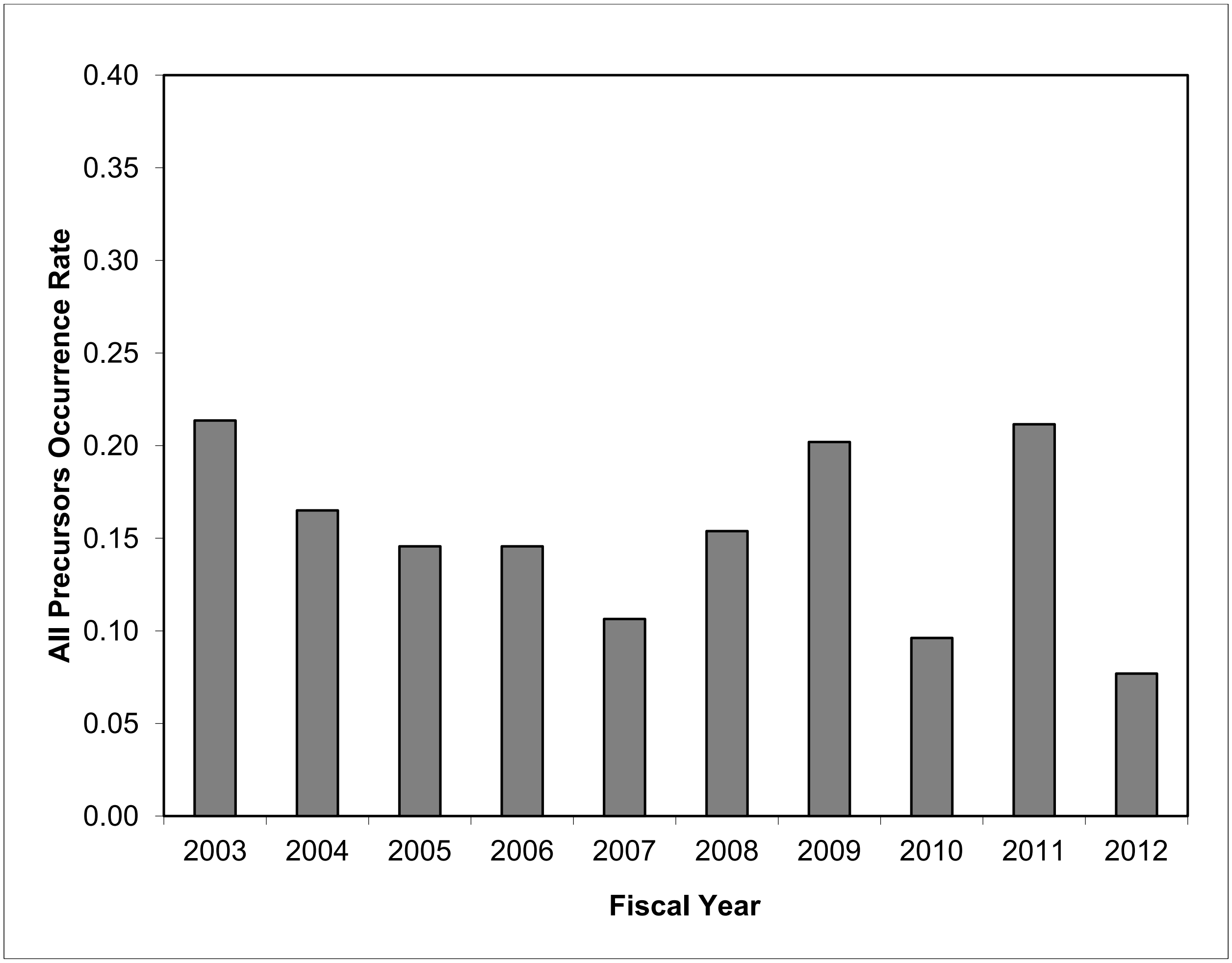

Figure 2. Total precursors

4.2 *Significant* Precursors

The ASP Program provides the basis for the safety measure of zero "number of significant accident sequence precursors of a nuclear reactor accident" (one measure associated with the safety goal established in the NRC's Congressional Budget Justification (Ref. 1)).

Results. A review of the data for the rolling 10-year period reveals the following insights:

- No *significant* precursors have been identified in the last 10 years.

- The last *significant* precursor was identified in FY 2002. The staff identified a *significant* precursor involving concurrent, multiple-degraded conditions at Davis-Besse.[6]

[6] Ref. 3 provides a complete list of all *significant* precursors from 1969–2012.

5.0 Insights and Other Trends

The following sections provide additional ASP trends and insights for the period from FY 2003–2012.

5.1 Occurrence Rate of Precursors with a CCDP or ΔCDP ≥ 1×10^{-4}

Precursors with a CCDP or ΔCDP ≥ 1×10^{-4} are considered important in the ASP Program because they generally have a CCDP higher than the annual core damage probability (CDP) estimated by most plant-specific probabilistic risk assessments (PRAs).

The staff identified three such precursors that occurred during FY 2012. Over the past 10-year period (FY 2003 to FY 2012), a total of eight precursors with CCDP or ΔCDP ≥ 1×10^{-4} occurred. Table 3 summarizes these *important* precursors over the last three years. The staff issued a total of five information notices and one bulletin for four of these events. In addition, the staff issued four greater than GREEN SDP findings (in addition to the two RED findings) as a result of these events.

Table 3. FY 2010–2012 *Important* Precursors (i.e., CCDP or ΔCDP ≥ 1×10^{-4})

Date	Plant (Risk Measure)	Event or Condition	Risk Insights
3/28/10	H. B. Robinson **CCDP = 4×10^{-4}**	Fire causes loss of non-vital busses along with a partial loss of offsite power with reactor coolant pump seal cooling challenges. ***LER 261/10-002***	Neither the fire nor the minor equipment failures individually should have led to a high risk event. However, poor operator performance created a much higher risk scenario. Risk was dominated by transient-induced reactor coolant pump seal loss of coolant accidents (LOCAs). The SDP assessment resulted in two WHITE findings.
10/23/10	Browns Ferry 1 **RED Finding[7] (7×10^{-4})**	Failure to establish adequate design control and perform adequate maintenance causes valve failure that led to a residual heat removal loop being unavailable. ***EA-11-018***	A valve failure coupled with a hypothetical fire that required execution of self-induced station blackout (SBO) procedures would have led to an unrecoverable situation. The self-induced SBO procedures added one to two orders of magnitude to the risk of this event. Risk was dominated by fire-initiated scenarios.
6/7/11	Fort Calhoun **RED Finding (4×10^{-4})**	Fire in safety-related 480-volt electrical breaker because of deficient design controls during breaker modifications. Eight other breakers were susceptible to similar fires. ***EA-12-023***	The plant operated with a poorly designed modification to nine breakers, all of which had a potential for a fire, especially in a relatively minor seismic event. Risk comes from a very wide variety of sequences.

[7] A RED finding corresponds to a licensee performance deficiency of high safety significance and has an increase in core damage frequency greater than 10^{-4}.

Date	Plant (Risk Measure)	Event or Condition	Risk Insights
8/23/11	North Anna, Unit 1 **CCDP = 3×10^{-4}**	Dual unit loss of offsite power caused by earthquake that coincided with the Unit 1 turbine-driven auxiliary feedwater (AFW) pump being out-of-service because of testing and the subsequent failure of a Unit 2 emergency diesel generator (EDG). ***LER 338/11-003***	Earthquake coupled with routine maintenance on the AFW pump and an unrelated failure of an EDG. Risk was dominated by SBO sequences. The SDP assessment resulted in a WHITE finding.
1/13/12	Wolf Creek **CCDP = 5×10^{-4}**	Multiple switchyard faults cause reactor trip and subsequent loss of offsite power. ***LER 482/12-001***	A moderate length LOOP (two to three hours) caused by equipment failures in the switchyard. Risk was dominated by SBO sequences. ASP looked at the LOOP initiating event while the SDP analysis performed a condition assessment on the loss of the startup transformer resulting in a YELLOW finding.
1/30/12	Byron, Unit 2 **CCDP = 1×10^{-4}**	Transformer and breaker failures cause loss of offsite power, reactor trip, and de-energized safety buses. ***LER 454/12-001***	The key issue for this event is the potential for operators to fail to recognize this scenario. Operator errors could lead to SBO-like sequences.
5/24/12	River Bend **CCDP = 3×10^{-4}**	Loss of normal service water, circulating water, and feedwater due to electrical fault. ***LER 458/12-003***	Initiating event coupled with postulated loss of safety-related service water would lead to complete loss of heat sink.

Results. A review of the data for FY 2003–2012 reveals the following insights:

- The mean occurrence rate of precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4} exhibited a statistically significant (p-value = 0.0042) trend during this same period (see Figure 3).

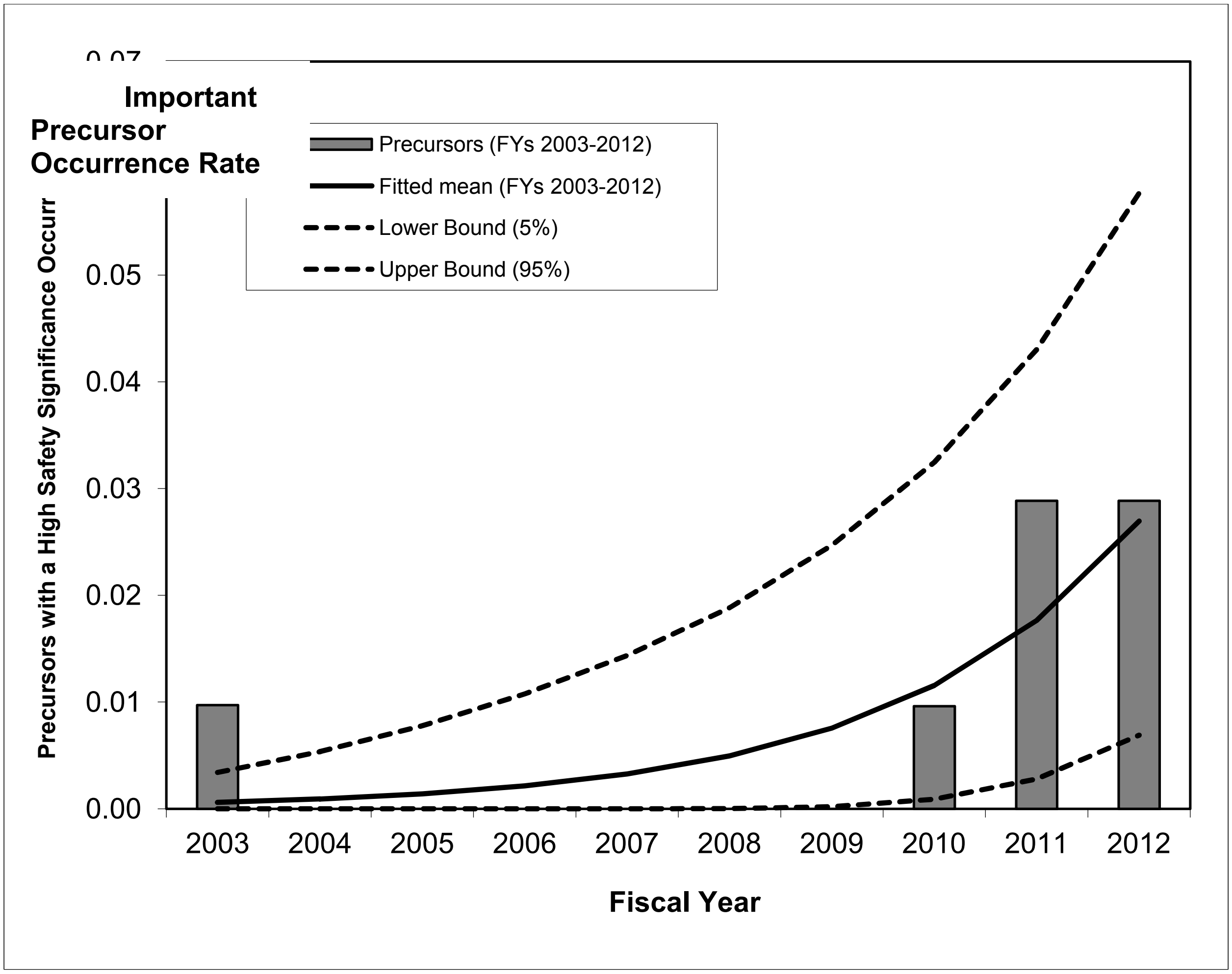

Figure 3. ***Important*** **Precursors (10 year)**

- Figure 3 shows that one precursor with a CCDP or ΔCDP greater than or equal to 1×10^{-4} occurred between 2003 and 2009 and seven such precursors have occurred since 2010.
  - Historically, 28 *important* precursors occurred over the last 20 years (Figure 3A). Thus, historic occurrence rates were somewhat higher.
  - Of these 28 *important* precursors, 36 percent involved a LOOP initiating event. This is generally consistent with recent experience.

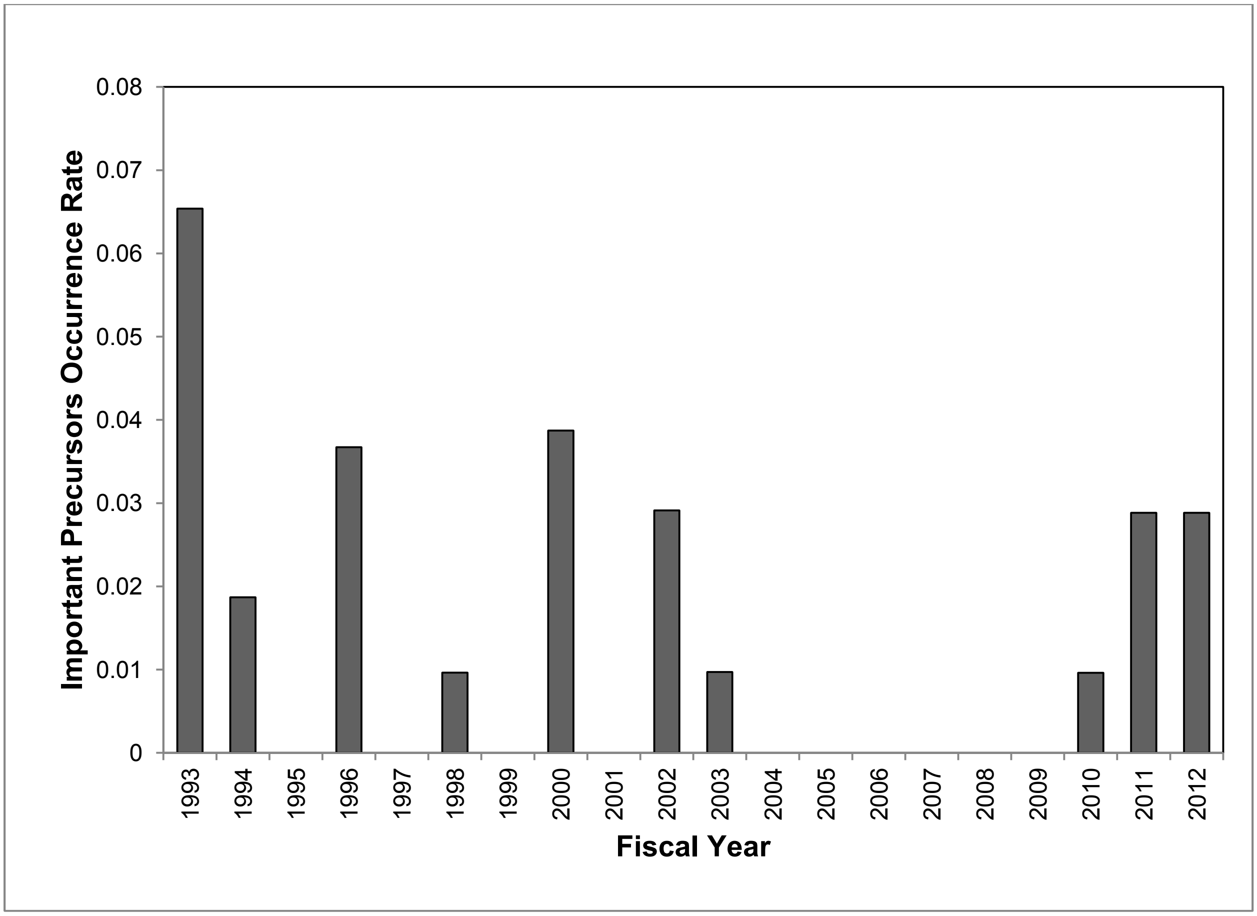

Figure 3A. *Important* Precursors (20 year)

- The events in this group over the last 10 years involve differing reactor types, causes, systems, and components.

A review of the *important* precursors in Table 3 reveals the following:

- Six of the seven precursors involved electrical-related events in electrical distribution systems. Five of the electrical-related events resulted in reactor trips, of which three were associated with LOOP initiating events. Fort Calhoun was in cold shutdown during the sixth electrical-related non-trip event.

- LOOP initiating events with no complications are not usually *important* precursors. However, the three LOOP events reviewed here involved one or more additional failures and/or test/maintenance unavailabilities of standby safety equipment that resulted in higher CCDPs (North Anna, Byron, and Wolf Creek). The LOOP at Byron was unique in that operator action was required to establish emergency power to the safety buses because of a design vulnerability associated with a single-phase open circuit condition.[8]

- Two precursors involved fires of electrical components caused by electrical faults (Robinson and Fort Calhoun). In the case of Robinson, multiple electrical fires occurred during the initial fault, and a second fire was caused during plant restoration (i.e., the

[8] See NRC Bulletin 2012-01, “Design Vulnerabilities in Electric Power System,” (Ref. 6).

operating crew attempted to reset an electrical distribution system control relay before isolating the fault, which re-initiated the electrical fault and caused a second fire). The fires at Robinson were extinguished by plant personnel using dry chemical fire extinguishers. The electrical fire in a switchgear room at Fort Calhoun was extinguished by the automatic fire suppression system.

- Four of the five precursors involving reactor trips had failures that were recoverable. In fact, the recovery actions were successfully implemented by the operators during each of these actual events.[9] These recovery actions were credited in the ASP analysis and contributed to risk reductions in these four events.

- Two of the seven precursors did not result in a reactor trip, but involved conditions resulting in the unavailability of safety components for some period of time. These components were not recoverable in the time necessary to mitigate a hypothetical initiating event.

- Three precursors involved failures and initiators that contributed to rarely seen accident sequences.
  - The Robinson electrical fault with subsequent reactor trip resulted in a complete loss of reactor coolant pump (RCP) cooling and a partial loss of seal injection for 39 minutes. In PRA models, including the standardized plant analysis risk (SPAR) models, loss of RCP seal injection and cooling significantly increases the likelihood of a RCP seal loss-of-coolant accident (LOCA) within 13 minutes of the loss of seal injection and cooling. The operators restarted the charging pumps within one minute; however, an open valve in the charging system diverted flow away from the RCP seals. The operators recovered seal cooling at 13 minutes. Recovery of seal injection was not credited in the ASP analysis and recovery of seal cooling within 13 minutes was assigned a very high failure probability (0.8), which contributed to the high risk result.
  - The Bryon Unit 2 LOOP and design vulnerability resulted in the complete loss of useful electrical power to the safety buses. The operators were able to diagnose the problem and restore power from the emergency diesel generators (EDGs) to the safety buses in eight minutes. Offsite power was restored to both safety buses approximately 34 hours after the LOOP occurred. Recovery of emergency power to the safety bus prior to station battery depletion was modeled in the ASP analysis.
  - The beyond design basis earthquake at North Anna induced a LOOP event and subsequent reactor trips in both units. During the LOOP event, one of four EDGs onsite failed, and the Unit 1 turbine-driven auxiliary feedwater (AFW) pump was out of service for surveillance testing. The station blackout diesel generator was manually aligned to the safety bus in 49 minutes. The turbine-driven AFW pump was placed back into service in 33 minutes. Offsite power was restored to all four safety buses approximately nine hours after the LOOP occurred. These recovery actions were modeled in the ASP analysis.

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9 Even though recovery actions were successfully accomplished during the actual events, the ASP Program does not take complete credit for these successful human actions. Human Reliability Analysis (HRA) is performed for each recovery action to calculate the probability of failure to recover. HRA considers complications in human performance that were observed during the actual event and impacts on human performance, both negative and positive, that would be experienced during each postulated accident sequence.

5.2 Initiating Event and Degraded Condition Precursor Subgroup Trends

A review of the data for FY 2003–2012 yields insights described below.

Initiating Events

- The mean occurrence rate of precursors involving initiating events does not exhibit a trend that is statistically significant (p-value = 0.37) for the period from FY 2003–2012, as shown in Figure 4.

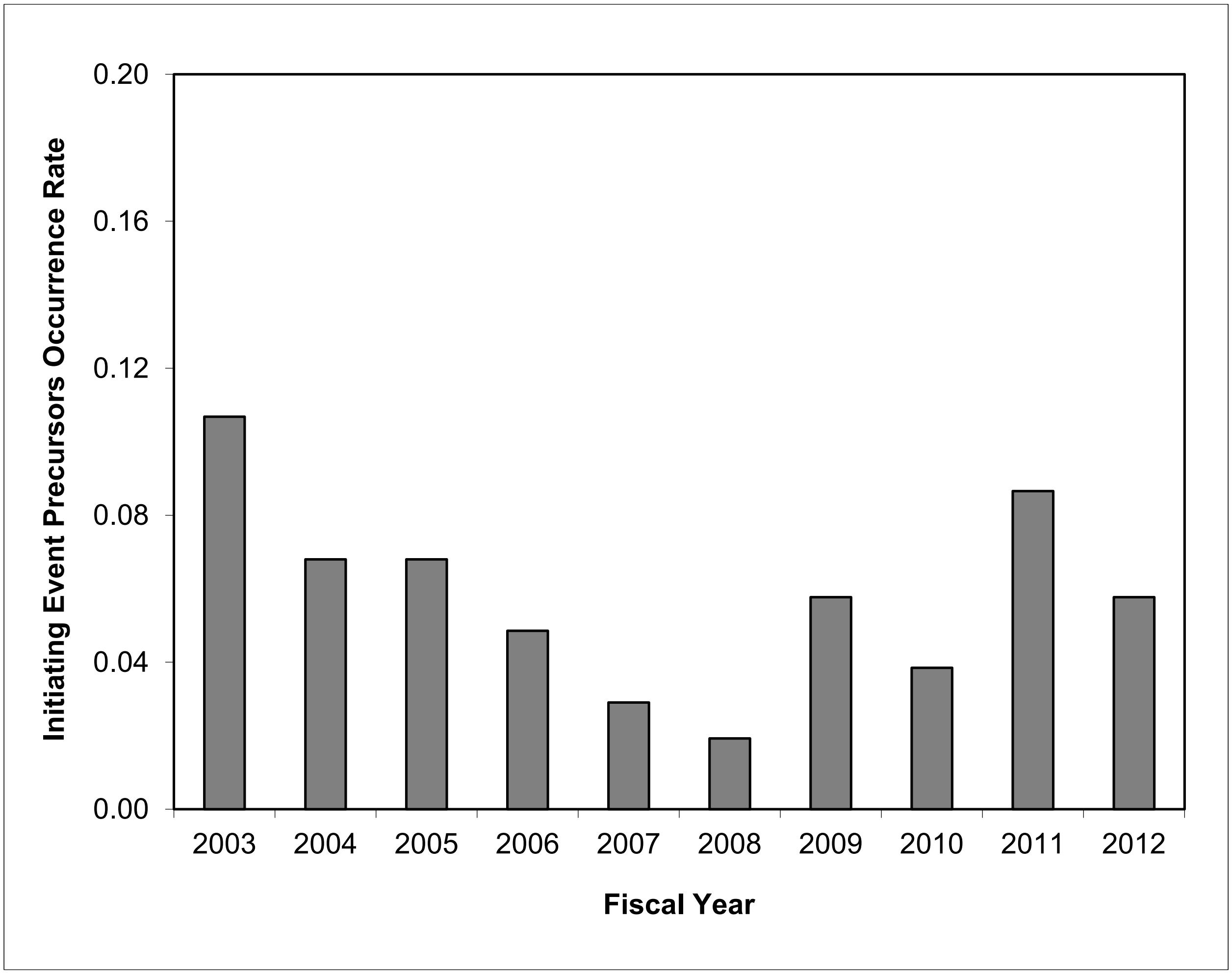

Figure 4. Precursors involving initiating events

- Of the 60 precursors involving initiating events during FY 2003–2012, 60 percent were LOOP events. This is expected because uncomplicated transients typically do not exceed the ASP threshold (10^{-6}), while essentially all LOOPs do exceed the threshold. While the frequency of complicated transients is about the same as the frequency of LOOPs, the risk estimates for LOOPs are somewhat higher.

Degraded Conditions

- The mean occurrence rate of precursors involving degraded conditions does not exhibit a trend that is statistically significant (p-value = 0.52) during FY 2003–2012, as shown in Figure 5.

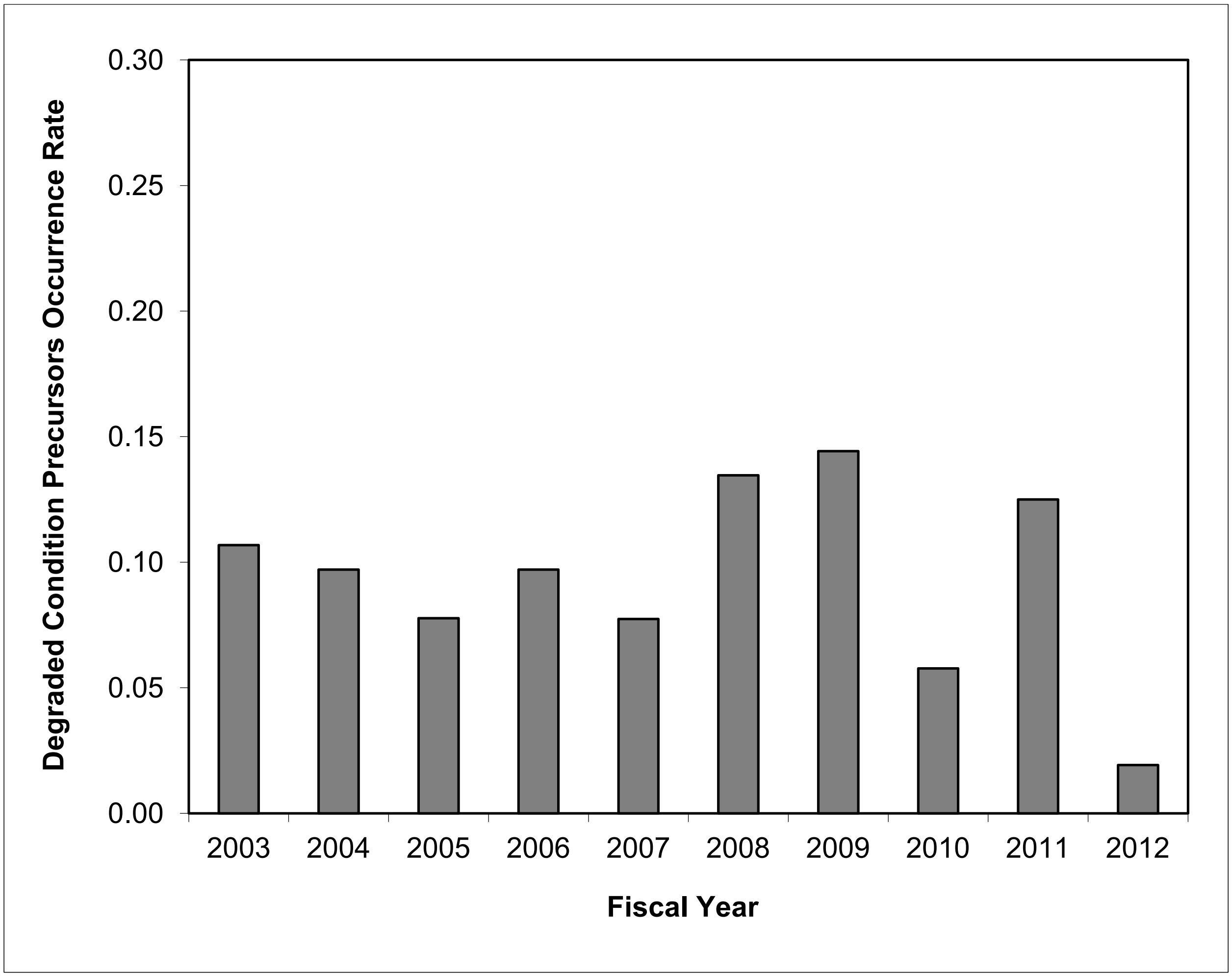

Figure 5. Precursors involving degraded conditions

- Over the past 10 years, precursors involving degraded conditions outnumbered initiating events by 60 percent.

- From FY 2003–2012, 27 percent of precursors involved degraded conditions existing for a decade or longer.[10] Of these precursors, 42 percent involved degraded conditions dating back to initial plant construction.

[10] Note that although these degraded conditions lasted for many years, ASP analyses limit the exposure period to 1 year.

5.3 Precursors Involving a Complete Loss of Offsite Power Initiating Events

In FY 2012, five precursors resulted from a complete LOOP initiating event. Typically, all complete LOOP events meet the precursor threshold.

Results. A review of the data for FY 2003–2012 leads to the following insights:

- The mean occurrence rate of precursors resulting from a LOOP does not exhibit a trend that is statistically significant (p-value = 0.45) for the period from FY 2003–2012, as shown in Figure 6.

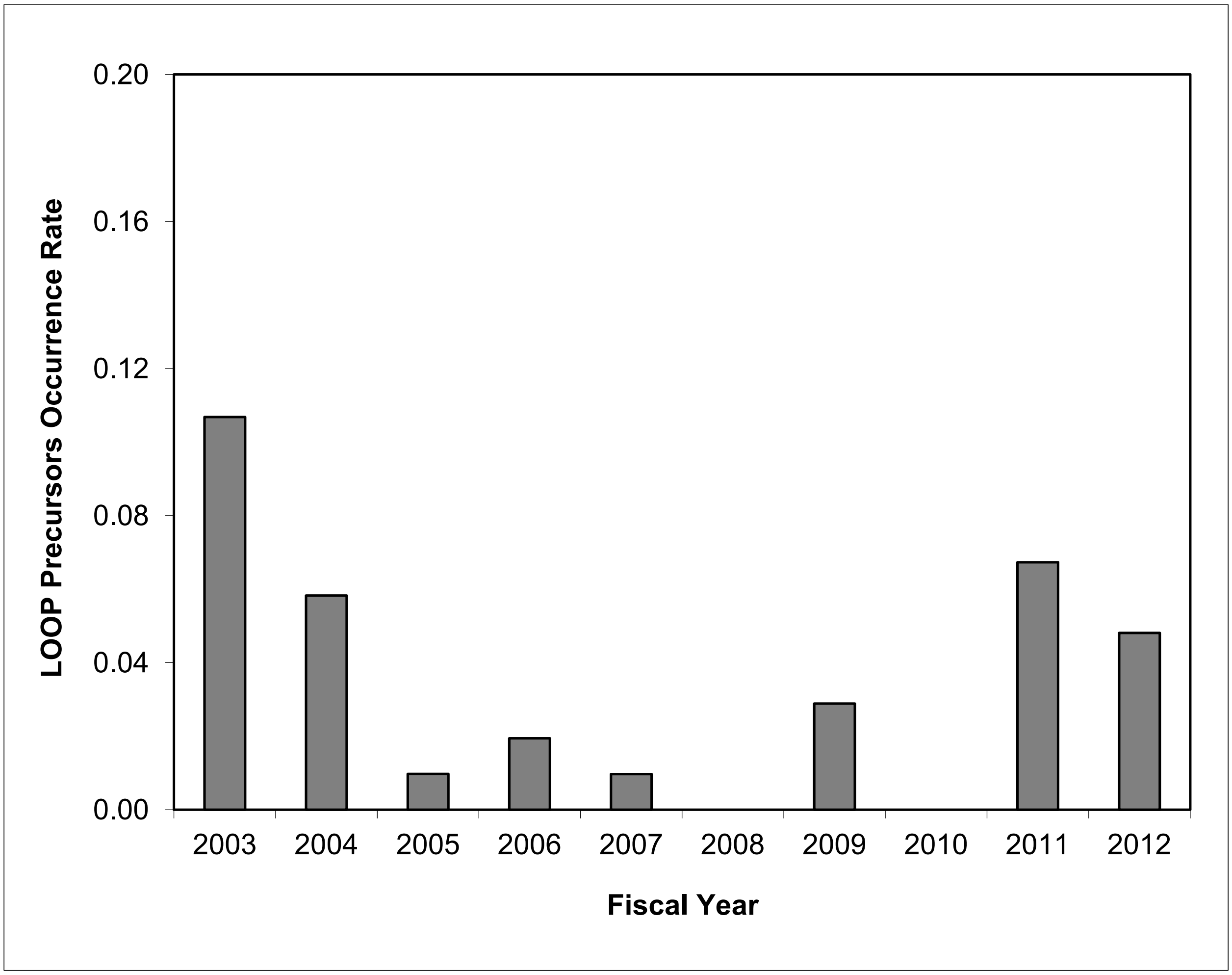

Figure 6. Precursors involving LOOP events

- Of the 36 LOOP precursors that occurred during FY 2003–2012, 33 percent resulted from external events and 33 percent resulted from a degraded electrical grid outside of the NPP boundary.
  - Eight of the 12 grid-related LOOP precursors were the result of the 2003 Northeast Blackout.
  - Seven of the 12 LOOP precursors that were caused by external events occurred in FY 2011. This is unusual and unprecedented, but there is no indication of a trend of these events.

- Four of the 36 LOOP precursor events during FY 2003–2012 involved a simultaneous unavailability of an emergency power system train.

5.4 Precursors at BWRs and PWRs Subgroup Trends

A review of the data for FY 2003–2012 reveals the results for boiling-water reactors (BWRs) and pressurized-water reactors (PWRs) described below.

BWRs

- The mean occurrence rate of precursors that occurred at BWRs does not exhibit a trend that is statistically significant (p-value = 0.71) for FY 2003–2012, as shown in Figure 7.

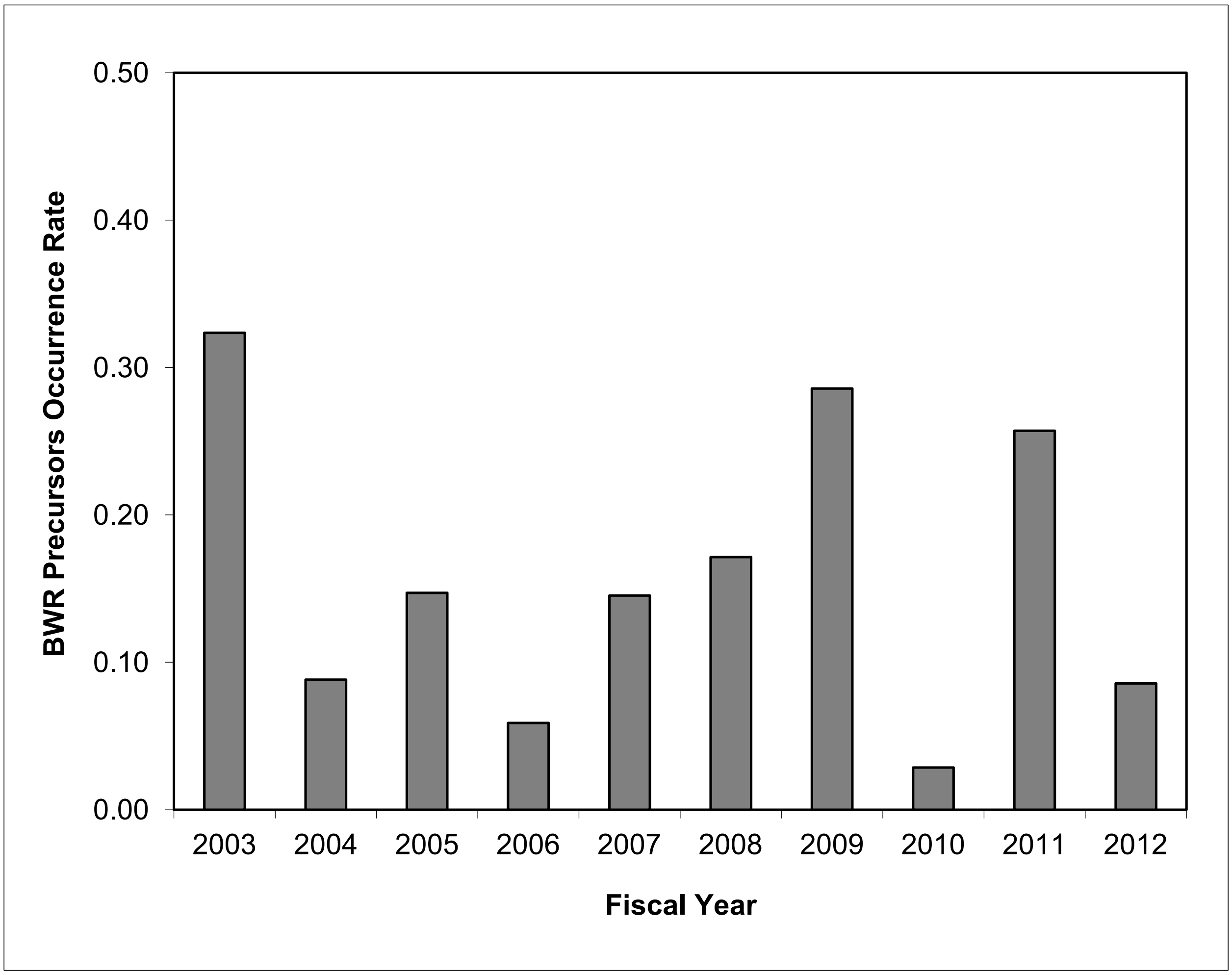

Figure 7. Precursors involving BWRs

- LOOP events contributed to 63 percent of precursors involving initiating events at BWRs.

- Of the 31 precursors involving the unavailability of safety-related equipment that occurred at BWRs during FY 2003–2012, most were caused by failures in the emergency power system (35 percent), emergency core cooling systems (23 percent), safety-related cooling water systems (13 percent), or electrical distribution system (10 percent).

PWRs

- The mean occurrence rate of precursors that occurred at PWRs does not exhibit a trend that is statistically significant (p-value = 0.20) for FY 2003–2012, as shown in Figure 8.

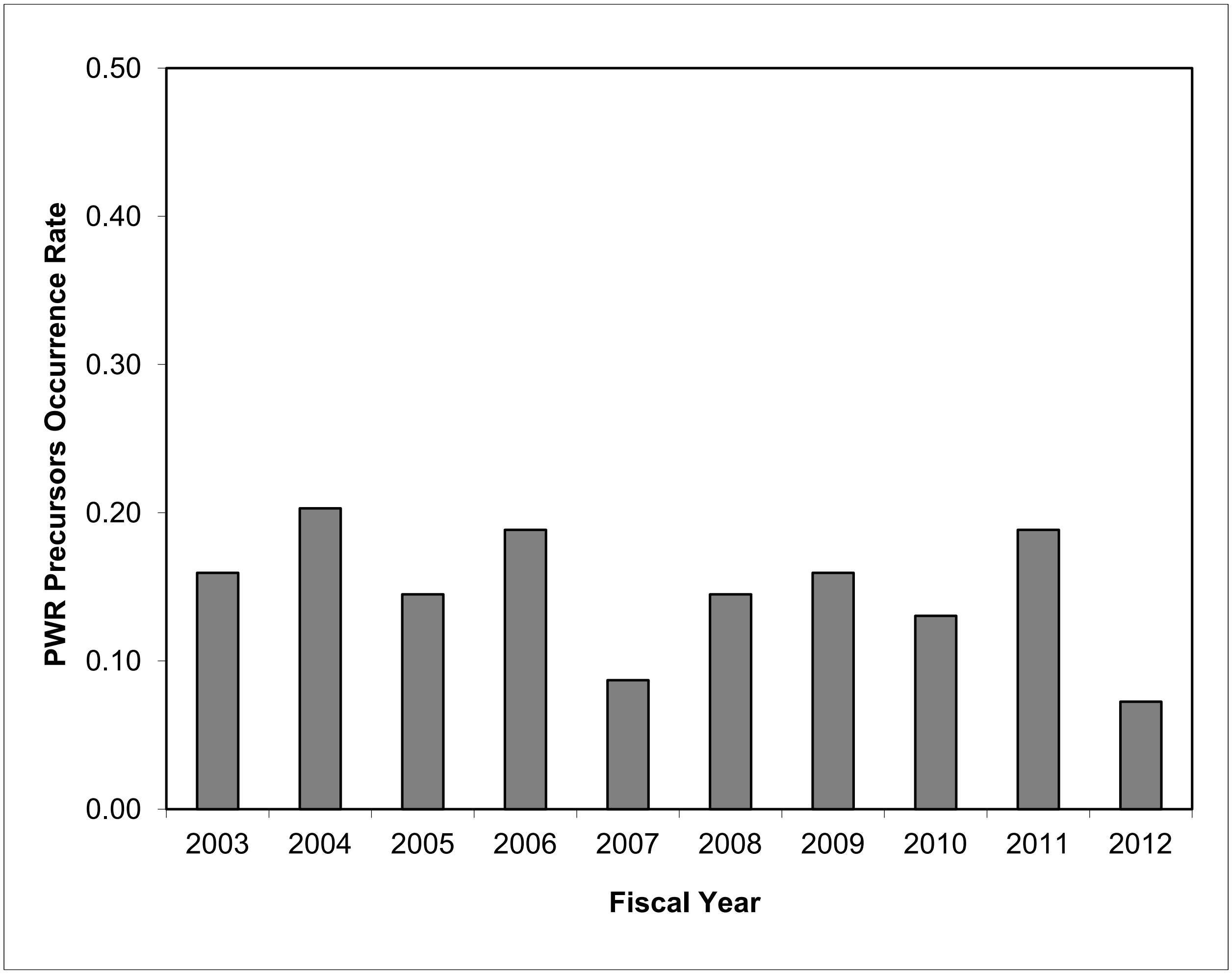

Figure 8. Precursors involving PWRs

- LOOP events contribute 58 percent of precursors involving initiating events at PWRs.

- Of the 66 precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2003–2012, most were caused by failures in the emergency power system (27 percent), emergency core cooling systems (14 percent), auxiliary feedwater system (18 percent), safety-related cooling water systems (14 percent), or electrical distribution system (14 percent).
  - Of the 9 precursors involving failures in the emergency core cooling systems, 7 precursors (78 percent) were because of conditions affecting sump recirculation during postulated LOCAs of varying break sizes. Design errors caused most of these precursors (71 percent).

- Of the 12 precursors involving failures of the auxiliary feedwater system, random hardware failures (58 percent) and design errors (42 percent) were the largest failure contributors. Eleven of the 12 precursors (92 percent) involved the unavailability of the turbine-driven auxiliary feedwater pump train.
- Of the 18 precursors involving failures of the emergency power system, 15 precursors (83 percent) were from hardware failures.
- Design errors contributed 41 percent of all precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2003–2012.

5.5 Integrated ASP Index

The staff derives the integrated ASP index for order-of-magnitude comparisons with industry-average core damage frequency (CDF) estimates derived from probabilistic risk assessments (PRAs) and the NRC's standardized plant analysis risk (SPAR) models. The index or CDF from precursors for a given fiscal year is the sum of CCDPs and ΔCDPs in the fiscal year divided by the number of reactor-operating years in the fiscal year.

The integrated ASP index includes the risk contribution of a precursor for the entire duration of the degraded condition (i.e., the risk contribution is included in each fiscal year that the condition exists). The risk contributions from precursors involving initiating events are included in the fiscal year that the event occurred.

Examples. A precursor involving a degraded condition is identified in FY 2011 and has a ΔCDP of 5×10^{-6}. A review of the LER reveals that the degraded condition has existed since a design modification that was performed in FY 2007. In the integrated ASP index, the ΔCDP of 5×10^{-6} is included in FY 2007, 2008, 2009, 2010, and 2011 and is not prorated for any portion of the year that this condition existed but rather implemented for the entire year, which conservatively estimates the risk contribution during the first and last year. For an initiating event occurring in FY 2011, only FY 2011 includes the CCDP from this precursor.

Results. Figure 9 depicts the integrated ASP indices for FY 2003–2012. A review of the ASP indices leads to the following insights:

- Based on the order of magnitude (10^{-5}), the average integrated ASP index for the period from FY 2003–2012 is consistent with the CDF estimates from the SPAR models and industry PRAs.

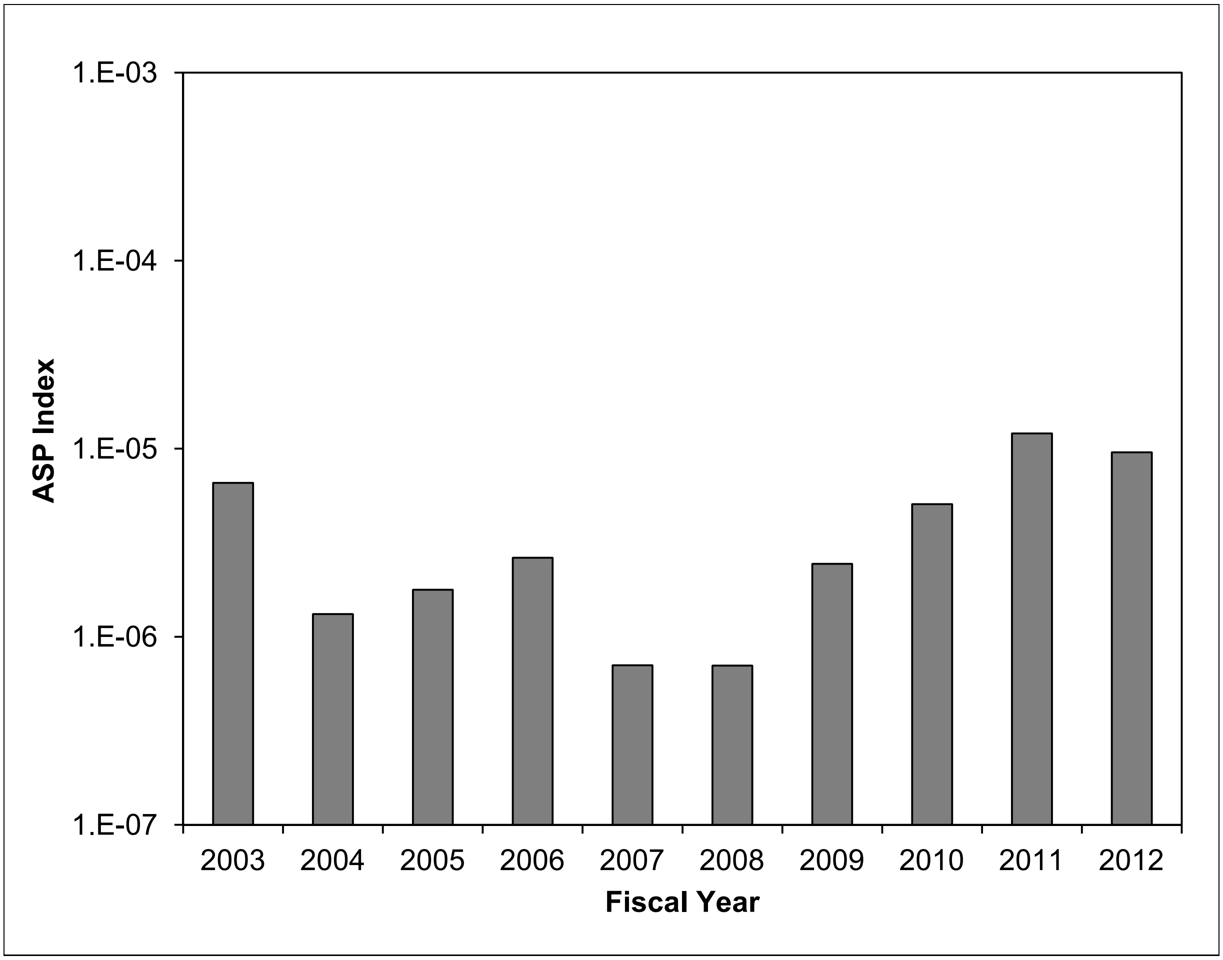

Figure 9. Integrated ASP index

- Precursors over the FY 2003–2012 period made the following contributions to the average integrated ASP index:
  - The average integrated ASP index resulted from contributions from the 157 precursors.
  - The number of precursors was a little higher than typical in FY 2011 and a little lower than typical in FY 2012. However, the value of this index is relatively high in both FY 2011 and FY 2012 because of the increase in precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4}, which tends to drive the indicator much more than the number of precursors. From a broad industry perspective, this increase is not viewed to be significant.

Limitations. Using CCDPs and ΔCDPs from ASP results to estimate CDF is difficult because (1) the mathematical relationship between CCDPs, ΔCDPs, and CDF requires a significant level of detail, (2) statistics for frequency of occurrence of specific precursor events are sparse, and (3) the assessment must also account for events and conditions that did not meet the ASP precursor criteria.

The integrated ASP index provides the contribution of risk (per fiscal year) resulting from precursors and cannot be used for direct trending purposes because the discovery of precursors involving longer-term degraded conditions in future years may change the cumulative risk from the previous year(s).

5.6 Operating Experience Insights Feedback for PRA Standards and Guidance

A secondary objective of the ASP Program is to provide insights into the current state of practice in risk assessment. ASP events from this fiscal year were reviewed against the approaches to PRA described in the American Society of Mechanical Engineers (ASME)/ American Nuclear Society (ANS) RA-S-2008, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," (Ref. 4), as endorsed in Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," (Ref. 5). This review sought to identify aspects of the events for which the risk-significant ASME/ANS PRA Standard did not provide guidance. None of the events indicated an inadequacy in the state of PRA practice as described in ASME/ANS RA-Sa-2009.

6.0 Summary

This section summarizes the ASP results, trends, and insights:

- ***Significant Precursors.*** The staff identified no *significant* precursors (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-3}) in FY 2012. The staff identified no potentially *significant* precursors in FY 2013. The ASP Program provides the basis for the safety-performance measure goal of zero "number of *significant* accident sequence precursors of a nuclear reactor accident." The final results will be provided in the FY 2013 NRC Performance and Accountability Report (NUREG-1542).

- ***Occurrence Rate of All Precursors.*** The occurrence rate of all precursors does not exhibit a trend that is statistically significant during FY 2003–2012. The trend of all precursors is one input into the ITP to assess industry performance and is part of the input into the adverse trends safety measure. These results will be provided in the FY 2013 NRC Performance and Accountability Report.

- ***Additional Trend Results.*** During the same period, a statistically significant increasing trend was observed in precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4}. There is an increase of precursors in this subgroup the past three years after no events were identified in the previous six years.

As documented in SECY-13-0038, "Fiscal Year 2012 Results of the Industry Trends Program for Operating Power Reactors," the long-term trend for the significant events indicator did not show a statistically significant adverse trend. However, the paper did note that final analysis of FY 2011 events by the ASP program had pushed the number of significant events in FY 2011 above the short-term prediction limit.

SECY-13-0038 also notes that the Office of Nuclear Reactor Regulation is reviewing significant events from the past 5 years as documented in the FY 2012 Industry Trends annual report, including the seven events noted in this paper as *important* precursors, to determine if there is any trend of concern that the Nuclear Regulatory Commission will need to address. This evaluation found that loss of offsite power was a significant contributor to risk in some of the *important* precursors from the past three years. Rulemaking actions already underway to address station blackout as part of the follow-up to the Fukushima Task Force recommendations should have an impact on the risk significance posed by future loss of offsite power events. The evaluation also found that the risk in many of the most significant events was being driven by equipment failures and human errors that compounded the significance of expected initiators, and that weaknesses in licensee corrective action programs were a contributing factor in all of the events listed in Table 3 above. The staff is considering the conclusions and recommendations from this review as part of the ongoing ROP Enhancement Project effort discussed in the SECY-13-0037, "Reactor Oversight Process Self-Assessment for Calendar Year 2012."

7.0 References

1. U.S. Nuclear Regulatory Commission, "Performance Budget: Fiscal Year 2014," NUREG-1100, Vol. 29, April 2013.

2. U.S. Nuclear Regulatory Commission, "Revised Review and Transmittal Process for Accident Sequence Precursor Analyses," Regulatory Issue Summary 2006-24, December 2006.

3. U.S. Nuclear Regulatory Commission, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models," Commission Paper SECY-12-0133, October 4, 2012.

4. American Society of Mechanical Engineers/American Nuclear Society, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," ASME/ANS RA-Sa-2009, March 2009.

5. U.S. Nuclear Regulatory Commission, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," Regulatory Guide 1.200, Revision 2, March 2009.

6. U.S. Nuclear Regulatory Commission, "Design Vulnerabilities in Electric Power System," NRC Bulletin 2012-01, July 27, 2012.

Status of the Standardized Plant Analysis Risk Models

1.0 Background

The objective of the U.S. Nuclear Regulatory Commission's (NRC's) Standardized Plant Analysis Risk (SPAR) Model Program is to develop standardized risk analysis models and tools for staff analysts to support various regulatory activities, including the Accident Sequence Precursor (ASP) Program and Phase 3 of the Significance Determination Process (SDP). The SPAR models have evolved from two sets of simplified event trees initially used to perform precursor analyses in the early 1980s. Today's SPAR models for internal events are far more comprehensive than their predecessors. For example, the revised SPAR models include improved loss of offsite power (LOOP) and station blackout modules; an improved reactor coolant pump seal failure model; new support system initiating event models; and updated estimates of accident initiator frequencies and equipment reliability based on recent operating experience data.

The SPAR models consist of a standardized, plant-specific set of risk models that use the event-tree and fault-tree linking methodology. They employ a standard approach for event-tree development, as well as a standard approach for input data for initiating event frequencies, equipment performance, and human performance. These input data can be modified to be more plant- and event-specific, when needed. SPAR standardization is needed to allow agency risk analysts to efficiently use SPAR models for a wide variety of nuclear plants without having to relearn modeling conventions and basic assumptions. The system fault trees contained in the SPAR models generally are not as detailed as those in licensee probabilistic risk assessments (PRAs), although, in some cases, SPAR models may contain more sophisticated modeling for common cause failure, support systems, and loss of offsite power modeling. To date, the staff has completed 80 SPAR models representing all 104 commercial nuclear power units. All SPAR models are developed under a comprehensive quality assurance program and have been benchmarked against licensee PRAs through either onsite quality assurance reviews or information changes with the licensee.

The staff initiated the Risk Assessment Standardization Project (RASP) in 2004. A primary focus of RASP was to standardize risk analyses performed in SDP Phase 3, ASP, and Management Directive (MD) 8.3, "NRC Incident Investigation Program." Under this project, the staff initiated the following activities:

- Enhance SPAR models to be more plant specific and improve the Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) code used to manipulate the SPAR models.

- Document consistent methods and guidelines for risk assessments of internal events during power operations; internal fires and floods; external hazards (e.g., seismic events and tornadoes); and internal events during low-power and shutdown (LPSD) operations.

- Provide on-call technical support for staff involved with licensing and inspection issues.

2.0 SPAR Model Program Status

The SPAR Model Program continues to play an integral role in the ASP analysis of operating events. Many other agency activities, such as the SDP analyses and MD 8.3 evaluations, involve the use of SPAR models. The NRC is developing new SPAR modules in response to staff needs for assessing plant risk for external hazards and for assessing accident progression to the plant damage state level.

The staff has completed the following activities in model and method development since the previous status report (SECY-12-0133, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models," dated October 4, 2012), as described below.

Technical Adequacy of SPAR Models

The staff implemented a Quality Assurance (QA) Plan covering the SPAR models in 2006. The SPAR QA plan was updated in fiscal year (FY) 2013. The main objective of this plan is to ensure that the SPAR models continue to represent the as-built, as-operated nuclear plants and be of sufficient quality for performing event assessments of operational events in support of the staff's risk-informed activities. The staff has processes in place to verify, validate, and benchmark these models according to the guidelines and standards established by the SPAR Model Program. As part of this process, the staff performs reviews of the SPAR models and results against the licensee PRA models, when applicable. The staff also has processes in place for the proper use of these models in agency programs such as the ASP Program, the SDP, and the MD 8.3 process. These processes are documented in the RASP handbook, which serves as a desktop guidance document for agency risk analysts.

In addition, in 2010 the staff (with the cooperation of industry experts) performed a peer review of a representative boiling-water reactor (BWR) SPAR model and pressurized-water (PWR) reactor SPAR model in accordance with American Society of Mechanical Engineers (ASME)/American Nuclear Society (ANS) RA-S-2008, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," and Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities." The staff has reviewed the peer review comments and has initiated projects to address these comments, where appropriate. Activities in progress to address these peer review items include structuring the SPAR model documentation to more closely align with the structure of the PRA standard, incorporation of improved LOOP modeling, and addressing the high priority items for the BWR models. These activities have been conducted at a significantly reduced pace during FY 2013 because of sequestration-related budget cuts. However, pending the availability of sufficient resources, the staff is planning to continue resolution of peer review items in FY 2014, including documentation enhancements, model updates, and high priority BWR peer review items. Resolution of PWR peer review issues have been deferred until sufficient funding becomes available.

Routine SPAR Model Updates

Existing SPAR models need to be updated regularly as a result of any significant plant changes that may affect the risk profile of the plant. As the SPAR model is updated, its documentation (i.e., model and plant risk information eBook summary reports) is also updated to represent the latest PRA information included in the SPAR model. Although the goal is to update approximately 12 models per year, because of budget constraints, the effort was reduced to six model updates for FY 2013.

In FY 2013, the staff updated the SPAR models for the Byron, Braidwood, Turkey Point, Monticello, Duane Arnold and Watts Bar plants. The staff is currently working on identifying the next set of SPAR models to be updated in FY 2014.

SPAR Models for the Analysis of All Hazards (External Events)

Development of SPAR All HaZard (SPAR-AHZ) models that contain accident scenarios from all hazard categories applicable to a given site, has continued during FY 2013, although at a lower intensity because of budgetary constraints and conflicts with other high priority work, such as the Level 3 PRA project for the Vogtle site. Two SPAR-AHZ models, which include internal fire models extracted from National Fire Protection Association (NFPA)-compliant fire models for the Shearon Harris and D.C. Cook plants, have been constructed and placed in the SPAR model library for use by NRC risk analysts. The NRC has also initiated additional external hazard models for the V.C. Summer and the Vogtle operating nuclear plant SPAR models. Development of these models includes licensee site visits to gather information and discuss modeling assumptions and results. Because the licensee-developed NFPA 805-compliant fire PRA models contain thousands of quantified sequences, a significant focus of the SPAR-AHZ effort was combining similar sequences to enhance model usability while maintaining the ability to retain the resolution contained in the licensee models. Currently, the NRC Office of Nuclear Regulatory Research (RES) and the NRC Office of Nuclear Reactor Regulation (NRR) are working together to identify ways to increase the pace of SPAR-AHZ model development, given expected resource constraints in FY 2014 and beyond.

New Reactor SPAR Models

Before new plant operation, the staff may perform risk assessments to inform potential risk-informed applications for Combined Licenses (COLs), focus construction inspection scope, or assess the significance of construction inspection findings. Once the plants begin operation, the results from licensee PRAs or independent assessments using SPAR models may be used by the staff for the evaluation of operational findings and events similar to the assessments performed for current operating reactors.

There are currently five new reactor internal hazard SPAR models. These include one model for the AP1000, two Advanced Boiling-Water Reactor (ABWR) models (one for the Toshiba design and one for the General Electric-Hitachi design), and one model for the U.S. Advanced Pressurized-Water Reactor (US-APWR). In addition to these internal events models, there is a seismic model for the AP1000 and a low power and shutdown model for the Toshiba ABWR. In FY 2013, the staff completed the development of the SPAR model for the U.S. Evolutionary Power Reactor (U.S. EPR) and the requisite supporting documentation for the model. The staff also started to develop a SPAR-AHZ model for the AP1000 reactor design. The first module completed included the incorporation of internal flooding. The staff plans to continue building additional modules to include internal fire and low power and shutdown models.

The staff plans to continue developing new reactor SPAR models, including external hazards and low power and shutdown models, as needed, to support licensing and oversight activities. Because design standardization is a key aspect of the new plants, it should only be necessary to develop one internal events SPAR model for each of the new designs.

MELCOR Thermal Hydraulic Analysis for SPAR Model Success Criteria

The staff continues to perform MELCOR analyses to investigate success criteria associated with specific Level 1 PRA sequences. In some cases, these analyses confirm the existing technical basis and in other cases they support modifications that can be made to increase the realism of the agency’s SPAR models. The latest round of activity is documented in two reports: (1) an upcoming NUREG report to be issued for public comment entitled, "Confirmatory Thermal-Hydraulic Analysis to Support Specific Success Criteria in the Standardized Plant Analysis Risk Models—Byron," and (2) a final NUREG/CR report to be issued later in calendar year (CY) 2013 entitled, "Compendium of Analyses to Investigate Select Level 1 Probabilistic Risk Assessment End-State Definition and Success Criteria Modeling Issues." The results of these studies will be used to confirm specific success criteria for a suite of four-loop Westinghouse plants, which are similar to Byron, with appropriate consideration of the design and operational differences of these plants. They also will be used to support application-specific consultation on the use of the SPAR models.

This effort directly supports the agency's goal of using state-of-the-art tools that promote effectiveness and realism. The NRC is communicating the project plans and results to internal and external stakeholders through mechanisms such as the Regulatory Information Conference and the industry's Modular Accident Analysis Program Users' Group.

3.0 Additional Activities

SAPHIRE Maintenance and Improvements

In FY 2013, new features and capabilities have been implemented in SAPHIRE to better support NRC regulatory activities. A new cutset editor tool is being incorporated into SAPHIRE. The cutset editor will allow users to efficiently review cutset results, quickly apply changes and sensitivity cases, and recalculate the results. The work on this tool is expected to be completed this calendar year. In an effort to improve calculation speed, SAPHIRE includes a new feature to automatically adjust the model truncation level to permit more efficient solution convergences.

In addition, the SAPHIRE developers continue to explore advanced quantification techniques that can improve accuracy and solving speeds. A Binary Decision Diagram (BDD) solving tool has been incorporated into SAPHIRE and other solving options are being considered. Binary Decision Diagram-based methods quantify the overall probability directly from the logic model and avoid truncation and the use of approximations seen in cutset-based methods. The implementation of advanced quantification techniques, such as BDDs, can help to support: (1) consistency with the PRA practices and tools that are used throughout the nuclear industry and (2) quantification challenges associated with the expanded scope and complexity of the SPAR models that may include external hazards, low power and shutdown, or other accident scenarios. Other SAPHIRE enhancements have focused on improving flexibility for Level 2 PRA modeling. New SAPHIRE features support a Level 2 model quantification process similar to what is routinely used in the Level 1 SPAR models, and the ability to utilize decomposition event trees.

The SAPHIRE developers have also completed transitioning the SAPHIRE legacy source code to a new programming language for the purpose of improving long-term maintenance and support of the software. All of these improvements to SAPHIRE have been performed in accordance with the SAPHIRE software QA program. A set of software QA documents has been developed for SAPHIRE. These documents cover topics such as the software development plan, configuration management, software requirements tracking, and software testing and acceptance. The NRC project manager performs an annual audit of the SAPHIRE software quality assurance program. The most recent audit was completed on December 13, 2012 and no significant issues were identified. The NRC Project Manager confirmed that the maintenance and implementation of the SAPHIRE software quality assurance program is consistent with the guidance contained in NUREG/BR-0167, "Software Quality Assurance Program and Guidelines."

Cooperative Research for PRA

The staff has executed an addendum to the memorandum of understanding (MOU) with Electric Power Research Institute (EPRI) to conduct cooperative nuclear safety research for PRA. Several of the initiatives included in the addendum are intended to help resolve technical issues that account for the key differences between NRC SPAR models and licensee PRA models.

During FY 2013, significant efforts have been made in implementing PRA methodologies for support system initiating event (SSIE) analysis and treatment of LOOP in PRAs. These methodologies are being implemented in the SPAR models as one of the activities associated with addressing the peer review comments. To date, 40 models have been enhanced with the improved SSIE modeling methodology and 66 models have been enhanced with the improved LOOP methodology. The staff plans to continue these cooperative efforts with EPRI and other stakeholders to address the remaining issues over the next several years.

Integrated Modeling

The Office of Nuclear Regulatory Research continues to enhance SAPHIRE and the SPAR models to support development of integrated models. To this end, RES recently completed an integrated model for Peach Bottom Unit 2 containing state-of-the-practice SPAR models for Level 1 internal events at-power, shutdown, other hazards, and Level 2. This effort included the incorporation of other ongoing modeling initiatives (e.g., modeling of SSIEs), use of modeling features new to SAPHIRE8 (e.g., decomposition event trees), and further validation of the Level 2 PRA model. This work directly benefits the RES Vogtle site Level 3 PRA project (SRM SECY 11-0089) by guiding the approach to Level 2 and integrated hazard modeling.