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 U.S. Nuclear Regulatory Commission (NRC) staff as they relate to events that occurred during fiscal years (FYs) 2013 and 2014. 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 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 operational events that have a conditional core damage probability (CCDP[1]) or an increase in core damage probability (ΔCDP[2]) greater than or equal to 1×10^{-6}. That is, for any given operational event analyzed the likelihood of inadequate core cooling and severe core damage was greater than or equal to one in one million.

To identify potential precursors, the staff reviews operational 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. An operational event can be one of two types—(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 characterized by the unavailability or degradation of equipment without the occurrence of an initiating event.

For the first type of event, the staff calculates a CCDP. This metric represents a conditional probability that a core damage state is reached given the occurrence of an initiating event (and any subsequent equipment failure or degradation). For the second type of event, the staff calculates a ΔCDP. This metric represents the increase in core-damage probability for a time period during which a component or multiple components are deemed unavailable or degraded.

The ASP Program defines an event with a CCDP or a ΔCDP greater than or equal to 1×10^{-6} to be a precursor. For initiating event analyses, and to focus analyses on the more safety-significant events, the ASP Program excludes as precursors reactor transients whose results would be similar to or less significant than the loss of balance-of-plant systems (e.g., feedwater and condenser heat sink) with no degradation of safety-related equipment. Therefore, the ASP Program uses an initiating-event precursor threshold of a CCDP of 1×10^{-6} or the plant-specific

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1 The term CCDP is the probability of the occurrence of core damage given that an initiating event has occurred.

2 The term ΔCDP is the increase in probability of core damage (from the baseline core damage probability) due to a failure of plant equipment or an identified deficiency during the time the failure or deficiency existed.

CCDP[3] for the non-recoverable loss of balance-of-plant systems, whichever is greater. Since 1988, this initiating-event precursor threshold screens out reactor trips with no losses of safety-system equipment from being precursors because of their relatively low risk significance. 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 illustrates the complete ASP analysis process.

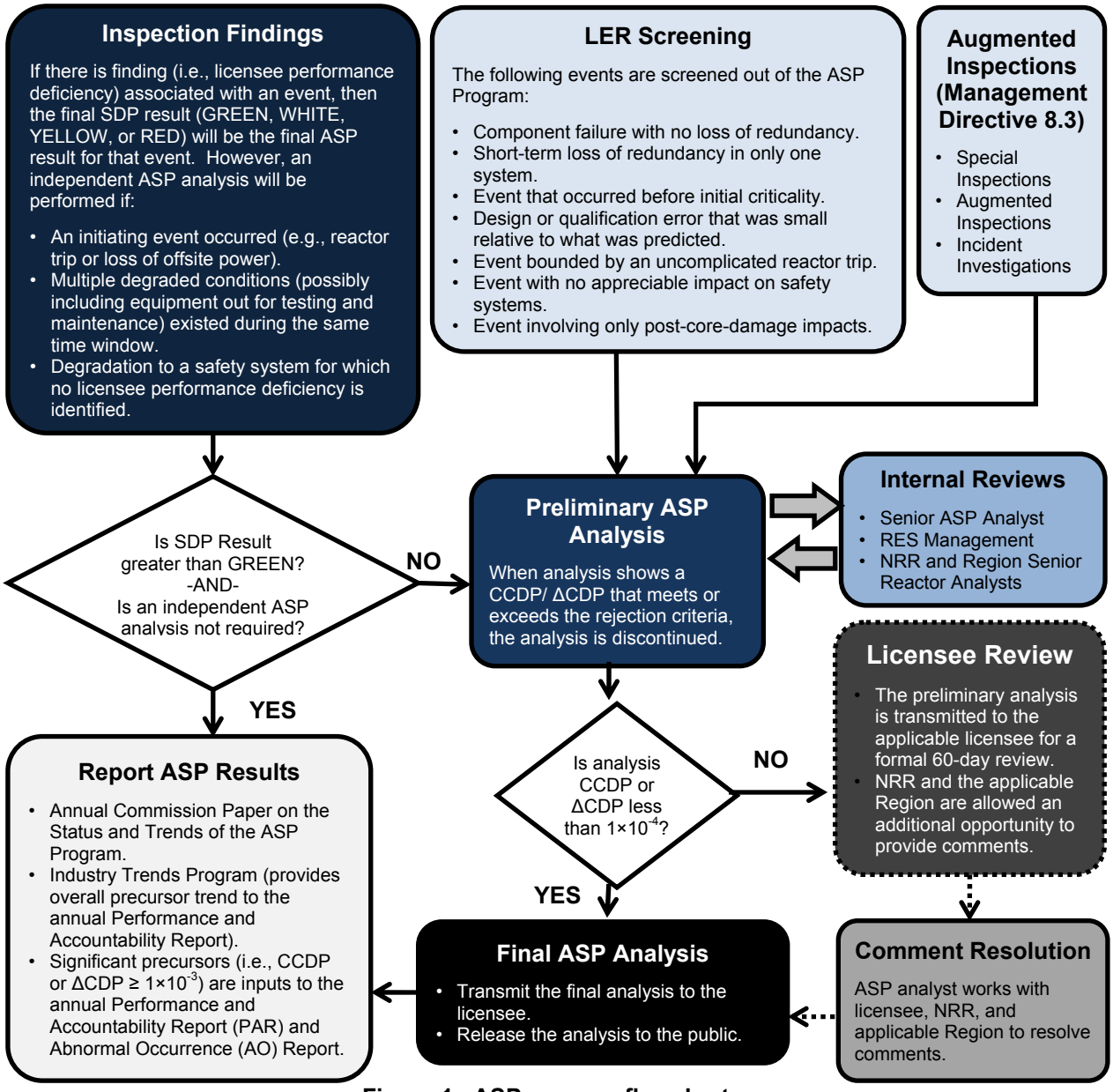

Figure 1. ASP process flowchart.

[3] The plant-specific CCDP is determined using NRC's Standardized Plant Analysis Risk (SPAR) models to analyze the non-recoverable loss of the condenser heat sink and the non-recoverable loss of main feedwater initiating events for each plant. If the results from either of these analyses are greater than 1×10^{-6}, the highest value is used as the precursor threshold for the subject plant.

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 results as an input to the NRC's Abnormal Occurrence Report and to monitor performance against the safety measures in the agency's Congressional Budget Justification (Ref. 1), which was formulated to support the agency's safety and security strategic goals and objectives. 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 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," and in 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 an 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 for which no identified deficiency occurred in the licensee's performance. The ASP Program also evaluates 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, 2014.

FY 2013 Analyses. The ASP analyses for FY 2013 identified 17 precursors (6 initiating events and 11 degraded conditions). An additional WHITE finding, identified under the SDP, was bounded by a non-recoverable loss of condenser heat sink and thus was screened out as an ASP precursor. One precursor occurred while the plant was shutdown. For 14 of the 17 precursors, the performance deficiency identified under the Reactor Oversight Process (ROP) documented the risk-significant aspects of the event completely. In these cases, the SDP significance category (i.e., the "color" of the finding) is reported in the ASP Program. For the remaining events, an independent ASP analysis was performed to determine the risk significance of three loss of offsite power (LOOP) initiating events.

Preliminary ASP analyses for loss of offsite power that occurred at LaSalle, Units 1 and 2 precursor events on April 17, 2014 will be 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 2013 precursors that involved initiating events. Table 2 presents the analysis results for FY 2013 precursors that involved degraded conditions.

Table 1. FY 2013 Precursors Involving Initiating Events

Event Date	Plant	Description	CCDP
12/22/12	Browns Ferry 2	Unplanned automatic reactor scram due to loss of power to the reactor protection system. ***LER 260/12-006***	WHITE[4]
2/8/13	Pilgrim	LOOP events due to Winter Storm Nemo. ***LER 293/13-003***	8×10^{-5}
3/31/13	Arkansas Nuclear One 1	Generator Stator drop causing Unit 1 LOOP while shutdown and Unit 2 trip with loss of Switchgear 2A1. ***LER 313/13-001***	YELLOW[5]
3/31/13	Arkansas Nuclear One 2	Generator Stator drop causing Unit 1 LOOP while shutdown and Unit 2 trip with loss of Switchgear 2A1. ***LER 313/13-001***	YELLOW
4/17/13	LaSalle 1	Dual Unit Loss of Offsite Power Due to Lightning Strike. ***LER 373/13-002***	1×10^{-5}
4/17/13	LaSalle 2	Dual Unit Loss of Offsite Power Due to Lightning Strike. ***LER 373/13-002***	1×10^{-5}

Table 2. FY 2013 Precursors Involving Degraded Conditions

Condition Duration	Plant	Description	ΔCDP/ SDP Color
34 days	Robinson	Failure of dedicated shutdown diesel generator. ***Enforcement Action (EA)-13-129***	WHITE
21 years[6]	Dresden 2[7]	Failure to establish procedure to address the effect of external flooding on the plant. ***EA-13-079***	WHITE
21 years[4]	Dresden 3[5]	Failure to establish procedure to address the effect of external flooding on the plant. ***EA-13-079***	WHITE
31 years[4]	Sequoyah 1[5]	Inadequate electrical conduit seals for the Essential Raw Cooling Water Pumping Station could result in loss of diesel generators during a flooding event. ***EA-13-045***	WHITE
30 years[4]	Sequoyah 2[5]	Inadequate electrical conduit seals for the Essential Raw Cooling Water Pumping Station could result in loss of diesel generators during a flooding event. ***EA-13-045***	WHITE
1 year	Monticello[5]	Failure to maintain flood plan to protect the site against external flooding events. ***EA-13-096***	YELLOW
22 days	Duane Arnold	Emergency diesel generator inoperability results in safety system's functional failure. ***EA-13-182***	WHITE

[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.

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

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

[7] These seven events resulted from the efforts undertaken by licensees and inspectors as part of the Fukushima Near-Term Task Force Recommendation 2.3 walkdowns (Ref. 8).

Condition Duration	Plant	Description	ΔCDP/ SDP Color
17 years[4]	Point Beach 1[5]	Flooding procedure failed to protect safety-related equipment. ***EA-13-125***	WHITE
17 years[4]	Point Beach 2[5]	Flooding procedure failed to protect safety-related equipment. ***EA-13-125***	WHITE
25 days	Waterford 3	Emergency diesel generator inoperable due to room exhaust-fan fire. ***EA-13-233***	WHITE
64 days	Duane Arnold	Reactor core isolation cooling turbine trip. ***EA-13-223***	WHITE

FY 2014 Analyses. The staff performs an initial review of all events to determine if they have the potential to be *significant* precursors. Specifically, the staff reviews LERs (in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) 50.73, "Licensee Event Report System") and daily event-notification reports (in accordance with 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 2014 events and identified no potentially *significant* precursors (as of September 30, 2014). The staff will inform the Commission if a *significant* precursor is identified during the more detailed evaluations of events.

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 less than or equal to 0.05 indicate that there is 95 percent confidence that a trend exists in the data (i.e., leading to a rejection of the null hypothesis of no trend).

Data Coverage. The data period for the ASP trending analyses is a rolling 10-year period aligned with a rolling 10-year period used in the Industry Trends Program.

4.1 Occurrence Rate of All Precursors

The NRC's Industry Trends Program 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 in the NRC's Strategic Plan). The mean occurrence rate of all precursors identified by the ASP Program is one indicator used by the Industry Trends Program to assess industry performance.[8]

Results. The mean occurrence rate of all precursors does not exhibit a statistically significant trend (p-value = 0.956) for the 10-year period from FY 2004–2013 (see Figure 2).

[8] The occurrence rate is calculated by dividing the number of precursors by the number of reactor years.

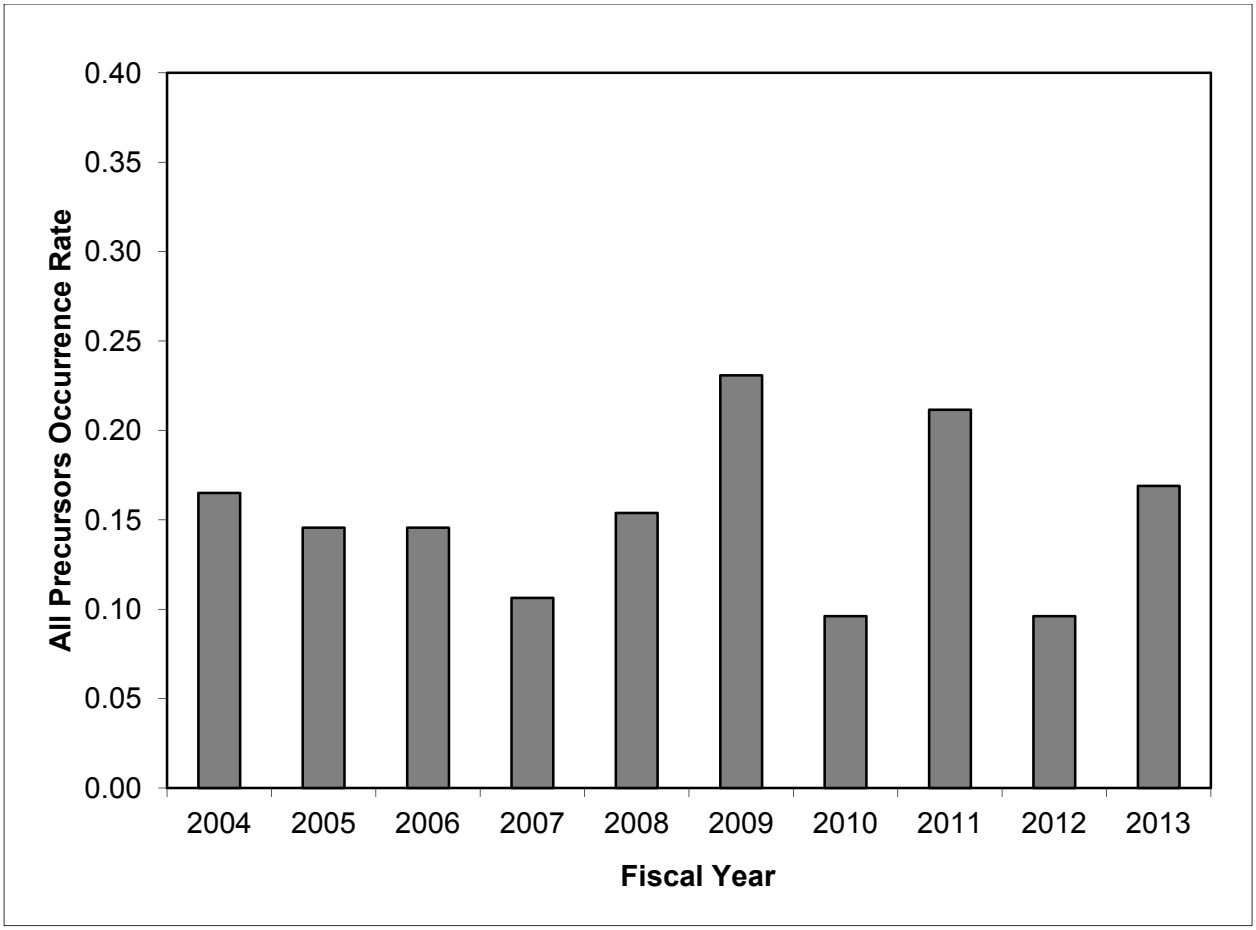

Figure 2. Occurrence rate of all precursors shows no statistically significant trend for the period from FY 2004 through FY 2013 (p-value = 0.956).

4.2 *Significant* Precursors

The ASP Program provides the input for determining if the safety measure regarding the "number of significant accident sequence precursors of a nuclear reactor accident" is zero. This is a safety measure associated with the safety goal in the NRC's Congressional Budget Justification (Ref. 1).

Results. A review of the data for the 10-year period from FY 2004 through FY 2013 reveals the following insights:

- No *significant* precursors have been identified during FYs 2004 through FY 2013. The staff has completed the initial review of FY 2014 events and identified no potentially significant precursors (as of September 30, 2014).

- The last *significant* precursor was identified in FY 2002 and involved concurrent, multiple degraded conditions at the Davis-Besse nuclear power plant.[9]

[9] Commission Paper SECY-10-0125, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models" (Ref. 7), provides a complete list of all *significant* precursors from 1969 through 2010.

5.0 Insights and Other Trends

The following sections provide additional ASP trends and insights for the 10-year period from FY 2004 through FY 2013.

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 did not identify any precursors with a CCDP or ΔCDP ≥ 1×10^{-4} for FY 2013. Over the past 10-year period (FY 2004 through FY 2013), a total of seven precursors with CCDP or ΔCDP ≥ 1×10^{-4} were identified. These seven precursors were identified between FY 2010 and FY 2012. As summarized in Table 3, the staff issued a total of six generic communications involving five information notices (INs) and one bulletin relating to four of these events. In addition, the staff issued two RED findings, one YELLOW finding, and three WHITE findings based on identified performance deficiencies associated with these precursor events.

Table 3. FY 2010–2013 Precursors with a CCDP or ΔCDP ≥ 1×10^{-4})

Date	Plant (Risk Measures)	Event or Condition	Risk Insights (Generic Communications)
3/28/10	H. B. Robinson **(CCDP = 4×10^{-4})**	Fire causes loss of non-vital buses 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** (one performance deficiency was for failure to adequately implement the requirements contained in OPS-NGGC-1000, "Fleet Conduct of Operations," and the other performance deficiency was for improper implementation of the Commission-approved requalification program). (NRC IN 2010-09, "Importance of Understanding Circuit Breaker Control Power Indications.")
10/23/10	Browns Ferry, Unit 1 **(RED Finding[10])**	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. (NRC IN 2012-14, "Motor-Operated Valve Inoperable due to Stem-Disc Separation.")

[10] 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 Measures)	Event or Condition	Risk Insights (Generic Communications)
6/7/11	Fort Calhoun **(RED Finding)**	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.
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** (one performance deficiency was for failure to establish and maintain maintenance procedures appropriate to the circumstances for the safety-related EDGs). (NRC IN 2012-01, "Seismic Considerations – Principally Issues Involving Tanks," and NRC IN 2012-25, "Performance Issues with Seismic Instrumentation and Associated Systems for Operating Reactors.")
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 LOOP of moderate length (two to three hours) caused by equipment failures in the switchyard. Risk was dominated by SBO sequences. ASP evaluated the LOOP initiating event while the SDP analysis performed a condition assessment on the loss of the startup transformer resulting in **a YELLOW finding** (one performance deficiency was for failure to identify that electrical maintenance contractors had not installed insulating sleeves on wires that affected the differential current protection circuit, contrary to work-order instructions).
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. (NRC IN 2012-03, "Design Vulnerability in Electric Power System," and NRC Bulletin 2012-01, "Design Vulnerability in Electric Power System.")
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 the 10-year period from FY 2004 through FY 2013 reveals the following insights:

- The mean occurrence rate of precursors with a CCDP or ΔCDP $\geq 1\times10^{-4}$ exhibits a statistically significant trend (p-value = 0.007; see Figure 3).

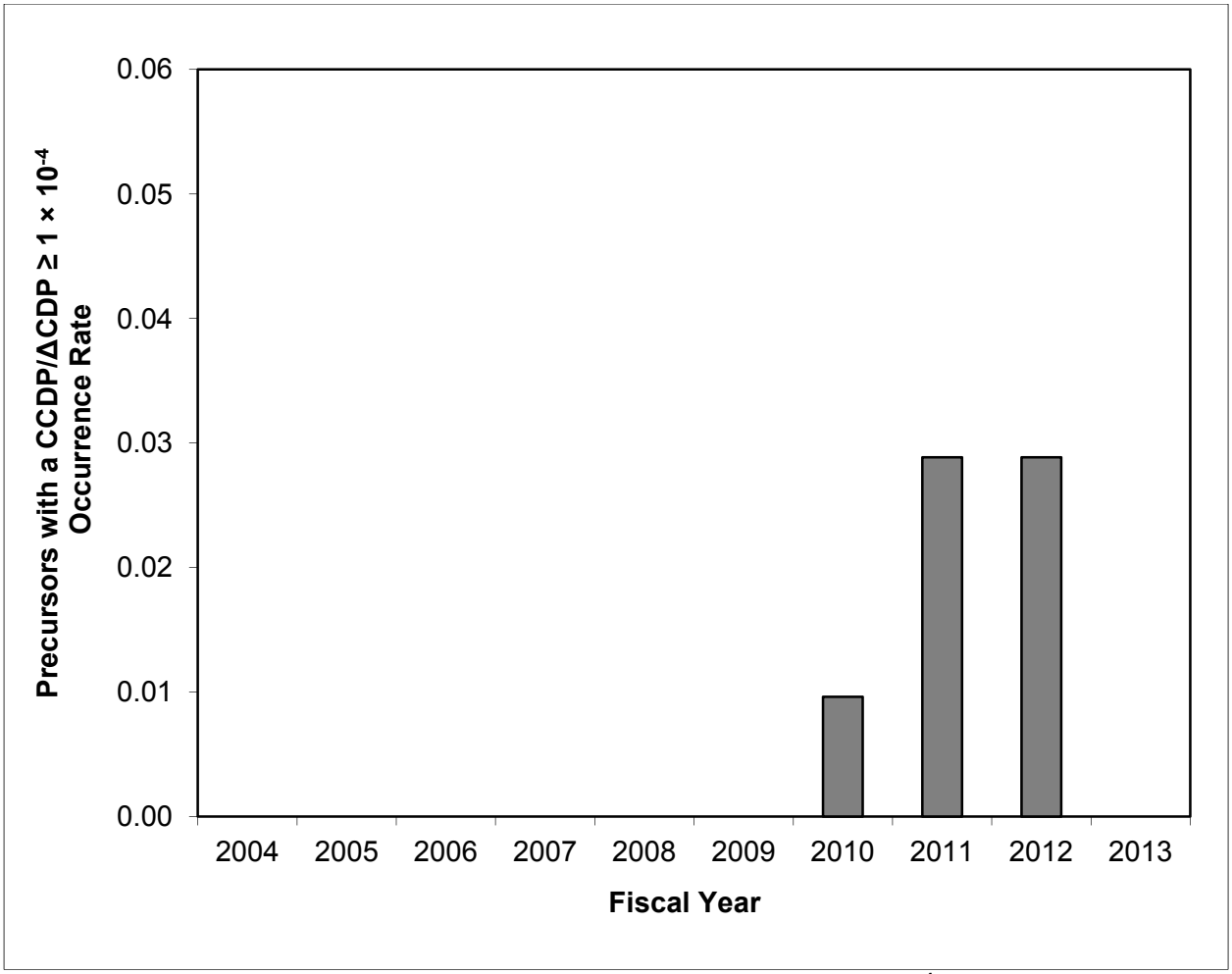

Figure 3. Occurrence rate of precursors with a CCDP or ΔCDP ≥ 1 × 10^{-4} shows a statistically significant trend for the period from FY 2004 through FY 2013 (p-value = 0.007).

Figure 3 shows that no precursor with a CCDP or ΔCDP ≥ 1×10^{-4} occurred between 2004 and 2009 and seven such precursors occurred during FYs 2010-2012. The events related to these precursors over this period involved differing reactor types, causes, systems, and components.

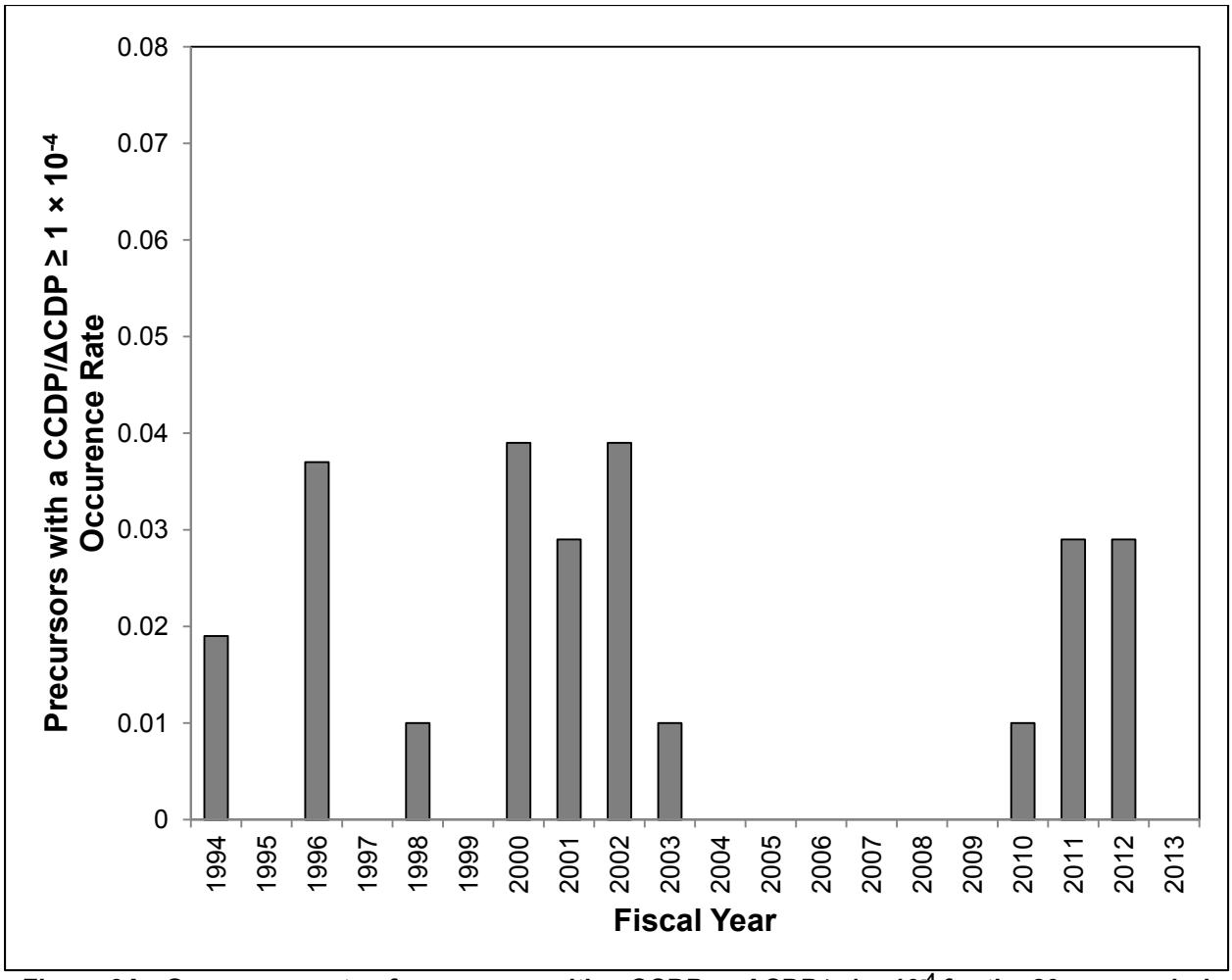

Figure 3A. Occurrence rate of precursors with a CCDP or ΔCDP ≥ 1 × 10^{-4} for the 20-year period from FY 1994 through FY 2013

Figure 3A shows the 20-year historical occurrence rate of precursors with a CCDP or ΔCDP ≥ 1×10^{-4}. Over the last 20 years, 27 precursors with a CCDP or ΔCDP ≥ 1×10^{-4} have occurred. Of these 27 precursors, 26 percent involved a LOOP initiating event. This is generally consistent with recent operating experience.

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

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

- LOOP initiating events with no complications typically do not have a CCDP $\underline{\geq}$ 1×10^{-4}. However, the three LOOP events reviewed featured complications that involved one or more additional failures 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.[11]

- 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 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 six 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.[12] 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 (Browns Ferry 1, Fort Calhoun). 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) seal 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 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 before station battery depletion was modeled in the ASP analysis.
  - A 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

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

[12] 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 could be experienced during each postulated accident sequence.

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.

5.2 Precursors Involving Initiating Events and Degraded Conditions

A review of the data for the 10-year period from FY 2004 through FY 2013 reveals the following insights for precursors involving initiating events and degraded conditions.

Initiating Events

- The mean occurrence rate of precursors involving initiating events does not exhibit a trend that is statistically significant (p-value = 0.782) for the period from FY 2004 through FY 2013 (see Figure 4).

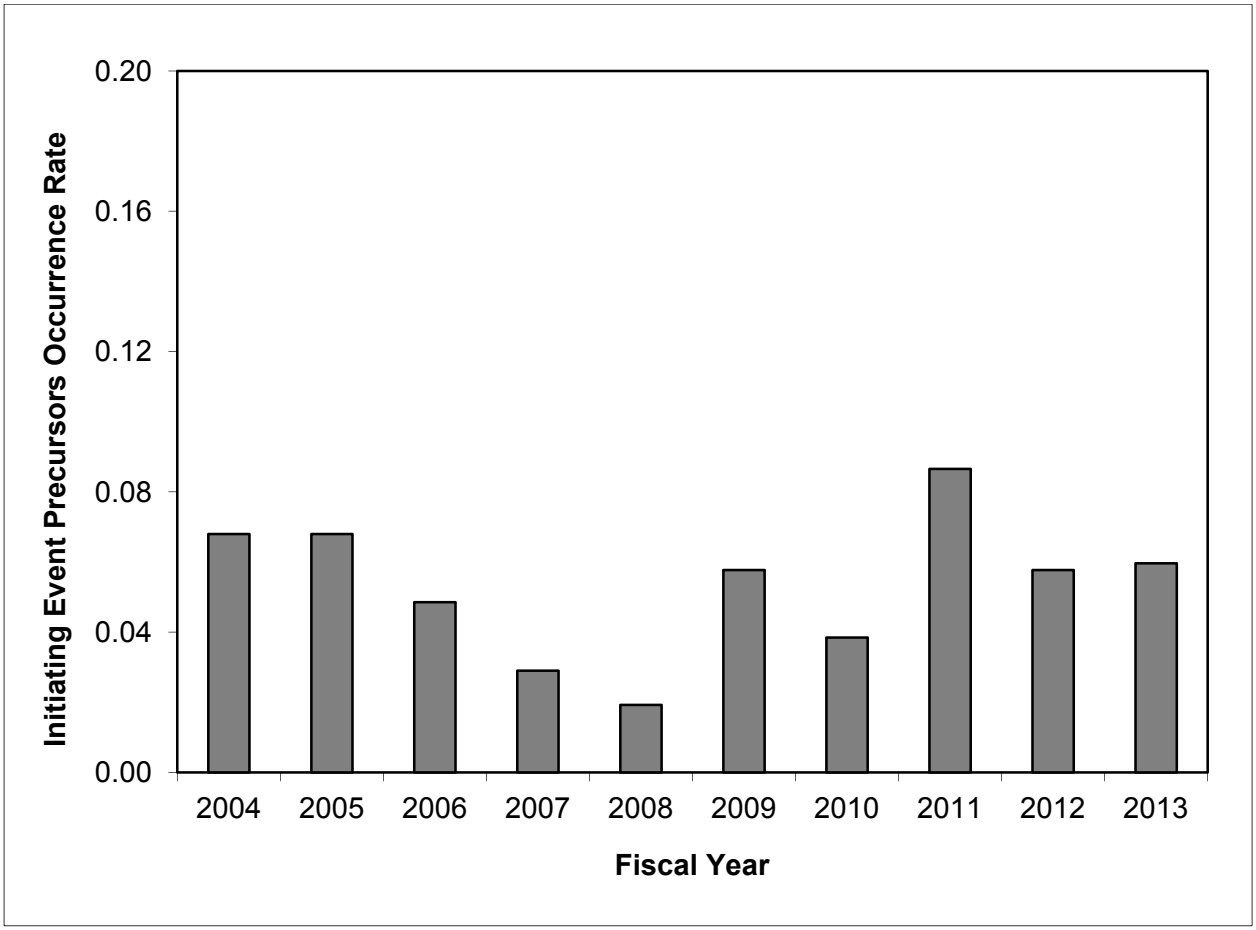

Figure 4. Occurrence rate of precursors involving initiating events shows no statistically significant trend for the period from FY 2004 through FY 2013 (p-value = 0.782)

- Of the 55 precursors involving initiating events, 55 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 = 0.939) during FY 2004 through FY 2013 (see Figure 5).

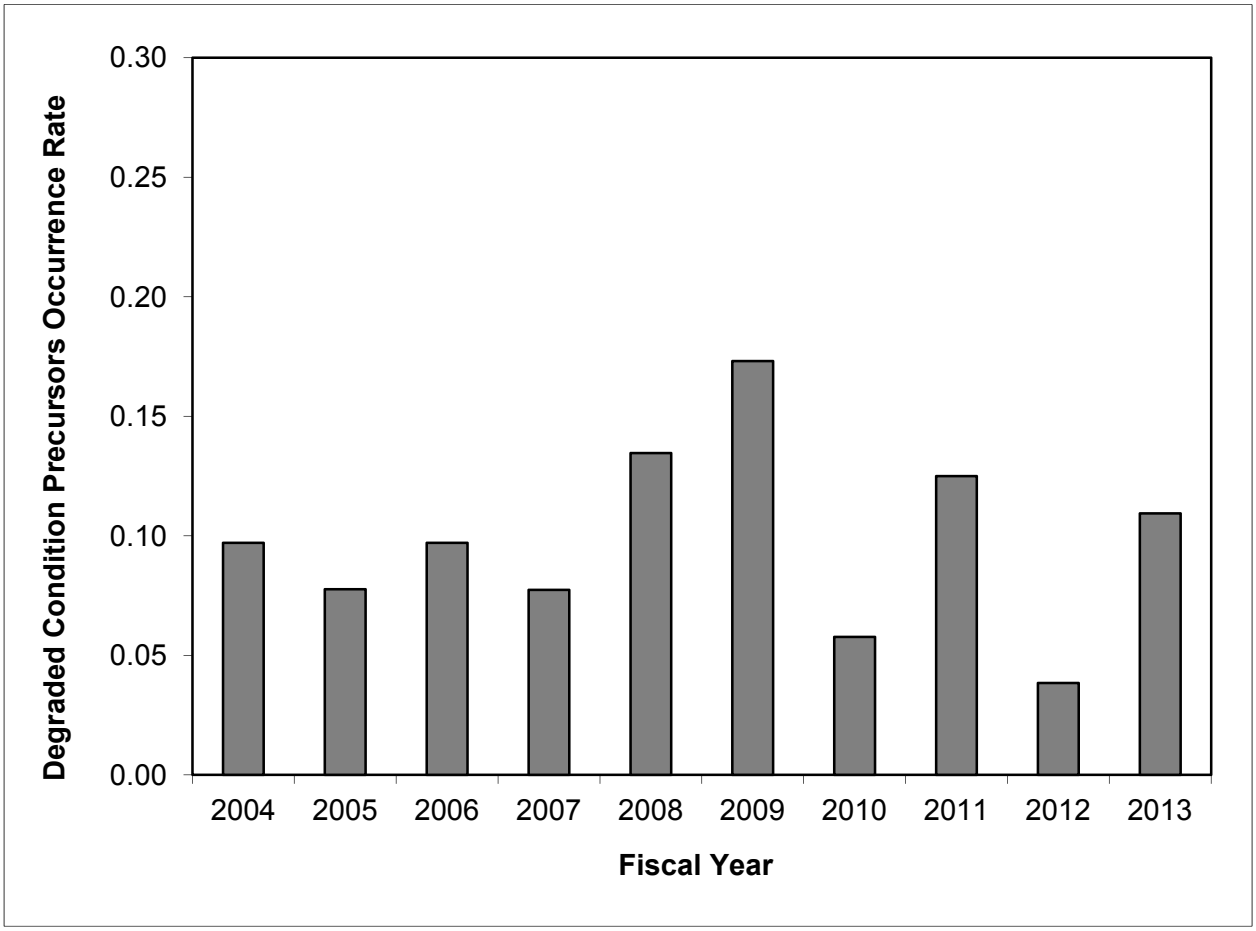

Figure 5. Occurrence rate of precursors involving degraded conditions shows no statistically significant trend for the period from FY 2004 through FY 2013 (p-value = 0.939)

- Over the past 10 years, precursors involving degraded conditions outnumbered initiating events by 85 percent.

- From FY 2004 through FY 2013, 33 percent of precursors involved degraded conditions existing for a decade or longer.[13] Of these precursors, 44 percent involved degraded conditions dating back to initial plant construction.

[13] 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 Event

In FY 2013, 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 the 10-year period from FY 2004 through FY 2013 reveals the following insights:

- The mean occurrence rate of precursors resulting from a LOOP does not exhibit a statistically significant trend (p-value = 0.371; see Figure 6).

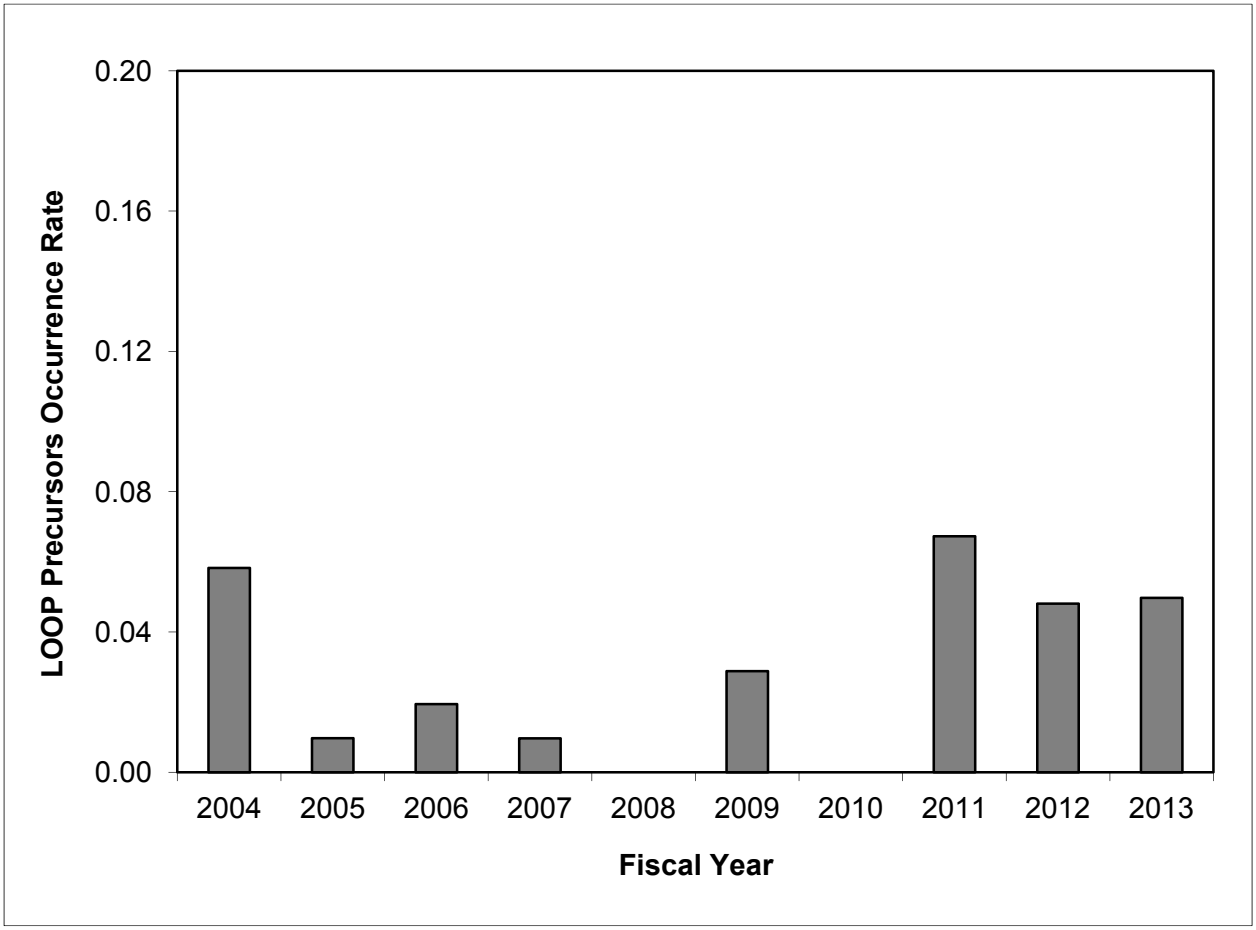

Figure 6. Occurrence rate of precursors involving LOOP events shows no statistically significant trend for the period from FY 2004 through FY 2013 (p-value = 0.371)

- Of the 30 LOOP precursors, 43 percent resulted from external events and 13 percent resulted from a degraded electrical grid outside of the NPP boundary. Seven of the 13 LOOP precursors that were caused by external events occurred in FY 2011[14]. This is unusual and unprecedented, but there is no indication of a trend from these events.

[14] These FY 2011 events were Surry Units 1 and 2 tornado precursor events that occurred on April 16, 2011, Browns Ferry Units 1, 2, and 3 tornado precursor events that occurred on April 27, 2011, and North Anna Units 1 and 2 earthquake precursor events that occurred on August 23, 2011.

- Three of the 30 LOOP precursor events involved the simultaneous unavailability of an emergency power system train.

5.4 Precursors at BWRs and PWRs

A review of the data for the 10-year period from FY 2004 through FY 2013 reveals the following insights for boiling-water reactors (BWRs) and pressurized-water reactors (PWRs).

BWRs

- The mean occurrence rate of precursors that occurred at BWRs does not exhibit a statistically significant trend (p-value = 0.216; see Figure 7).

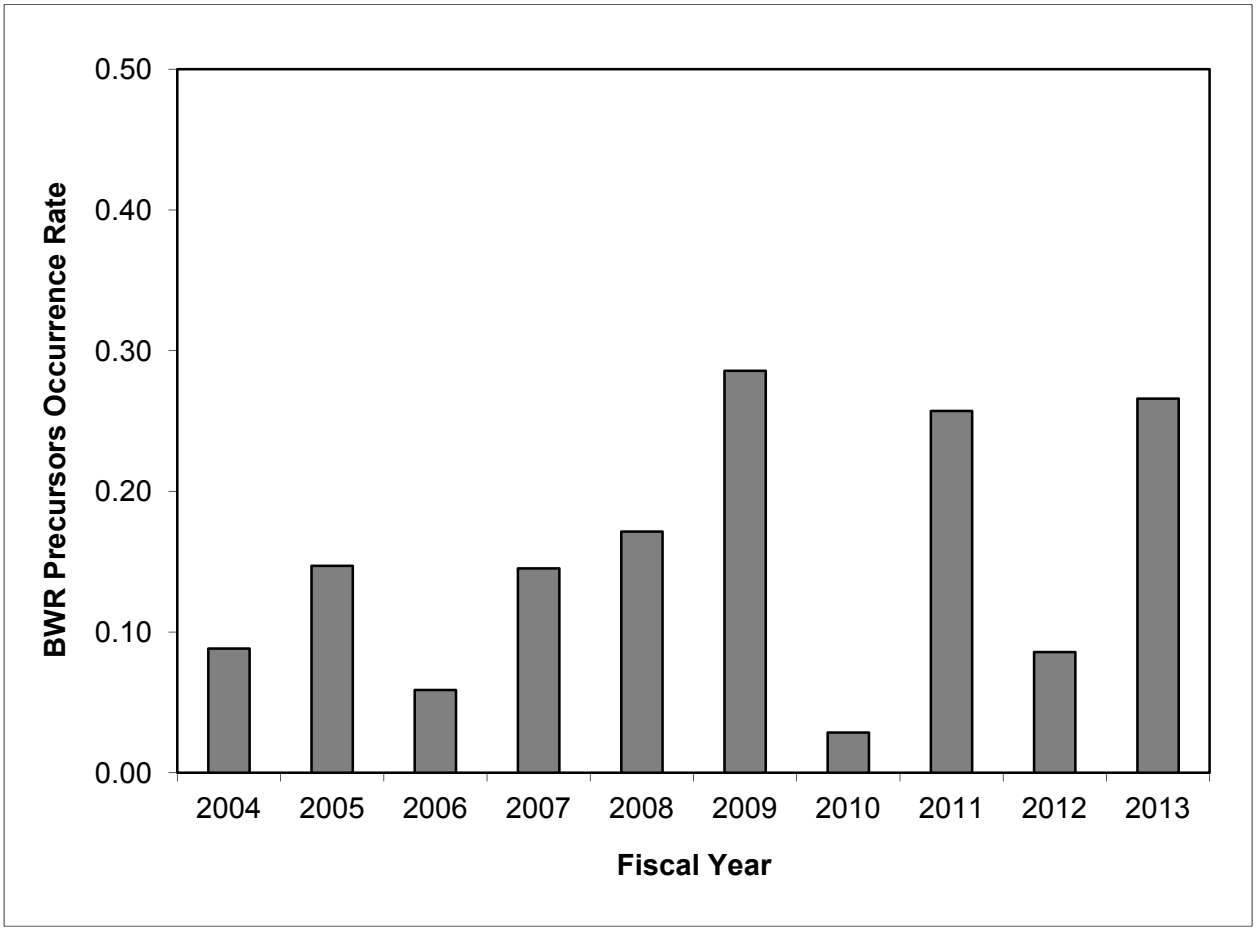

Figure 7. Occurrence rate of precursors involving events at BWRs shows no statistically significant trend for the period from FY 2004 through FY 2013 (p-value = 0.216)

- LOOP events contributed to 52 percent of precursors involving initiating events at BWRs.

- Of the 32 precursors involving the unavailability of safety-related equipment that occurred at BWRs, most were caused by failures in the emergency power system (34 percent), emergency core cooling systems (22 percent), safety-related cooling water systems (3 percent), or electrical distribution system (6 percent).

PWRs

- The mean occurrence rate of precursors that occurred at PWRs does not exhibit a statistically significant trend (p-value = 0.238; see Figure 8).

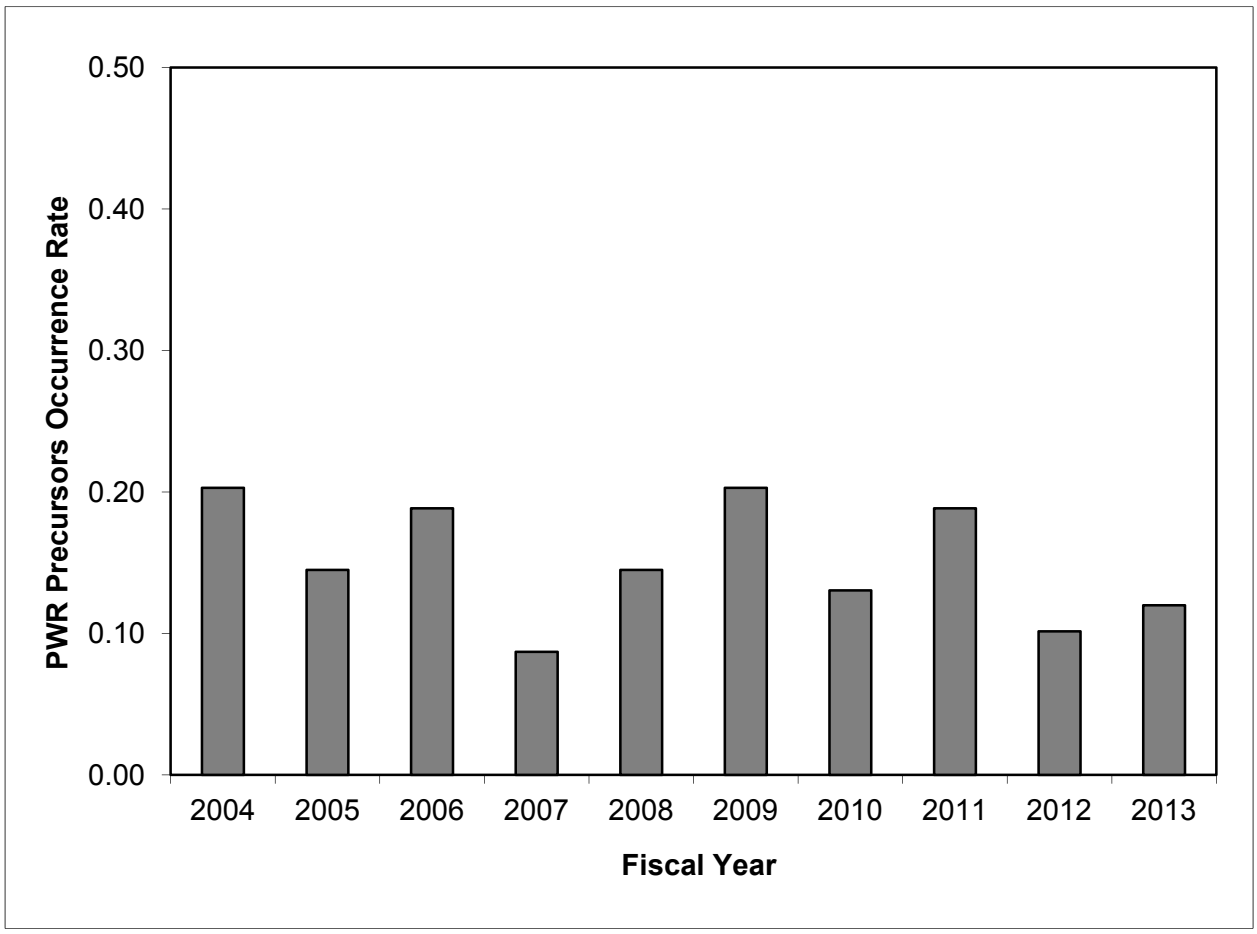

Figure 8. Occurrence rate of precursors involving events at PWRs shows no statistically significant trend for the period from FY 2004 through FY 2013 (p-value = 0.238)

- LOOP events contribute 56 percent of precursors involving initiating events at PWRs.

- Of the 70 precursors involving the unavailability of safety-related equipment that occurred at PWRs, most were caused by failures in the emergency power system (26 percent), emergency core cooling systems (11 percent), auxiliary feedwater system (13 percent), safety-related cooling water systems (13 percent), or electrical distribution system (11 percent).
  - Of the 8 precursors involving failures in the emergency core-cooling systems, 6 precursors (75 percent) were because of conditions affecting sump recirculation during postulated LOCAs of varying break sizes. Design errors caused most of these precursors (67 percent).
  - Of the 9 precursors involving failures of the auxiliary feedwater system, random hardware failures (78 percent) and design errors (22 percent) were the largest failure contributors. Eight of the 9 precursors (89 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 31 percent of all precursors involving the unavailability of safety-related equipment that occurred at PWRs.

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 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; this shows the cumulative plant average of the precursors for a given 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. In addition, the ΔCDP 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 the 10-year period from FY 2004 through FY 2013. A review of the ASP indices reveals the following insights:

- Based on the order of magnitude (10^{-5}), the average integrated ASP index for the period from FY 2004 through FY 2013 is consistent with the CDF estimates from the SPAR models and industry PRAs.

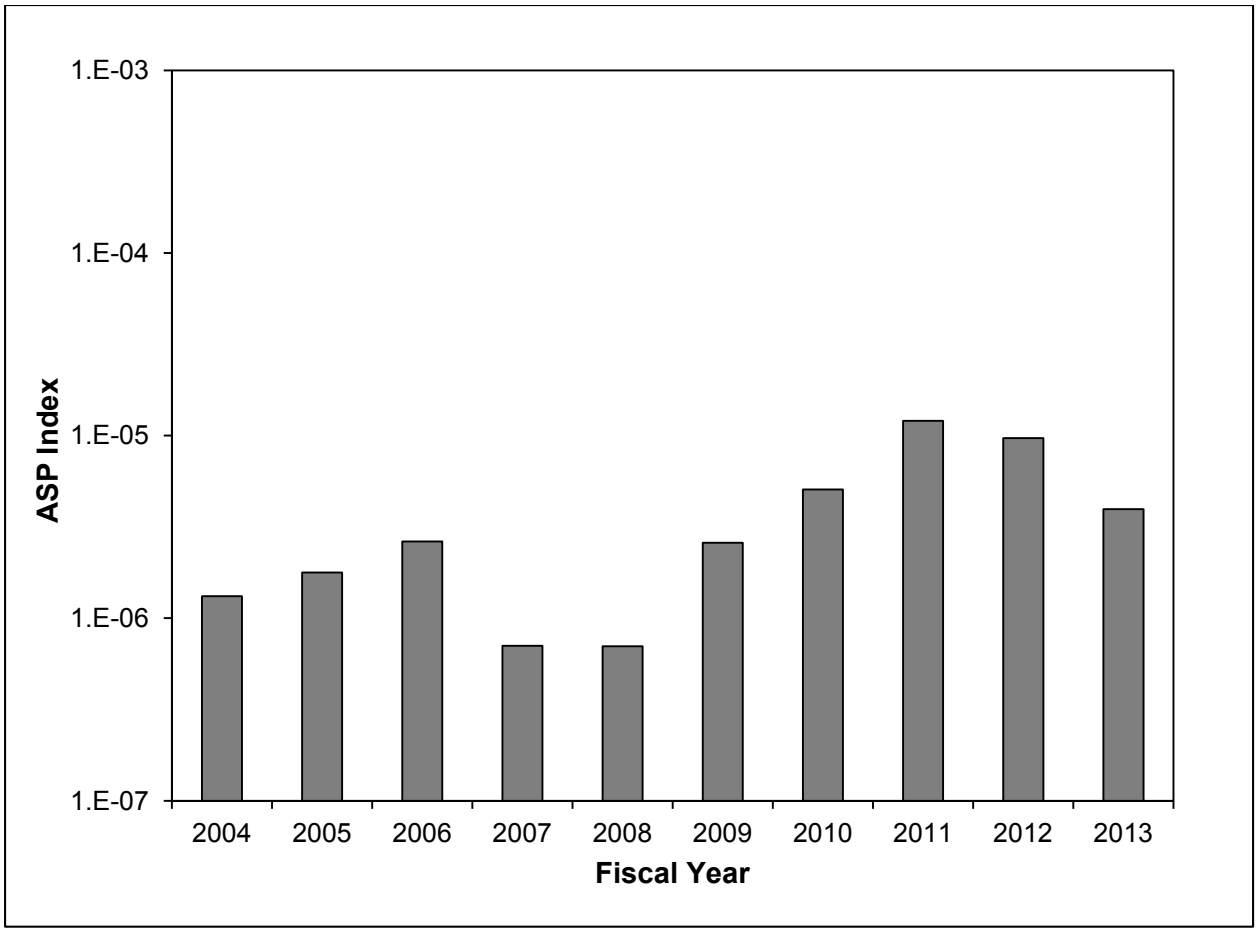

Figure 9. Integrated ASP index for the 10-year period from FY 2004 through FY 2013.

- Precursors over the period from FY 2004 through FY 2013 made the following contributions to the average integrated ASP index:
  - The average integrated ASP index was derived considering the contributions of the 157 precursors during this period.
  - 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 to a much greater degree than the number of precursors. The staff considers that from a broad industry risk perspective, this increase is not significant.

Limitations. Using CCDPs and ΔCDPs from ASP results to estimate CDF is challenging because (1) the mathematical relationship between CCDPs, ΔCDPs, and CDF requires a significant level of computation, (2) data for the 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 criteria to be considered an ASP precursor (such as low-risk events including, but not limited to, balance-of-plant failure events).

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 previous years.

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 event analyses, both precursors and non-precursors, from FY 2013 were reviewed against the approaches to PRA described in the American Society of Mechanical Engineers (ASME)/ American Nuclear Society (ANS) RA-Sa-2009, "Addenda to ASME/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 event analyses for which the risk-significant ASME/ANS PRA Standard did not provide guidance. None of the FY 2013 event analyses indicated an inadequacy in the state of PRA practice as described in ASME/ANS RA-Sa-2009. The staff continues to work with ASME/ANS on refinement to the standard to ensure that it provides sufficient guidance to assess the risk significance of external events, including external flooding.

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 2013. The staff identified no potentially *significant* precursors in FY 2014. The ASP Program provides the input for determining if the safety measure regarding the "number of significant accident sequence precursors of a nuclear reactor accident" is zero. The final results will be provided in the FY 2014 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 from FY 2004 through FY 2013. The trend of all precursors is one input to the Industry Trends Program to assess industry performance and is part of the input to the adverse trends safety measure. These results will be provided in the FY 2014 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 over the past four years after no events were identified in the previous six years.

7.0 References

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