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) 2011 and 2012. 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 (precursors).

To identify potential precursors, the staff reviews plant events, including the impact of external events (i.e., 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 piece or multiple pieces of equipment 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.

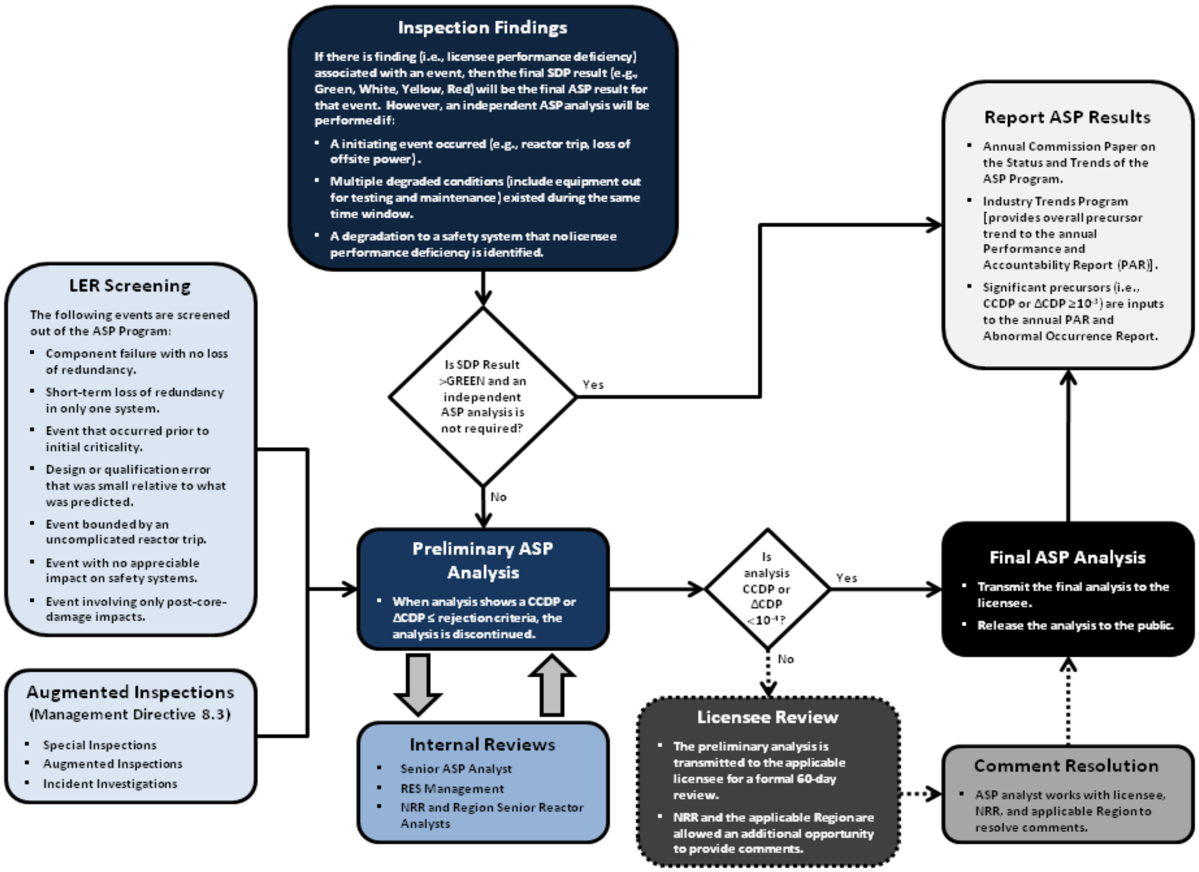

Figure 1. ASP process diagram

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.
- Less than one significant adverse trend in industry safety performance (determination principally made from the Industry Trends Program (ITP) but partially supported by ASP results).

[2] The performance measures involving precursor data (i.e., number of *significant* precursors and trend of all precursors) are the same for FYs 2009–2012.

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." The SDP evaluates the risk significance of licensee performance deficiencies, while assessments performed under MD 8.3 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, 2012.

FY 2011 Analyses. The ASP analyses for FY 2011 identified 22 precursors. All 22 precursors occurred while the plants were at power. The staff used the SDP to identify and assess 15 of the 22 precursors. In these cases, only the SDP significance category (i.e., the "color" of the finding) is reported in the ASP Program.

The CCDP for one FY 2011 analysis exceeded 1×10^{-4} (North Anna, Unit 1 precursor event that occurred on August 23, 2011); therefore, the analysis was sent for a formal 60-day review to the licensee, Region II, and the Office of Nuclear Reactor Regulation. 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).

In SECY-11-0138, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models," dated September 30, 2011, the staff committed to evaluate the flooding event at Fort Calhoun Station and the LOOP event caused by an earthquake at North Anna Nuclear Power Station, and to inform the Commission if *significant* precursors were identified. The ASP analysis of the North Anna event was completed on September 1, 2012. The final analysis results determined that precursors were not significant (i.e., the CCDPs were less than 1×10^{-3}). The final ASP results for the event at North Anna are provided in Table 1.

The staff also reviewed the plant information for Fort Calhoun Station during elevated Missouri River water levels that existed from June 2011 through August 2011 to determine if a separate ASP analysis was needed. The staff determined that a separate ASP analysis was not needed because of the following reasons. (1) The ASP Program analyzes the conditional risk of plant conditions caused by actual initiating events. As the Missouri river water level rose, the plant operators took actions in accordance with their procedures to maintain it in a safe condition. This was considered normal plant operations and not an "event". An external flooding that causes a plant upset (e.g. plant trip or loss of shutdown safety system) could be considered for ASP analysis. (2) The staff discussed the possibility of additional rain creating a more severe flood condition. However; the ASP program does not evaluate the hypothetical risk of initiating events that might have been more severe than the actual event. (3) An SDP analysis was conducted for the July 7th breaker fire which occurred during the flood condition and this was accepted by the ASP Program. (4) The plant entered the Inspection Manual Chapter 0350, "Oversight of Reactor Facilities in a Shutdown Condition Due to Significant Performance and/or

Operational Concerns," on December 13, 2011, which would address any additional risk-significant issues that were identified at Fort Calhoun Station.

Table 1 presents the results of the staff's ASP analyses for FY 2011 precursors that involved initiating events. Table 2 presents the analysis results for FY 2011 precursors that involved degraded conditions.

Table 1. FY 2011 precursors involving initiating events

Event Date	Plant	Description	CCDP
4/16/11	Surry 1	Dual unit loss of offsite power because of switchyard damage caused by a tornado. **LER 280/11-001**	9×10^{-5}
4/16/11	Surry 2	Dual unit loss of offsite power because of switchyard damage caused by a tornado. **LER 280/11-001**	7×10^{-5}
4/27/11	Browns Ferry 1	Extended loss of offsite power because of a tornado with an emergency diesel generator (EDG) unavailable due to test and maintenance. A subsequent loss of shutdown cooling occurred because of an EDG failure while the plant was in cold shutdown. **LER 259/11-001**	1×10^{-5}
4/27/11	Browns Ferry 2	Extended loss of offsite power because of a tornado with an emergency diesel generator (EDG) unavailable due to test and maintenance. A subsequent loss of shutdown cooling occurred because of an EDG failure while the plant was in cold shutdown. **LER 259/11-001**	1×10^{-5}
4/27/11	Browns Ferry 3	Extended loss of offsite power because of a tornado, with an EDG unavailable due to test and maintenance. **LER 259/11-001**	1×10^{-5}
5/10/11	Pilgrim	Failure to effectively implement operations and reactivity control standards and procedures during a reactor startup caused an unrecognized subcriticality and return to criticality with a subsequent reactor scram. ***Enforcement Action (EA)-11-174***	WHITE[3]
8/23/11	North Anna 1	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 EDG. **LER 338/11-003**	2×10^{-4}
8/23/11	North Anna 2	Dual unit loss of offsite power caused by earthquake that coincided with the Unit 1 turbine-driven AFW pump being out-of-service because of testing and the subsequent failure of a Unit 2 EDG. **LER 338/11-003**	4×10^{-5}
9/25/11	Palisades	Inadequate work instructions led to the loss of a 125-volt, direct-current train and subsequent reactor trip. ***EA-11-243***	YELLOW[4]

3 A WHITE finding corresponds to a licensee performance deficiency of substantial safety significance and has an increase in core damage frequency in the range of 10^{-6} to 10^{-5}.

4 A YELLOW finding corresponds to a licensee performance deficiency of substantial safety significance and has an increase in core damage frequency in the range of 10^{-5} to 10^{-4}.

Table 2. FY 2011 precursors involving degraded conditions

Condition Duration	Plant	Description	ΔCDP/ SDP Color
15 years	Prairie Island 1	Battery chargers potentially inoperable because of an under-voltage condition. ***EA-11-110***	WHITE
19 months	Browns Ferry 1	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***	RED[5]
13 years	Cooper	Deficient emergency procedures could lead to operators failing to position valves necessary for core cooling during a postulated fire. ***EA-11-024***	WHITE
10 months	Byron 2	Failure to ensure that a flange connection on the EDG lube oil cooler was correctly torqued following maintenance. ***EA-11-014***	WHITE
33 years	Millstone 2	Inadequate procedures and operator errors caused unplanned reactivity additions during main turbine control valve testing. ***EA-11-047***	WHITE
1 day	Brunswick	Penetrations in exterior wall of EDG fuel oil structure could lead to failure of the EDGs during postulated flooding. ***EA-11-251***	WHITE
193 days	Palisades	Turbine-driven AFW pump unavailable because of greasing of the wrong component in the pump. ***EA-11-227***	WHITE
30 days	Limerick 2	Reactor core isolation cooling (RCIC) inoperable because of main feedwater valve failures diverting RCIC flow to the main condenser. ***EA-11-221***	WHITE
28 years	Oconee 1	Failure to maintain design control of the Standby Shutdown Facility (SSF) pressurizer heater breakers. ***EA-11-226***	YELLOW
28 years	Oconee 2	Failure to maintain design control of the SSF pressurizer heater breakers. ***EA-11-226***	YELLOW
28 years	Oconee 3	Failure to maintain design control of the SSF pressurizer heater breakers. ***EA-11-226***	YELLOW
19 months	Fort Calhoun	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***	RED
3 years	Palisades	Failure of a service water pump because of coupling failure. ***EA-11-241***	WHITE

FY 2012 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 review of FY 2012 events and one potentially *significant* precursor was identified for loss of offsite power event and subsequent station blackout that occurred at Byron Station, Unit 2, on January 30, 2012. The ASP analysis of this event in underway. In addition, the evaluations of other FY 2012 events are ongoing. The staff will inform the Commission if *significant* precursors are identified. The staff will perform full ASP

5 A RED finding corresponds to a licensee performance deficiency of substantial safety significance and has an increase in core damage frequency greater than or equal to 10^{-4}.

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 exception applies to the data coverage of *significant* precursors.

- The data for *significant* precursors includes events that occurred during FY 2012. The results for FY 2012 are based on the staff’s screening and review of a combination of LERs and daily event notification reports (as of September 30, 2012). The staff analyzes all potential *significant* precursors (an event that has a probability of at least 1 in 1,000 of leading to a reactor accident) immediately.

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.[6]

Results. A review of the data for that period reveals the following insights:

- The mean occurrence rate of all precursors does not exhibit a trend that is statistically significant (p-value = 0.99) for the period from FY 2002–2011 (see Figure 2).

- In addition, the mean occurrence rate of precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4} does not exhibit a statistically significant (p-value = 0.74) trend during this same period (see Figure 3).
    - There is an apparent increase of precursors in this subgroup in the past two years (one precursor in FY 2010 and three precursors in FY 2011) after no events were identified in the previous six years. These precursors involved different types of operational events (e.g., LOOP, failure of containment suction valve, and degraded electrical breakers) at different plants. The staff will continue to monitor this precursor subgroup to determine if any insights can be gained into the increase of these higher-risk events.

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

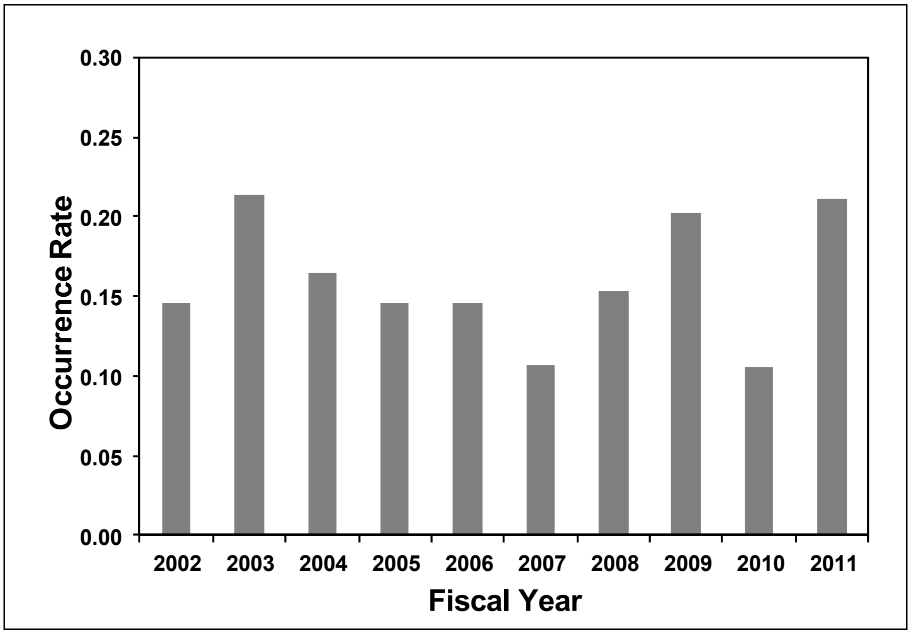

Figure 2. Total precursors

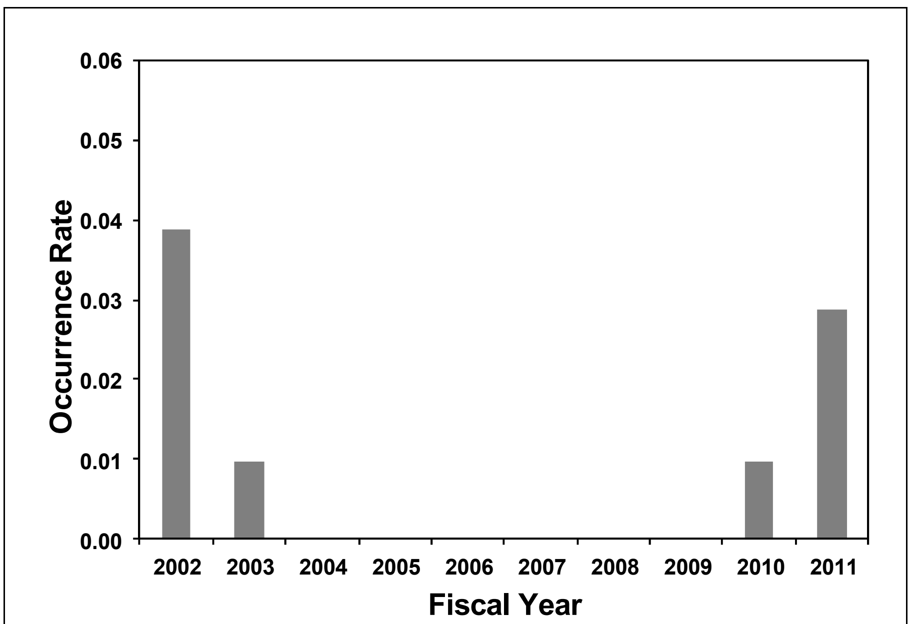

Figure 3. Precursors with a CCDP or ΔCDP ≥ 1×10^{-4}

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). Specifically, a *significant* precursor is an event that has a probability of at least 1 in 1,000 (i.e., greater than or equal to 1×10^{-3}) of leading to a reactor accident.

Results. A review of the data for that period reveals the following insights:

- Over the past 15 years, one *significant* precursor has been identified.[7] In FY 2002, the staff identified a *significant* precursor involving concurrent, multiple-degraded conditions at Davis-Besse.

5.0 Insights and Other Trends

The following sections provide additional ASP trends and insights for the period from FY 2002–2011.

5.1 Initiating Event and Degraded Condition Precursor Subgroup Trends

A review of the data for FY 2002–2011 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 = 0.81) for the period from FY 2002–2011, as shown in Figure 4.

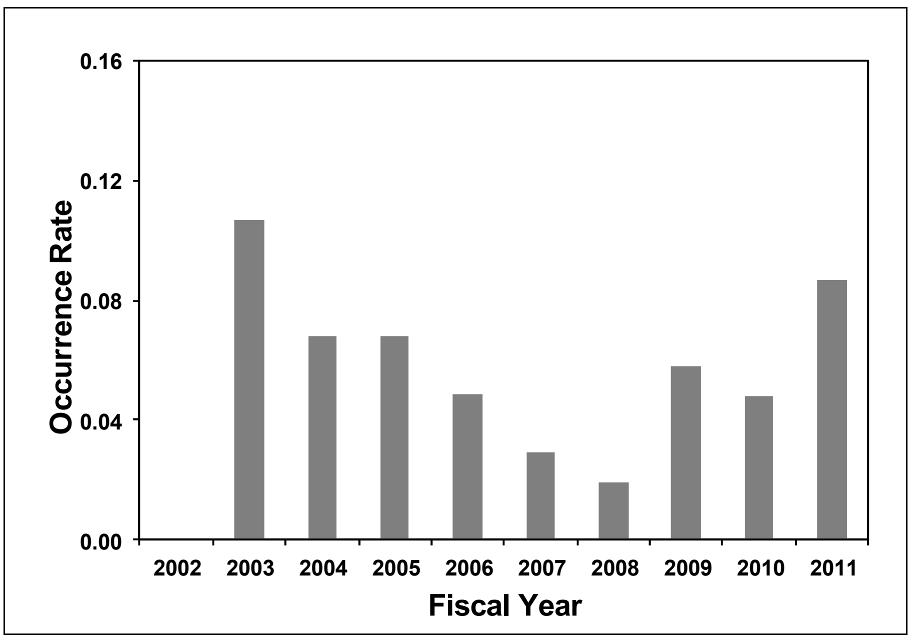

Figure 4. Precursors involving initiating events

- The apparent increase of precursors in this subgroup is largely attributed to the three LOOP events which resulted in seven FY 2011 precursors caused by external events (i.e., lightning strikes, tornadoes, and earthquake).

- Of the 55 precursors involving initiating events during FY 2002–2011, 56 percent were LOOP events. This is expected because uncomplicated transients typically do not exceed the threshold, while essentially all LOOPs do exceed the threshold. While the

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7 Reference 3 provides a complete list of all *significant* precursors from 1969–2011.

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 = 0.81) during FY 2002–2011, as shown in Figure 5.

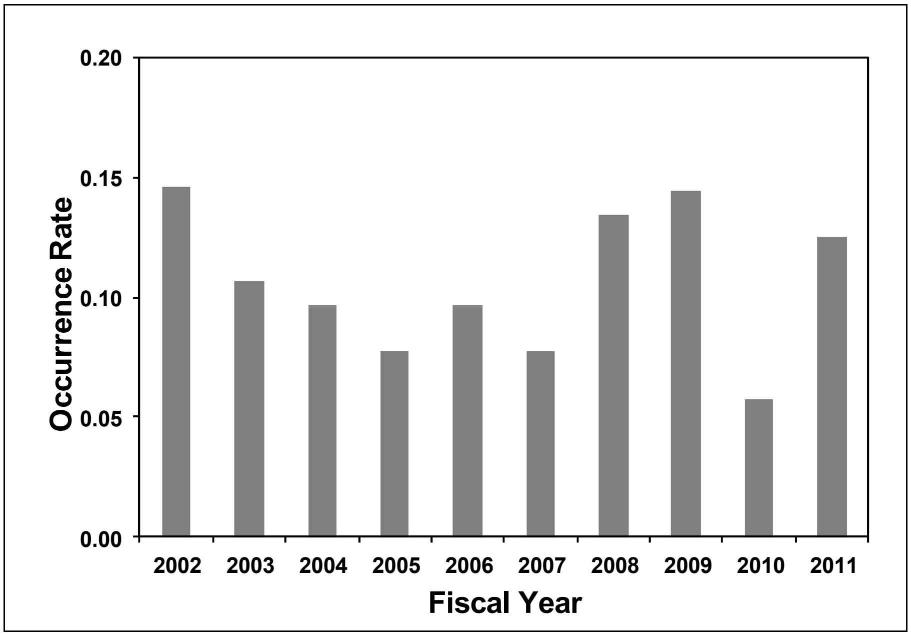

Figure 5. Precursors involving degraded conditions

- Over the past 10 years, precursors involving degraded conditions outnumbered initiating events two-to-one.

- From FY 2002–2011, 26 percent of precursors involved degraded conditions existing for a decade or longer.[8] Of these precursors, half involved degraded conditions dating back to initial plant construction.

5.2 Precursors Involving a Complete Loss of Offsite Power Initiating Events

In FY 2011, three LOOP events (resulting in seven precursors) were caused by external events (e.g., lightning strikes, hurricanes, tornadoes, and earthquake). Specifically, the LOOPs at Surry and Browns Ferry were caused by tornadoes and the LOOP at North Anna was caused by an earthquake. Typically, all complete LOOP events meet the precursor threshold.

Results. A review of the data for FY 2002–2011 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 = 0.65) for the period from FY 2002–2011, as shown in Figure 6.

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

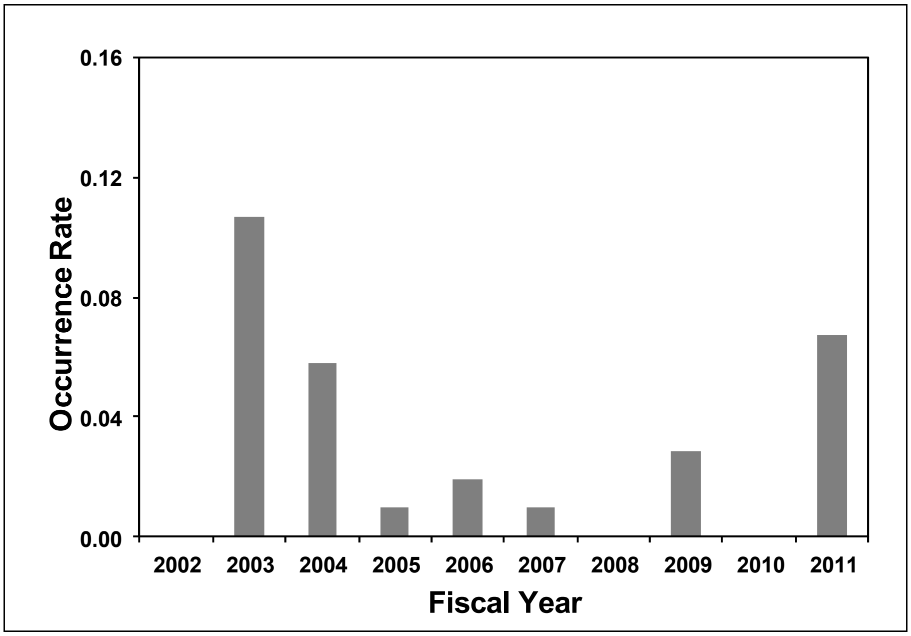

Figure 6. Precursors involving LOOP events

- Of the 31 LOOP precursors that occurred during FY 2002–2011, 39 percent resulted from external events and 35 percent resulted from a degraded electrical grid outside of the NPP boundary.
  - Eight of the 11 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 31 LOOP precursor events during FY 2002–2011 involved a simultaneous unavailability of an emergency power system train.

5.3 Precursors at Boiling-Water Reactors and Pressurized-Water Reactors Subgroup Trends

A review of the data for FY 2002–2011 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 = 0.56) for FY 2002–2011, as shown in Figure 7.

- LOOP events contributed to 62 percent of precursors involving initiating events at BWRs.

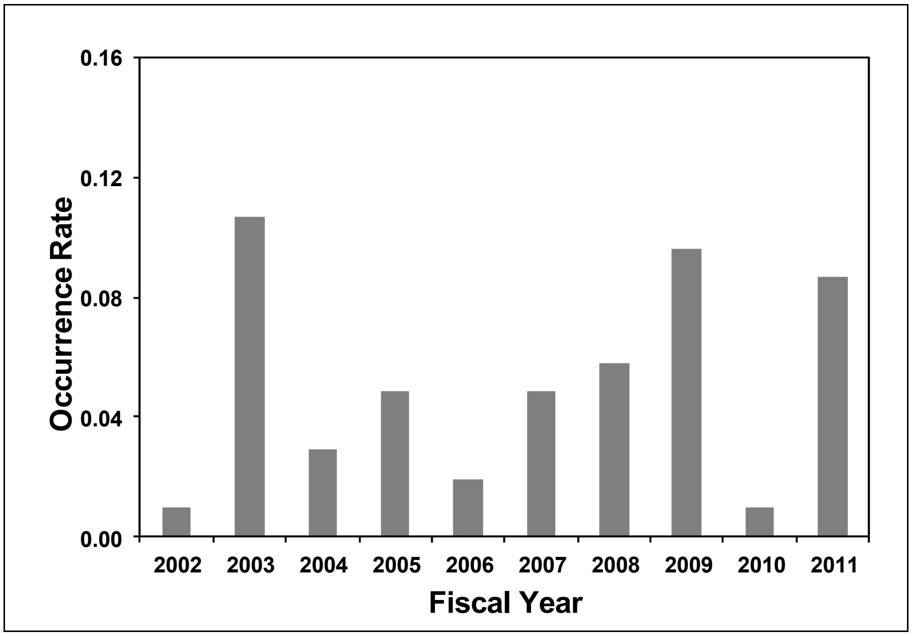

Figure 7. Precursors involving BWRs

- Of the 32 precursors involving the unavailability of safety-related equipment that occurred at BWRs during FY 2002–2011, most were caused by failures in the emergency power system (38 percent), emergency core cooling systems (25 percent), safety-related cooling water systems (13 percent), or electrical distribution system (9 percent).

PWRs

- The mean occurrence rate of precursors that occurred at PWRs does not exhibit a trend that is statistically significant (p-value = 0.39) for FY 2002–2011, as shown in Figure 8.

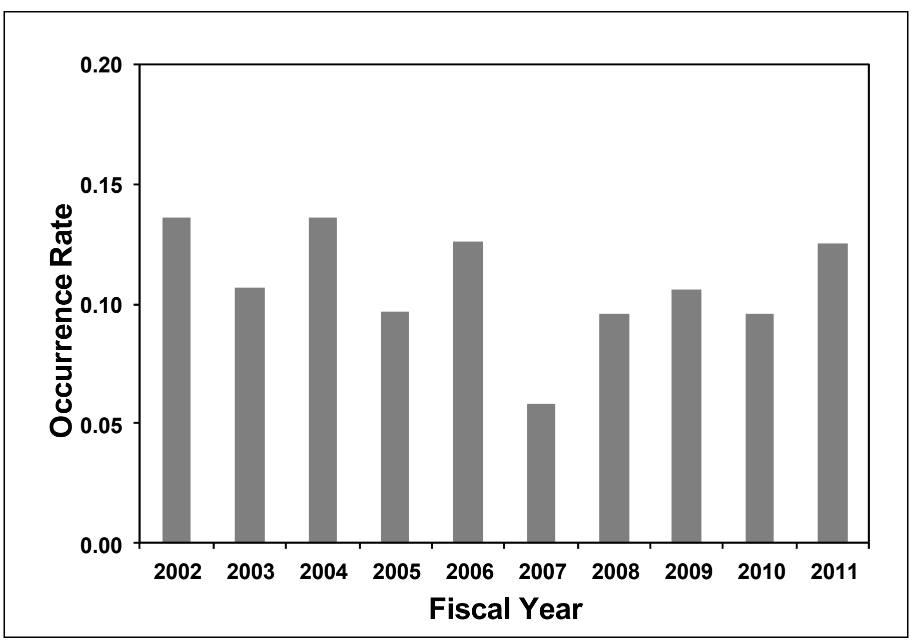

Figure 8. Precursors involving PWRs

- LOOP events contribute to 53 percent of precursors involving initiating events at PWRs.

- Of the 78 precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2002–2011, most were caused by failures in the emergency power system (23 percent), emergency core cooling systems (22 percent), auxiliary feedwater system (19 percent), safety-related cooling water systems (13 percent), or electrical distribution system (13 percent).
  - Of the 17 precursors involving failures in the emergency core cooling systems, 13 precursors (76 percent) were because of conditions affecting sump recirculation during postulated loss-of-coolant accidents of varying break sizes. Design errors were the cause of most of these precursors (85 percent).
  - Of the 15 precursors involving failures of the auxiliary feedwater system, random hardware failures (47 percent) and design errors (53 percent) were the largest failure contributors. Thirteen of the 15 precursors (87 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 46 percent of all precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2002–2011.

5.4 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 FYs 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 2002–2011. 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 2002–2011 is consistent with the CDF estimates from the SPAR models and industry PRAs.

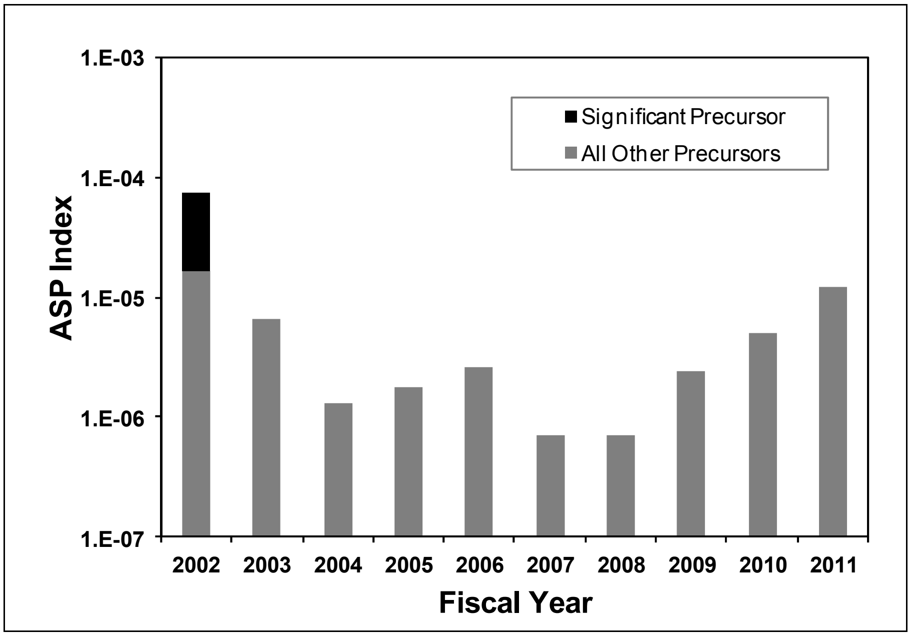

Figure 9. Integrated ASP index

- Precursors over the FY 2002–2011 period made the following contributions to the average integrated ASP index:
  - One *significant* precursor (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-3}) contributed to 60 percent of the average integrated ASP index. The *significant* precursor (Davis-Besse, FY 2002) existed for 1 year.
  - The remaining 40 percent of the average integrated ASP index resulted from contributions from the 164 precursors.
  - The occurrence of three LOOP events (resulting in seven precursors) caused by external events led to a somewhat higher than usual value of this index in FY 2011. These events were mitigated without serious problems; therefore, the 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 also must 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).

5.5 Operating Experience Insights Feedback for PRA Standards and Guidance

A secondary objective of the ASP Program is to provide a partial validation of 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) RA-S-2008, "Standard for 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). None of the events indicated an inadequacy in the state of PRA practice as described in ASME RA-S-2008.

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 2011. The staff identified one potentially *significant* precursor in FY 2012. The staff will continue the analysis of the event that occurred at Byron, Unit 2. 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 2012 Performance and Accountability Report.

- ***Occurrence Rate of All Precursors.*** The occurrence rate of all precursors does not exhibit a trend that is statistically significant during FY 2002–2011. 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 2012 Performance and Accountability Report.

- ***Additional Trend Results.*** During the same period, no trends were observed in other precursor subgroups.

7.0 References

1. U.S. Nuclear Regulatory Commission, “Performance Budget: Fiscal Year 2013,” NUREG-1100, Vol. 28, February 2012.

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-11-0138, September 30, 2011.

4. American Society of Mechanical Engineers, “Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications,” Revision 1, RA-S-2002, New York, NY, April 2008.

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.