POLICY ISSUE

(INFORMATION)

September 30, 2011 SECY-11-0138

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, provide the annual 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, the staff expanded the annual ASP SECY paper to include evaluation of precursor data trends and to summarize the continuing 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 most likely to lead to inadequate core cooling and severe core damage (precursors). The ASP Program provides insights to 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 27, “Congressional Budget Justification: Fiscal Year 2012,” issued February 2011). The SPAR Model Program develops and maintains independent risk-analysis tools and capabilities to support the use of probabilistic risk assessment (PRA) in the agency’s risk-informed regulatory activities.

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The staff uses SPAR models to support the Significance Determination Process (SDP), the ASP Program, the Incident Investigation Program event assessment process, and the Generic Issue Program resolution process. In addition, the staff uses SPAR models to inform licensing and 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-10-0125, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models," dated September 29, 2010.

ASP Program

The staff has completed the probabilistic analyses of all precursor events that were identified in fiscal year (FY) 2010 (11 precursors). Precursors are events with a conditional core damage probability (CCDP) for initiating event analyses or an increase in core damage probability (ΔCDP) for equipment deemed unavailable or degraded that is greater than or equal to 1×10^{-6}. In addition, the staff has completed the screening of FY 2011 events for *significant* precursors. *Significant* precursors have a CCDP or ΔCDP greater than or equal to 1×10^{-3}. Based on completed analyses, no *significant* precursors were identified in FY 2010, and based on screening and analyses in progress, no *significant* precursors have been identified in FY 2011. However, the staff will continue to evaluate the flooding situation at Fort Calhoun and the recent earthquake at North Anna and inform the Commission if *significant* precursors are identified.

The one event that was evaluated as a potential *significant* precursor in FY 2010 involved an electrical fire at H. B. Robinson Steam Electric Plant, Unit 2 that led to a plant trip with a subsequent loss of reactor coolant pump seal cooling and additional complications. The potential for the event to be a significant precursor was identified after new information became available in December 2010 during follow-up inspection activities. A preliminary ASP analysis was issued by NRC staff and transmitted to the licensee in accordance with established procedures. This prompted the licensee to perform some additional thermal-hydraulic analysis, which resulted in changes to modeling assumptions and reduced the CCDP of the event to 4×10^{-4}, which is lower than the CCDP threshold value of a *significant* precursor. Enclosure 1 presents additional details of the event analysis.

The staff evaluated precursor data during the period of FY 2001 through FY 2010 to identify statistically significant adverse trends for the Industry Trends Program (ITP). No statistically significant trend was detected for all precursors during this 10-year period. The ASP Program results are trended in the ITP to provide an input to the agency's safety performance measure of no significant adverse trend in industry safety performance.

In addition to the trend analysis of all precursors, the staff performs trend analyses on precursor subgroups. These subgroups include precursors with a high safety significance (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-4}), initiating events, degraded conditions, loss of offsite power initiating events, precursors at boiling-water reactors (BWRs), and precursors at pressurized-water reactors (PWRs). Statistically significant decreasing trends were detected for two subgroups of precursors—precursors corresponding to high safety significance (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-4}) and precursors that occurred at PWRs. No statistically significant trends were observed in other precursor subgroups. Enclosure 1 provides additional details on results and trends of the ASP Program.

SPAR Model Program

The staff continued to maintain and update the 78 SPAR models representing the 104 operating commercial NPPs during FY 2011. In addition to routine model updates, in October 2010, the staff completed an evaluation of the potential core damage risk reduction associated with the extensive damage mitigation strategies and guidance required by 10 CFR 50.54(hh). This was forwarded to the Office of Nuclear Reactor Regulation (NRR) to support an assessment of the effectiveness of the 10 CFR 50.54(hh) security enhancements implemented by licensees and the potential credit of these enhancements in the SDP.

In FY 2010, the staff, in cooperation with the Electric Power Research Institute (EPRI) and the Pressurized Water Reactor and Boiling Water Reactor Owner's groups, completed peer reviews of a representative PWR SPAR model and BWR SPAR model in accordance with American National Standard, ASME RA-S-2002, "Standard for 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 included individuals experienced with the peer review process used for licensee PRAs and NRC staff familiar with the agency's use of risk tools. The peer review teams concluded that, within the constraints of the program, the SPAR models provide an appropriate tool to provide an independent check on the technical adequacy of utility PRAs. The teams also identified a number of areas where enhancements could be made to the SPAR models and supporting documentation. The staff has evaluated the peer review comments and has initiated projects to address these comments, where appropriate. The staff plans to complete this effort in 2013.

The staff continued to expand the SPAR model capability beyond internal events at full-power operation. Currently, a total of 16 SPAR external event (EE) models exist (e.g., fires, floods, and seismic events). Three of the integrated SPAR models (which include both internal and external hazards) were previously used in identifying and evaluating severe accident sequences for the consequential steam generator tube rupture (SGTR) project in support of the closure of the Steam Generator Action Plan. Consequential SGTR events are potentially risk significant because of the possibility of a severe core damage event leading to failure of the steam generator tubes and reactor coolant bypass of the containment building. In addition, the SPAR-EE models have been used to provide background information to NRR on the impact of assessing external hazard risk in 10 CFR 50.65 maintenance risk assessments. This study concluded that including consideration of fire and external hazards in pre-maintenance risk assessments could prompt beneficial changes in maintenance configurations and result in lower cumulative plant risk. The staff also plans to incorporate internal fire scenarios from the National Fire Protection Association (NFPA) 805, "Performance-Based Standard for Fire Protection for Light-Water Reactor Electric Generating Plants," pilot applications into two SPAR models. The Office of Nuclear Regulatory Research (RES) staff continues to work with NRR and the Office of New Reactors (NRO) to identify future enhancements to the SPAR-EE models.

The staff has continued the development and enhancement of the shutdown template models, resulting in a total of eight shutdown SPAR models available to support the Reactor Oversight Process evaluations of shutdown events and degraded conditions during shutdown conditions. The staff also developed a preliminary new reactor SPAR model for the Advanced Boiling Water Reactor (ABWR) Toshiba design and a preliminary model for the AP1000 design including a seismic analysis. Quality assurance and internal review activities are ongoing for these models. A SPAR model for the ABWR/GE design was completed in May 2011. These new reactor SPAR models allow confirmation of PRA results presented in licensing submittals, evaluation of risk-informed license applications prior to plant operation, and assessment of operational findings and events once operation commences. Enclosure 2 provides a detailed status of SPAR models.

The staff continues to maintain and improve the Systems Analysis Program for Hands-On Integrated Reliability Evaluations (SAPHIRE) Version 8 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 2011, the new features, capabilities, and user support activities that have been implemented for SAPHIRE Version 8 include:

- Effective use of multi-core computers to decrease overall analysis time.

- User-friendly links to SPAR model documentation and new risk insights reports.

- Training to NRC resident inspectors participating in the piloting of a new process for SDP Phase 2 analyses using SPAR models.

- Completion of NUREG/CR-7039, Volumes 1 through 7, the companion documentation for the SAPHIRE Version 8 software.

On September 19, 2011, the Office of the Inspector General (OIG) issued audit report OIG-11-A-18, "Memorandum Report: Audit of NRC's SAPHIRE 8 System." Although the OIG concluded that SAPHIRE 8 meets its operational capabilities and there is limited security risk to the software, the OIG recommended several additional measures relating to software distribution policies and website access controls to ensure that the software was properly managed. The staff is currently evaluating the need for corrective actions to address the three recommendations identified by the OIG in the audit report.

Planned Activities

- The staff will continue the screening, review, and analysis (preliminary and final) of potential precursors for FY 2011 and FY 2012 events.

- The staff will continue to implement enhancements to the internal event SPAR models for full-power operations as needed. Anticipated enhancements include incorporating new models for support-system initiators and revised success criteria based on insights from thermal-hydraulic analyses. The staff also is working with industry representatives through a memorandum of understanding with EPRI to resolve other PRA technical issues common to both licensee PRAs and NRC SPAR models. In support of this effort, the memorandum of understanding addendum on PRA with EPRI had been previously extended through 2016.

- The staff has reviewed the SPAR model peer review comments. A project plan has been developed to address peer review comments, where appropriate, and is planned to be completed in 2013. The main objective of this effort is to ensure the SPAR models continue to be of sufficient quality for performing SDP Phase 3, ASP, and Management Directive (MD) 8.3 event assessments in support of the staff's risk-informed activities.
- The staff will use information obtained as part of the NFPA-805 application process to create new SPAR fire models with updated fire scenarios.

- 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.

- The staff will continue the development of SPAR models for new reactors to allow confirmation of PRA results presented in licensing submittals, evaluation of risk-informed applications prior to plant operation, and assessment of operational findings and events once operation commences.

- The staff will develop about one new all-hazards SPAR model per year as well as perform validation activities for about two existing all hazards models per year.

- SPAR Model development efforts will be leveraged to the extent practical to support the full-scope Site Level 3 PRA described in Staff Requirements Memorandum (SRM) SECY-11-0089.

- The staff will continue to maintain and improve the SAPHIRE Version 8 software to support the SPAR Model Program. In addition, the staff plans to address the three recommendations contained in audit report OIG-11-A-18 in FY2012.

<u>SUMMARY</u>:

The ASP Program continues to evaluate the safety significance of operating events at NPPs and to provide insights to NRC's risk-informed and performance-based regulatory programs. The analyses of FY 2010 events and the screening of FY2011 events are complete, and the analysis of FY 2011 events is in progress. The staff identified no *significant* precursors in FY 2010 or FY 2011. No statistically significant trend was detected for all precursors during the FY 2001 through FY 2010 period. 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.

COORDINATION:

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

/RA/

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) 2010–2011. 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 that are 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., external, fire, flood, and shutdown 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 characterized 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}.

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 trip with a nonrecoverable 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.

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.

NRC also uses the ASP Program as a means to monitor performance against the safety measures established in the agency's Congressional Budget Justification (Reference 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).

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 in the determination of 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, 2011.

FY 2010 Analyses. The ASP analyses for FY 2010 identified 11 precursors. All 11 precursors occurred while the plants were at power. The staff used the SDP to identify and assess 5 of the 11 precursors without performing duplicative analyses. 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 2010 analysis exceeded the high safety significance probability of 1×10^{-4} (H. B. Robinson, Unit 2 precursor event that occurred on March 28, 2010); therefore, the analysis was sent for a formal 60-day review to the licensee, the Region II office, and the Office of Nuclear Reactor Regulation (NRR). All of the other ASP analyses were issued as final after completion of internal reviews in accordance with the revised ASP review process (see Reference 2 and Figure 1).

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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 2009–2011.

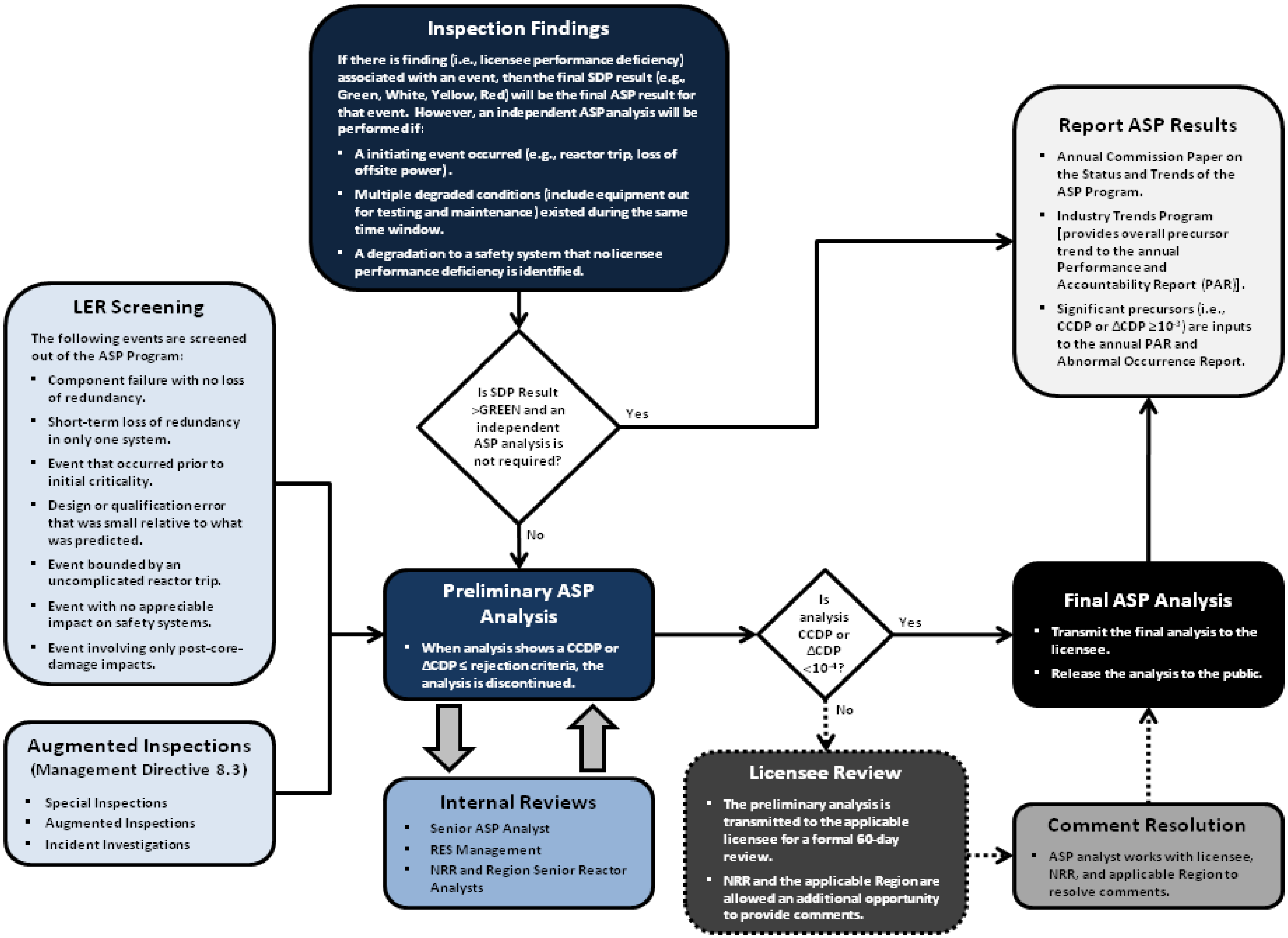

Figure 1. ASP Process Diagram.

Table 1 presents the results of the staff's ASP analyses for FY 2010 precursors that involved initiating events. Table 2 presents the analysis results for FY 2010 precursors that involved degraded conditions.

Table 1. FY 2010 Precursors Involving Initiating Events.

Event Date	Plant	Description	CCDP
02/18/10	Calvert Cliffs 2	Failure of emergency diesel generator to start during a partial loss of offsite power due to faulty relay. ***LER 318/10-006***	2×10^{-5}
03/28/10	H. B. Robinson 2	Fire causes loss of nonvital busses along with a partial loss of offsite power with reactor coolant pump seal cooling challenges. ***IR 50-261/10-09***	4×10^{-4}
06/08/10	Surry 1	Reactor trip due to loss of electrical bus and additional complications. **LER 280/10-003**	5×10^{-6}
07/16/10	Susquehanna 1	Manual reactor scram due to leakage from the circulating water system and subsequent flooding of the condenser bay. ***LER 387/10-008***	4×10^{-6}
09/09/10	H. B. Robinson 2	Reactor trip due to a degraded connection on a circuit board in the electro-hydraulic control cabinet. ***LER 261/10-007***	3×10^{-6}

Table 2. FY 2010 Precursors Involving Degraded Conditions.

Condition Duration	Plant	Description	ΔCDP/ SDP Color
4 months	Oconee 1	Standby shutdown facility reactor coolant makeup system letdown line orifice strainer blocked by valve gasket. ***Enforcement Action (EA)-10-094***	YELLOW[3,4]
14 months	Oconee 2	Standby shutdown facility reactor coolant make-up system letdown line orifice strainer blocked by valve gasket. ***EA-10-094***	YELLOW[3,4]
9 months	Oconee 3	Standby shutdown facility reactor coolant make-up system letdown line orifice strainer blocked by valve gasket. ***EA-10-094***	YELLOW[3,4]

3 Each unit at Oconee experienced degradation of gasket material that rendered the reactor coolant makeup system inoperable. However, since the condition was discovered at different times in each unit and the system is only required in certain modes of operation, the duration of the condition is different for each unit.

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}.

6 years	Fort Calhoun	Failure to establish and maintain procedures to protect the heat sink cooling water intake structure and auxiliary building from external floods. ***EA-10-084***	YELLOW[4]
25 days	H. B. Robinson 2	Concurrent unavailabilities- EDG B inoperable due to failed output breaker and EDG A unavailable due to testing and maintenance. ***LER 261/10-001***	3×10^{-6}
2 months	Fort Calhoun	Failure to identify the cause and prevent the failure of a trip contact assembly in the reactor protection system. ***EA-11-025***	YELLOW[4]

FY 2011 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, Section 50.73, "Licensee Event Report System," of the *Code of Federal Regulations* [10 CFR 50.73]) 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 screening review of FY 2011 events and the probabilistic analyses are in progress. No *significant* precursors were identified. However, the staff will continue to evaluate the flooding situation at Fort Calhoun and the recent earthquake at North Anna and inform the Commission if *significant* precursors are identified. We will perform full ASP analyses of these 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 2011. The results for FY 2011 are based on the staff's screening and review of a combination of LERs and daily event notification reports (as of September 30, 2011). 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

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 NRC's Strategic Plan). The mean occurrence rate[5] of all precursors identified by the ASP Program is one indicator used by the ITP to assess industry performance.

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 = 0.13) for the period from FY 2001–2010 (see Figure 2).

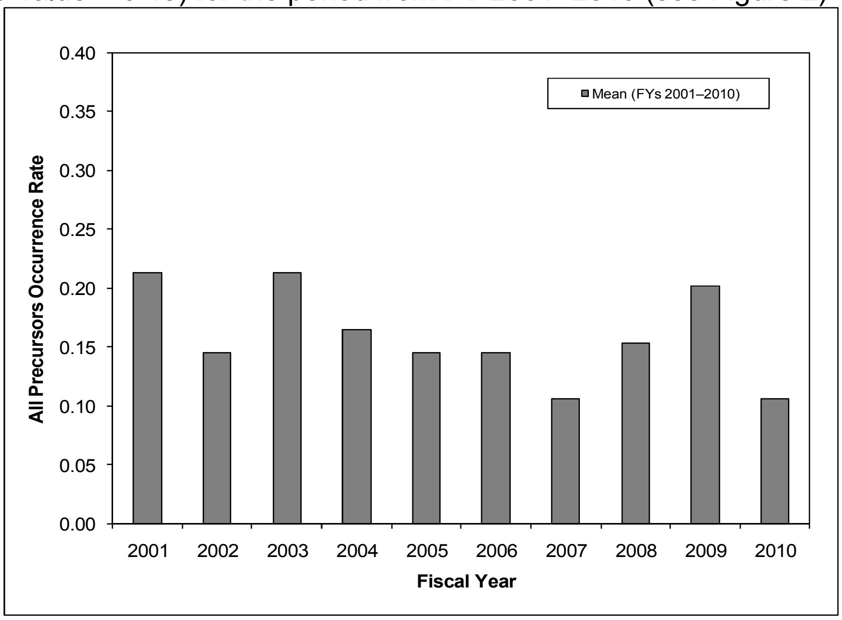

Figure 2. Total Precursors.

- The analysis detected a statistically significant decreasing trend (p-value = 0.002) for precursors with a high safety significance (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-4}) during this same period (see Figure 3).

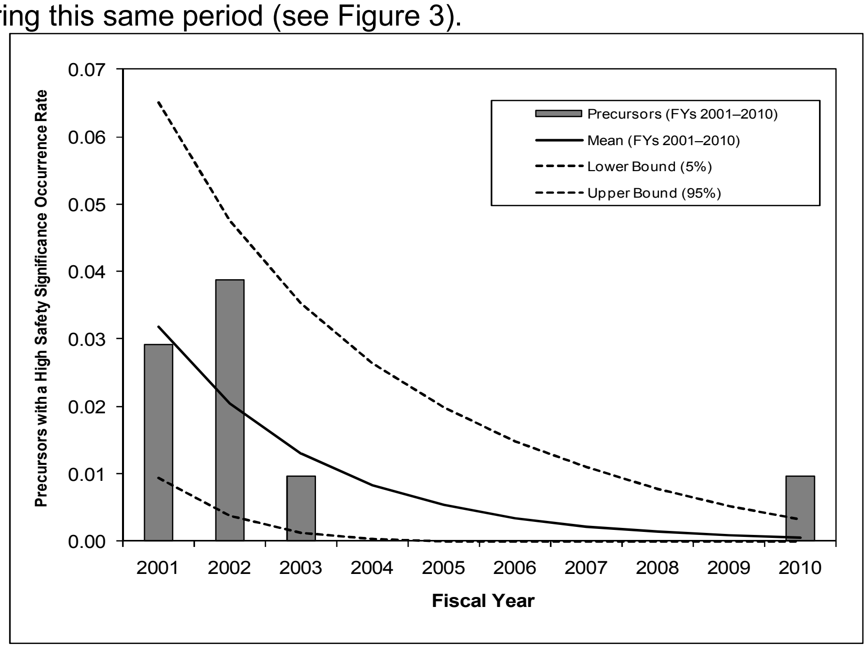

Figure 3. Precursors with High Safety Significance.

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

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 NRC's Congressional Budget Justification [Reference 1]). Specifically, a *significant* precursor is an event that has a probability of at least 1 in 1,000 (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:

- One potential *significant* precursor was identified in FY 2010. This precursor event involved an electrical fire at H. B. Robinson Steam Electric Plant, Unit 2, on March 28, 2010, that led to a plant trip with a subsequent loss of reactor coolant pump seal cooling and additional complications. The key contributors to the event risk were the failures of an electrical cable and a breaker which caused a fire, control room supervisor failure to implement proper command and control, operator training deficiencies, and the reliance on knowledge-based emergency operating procedures.

  Initial evaluations of the event indicated that it was not a *significant* precursor, and SECY-10-0125 reported that no *significant* precursors occurred in FY 2010. The potential for this event to be a *significant* precursor was identified after new information concerning the loss of seal injection became available in December 2010 during follow-up inspection activities. A preliminary ASP analysis, performed by NRC staff, indicated that the event may be a *significant* precursor. In accordance with established procedures, the preliminary ASP analysis was transmitted to the licensee for comment. This prompted the licensee to perform detailed thermal-hydraulic analyses of hypothetical accident sequences. This resulted in some changes to modeling assumptions concerning the size of a potential loss of coolant accident and the timing of operator actions. Subsequent NRC risk analysis reduced the CCDP of the event to 4×10^{-4}, which is lower than the CCDP threshold value of a *significant* precursor. Further information can be found in the final ASP report (Reference 3).

  On June 2, 2010, NRC completed an augmented inspection that identified 14 unresolved issues. The analysis of these issues revealed two WHITE findings[6] involving the operators failing to implement proper command and control and the licensee failing to correctly implement proper training protocols in its Licensed Operator Requalification Program. In addition, five GREEN findings[7] were identified. Further information on the inspection activities related to this event can be found in References 4–7.

- Over the past 15 years, one *significant* precursor has been identified.[8] In FY 2002, the staff identified a *significant* precursor involving concurrent, multiple-degraded conditions at Davis-Besse. While not a *significant* precursor, the H. B. Robinson event is an important precursor and the highest-risk precursor since Davis-Besse.

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6 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 10^{-6} to 10^{-5}.

7 A GREEN finding corresponds to a licensee performance deficiency of very low safety significance and has an increase in core damage frequency of less than 10^{-6}.

8 Reference 8 provides a complete list of all *significant* precursors from 1969–2010.

5.0 Insights and Other Trend*s*

The following sections provide additional ASP trends and insights from the period FY 2001–2010.

5.1 Initiating Event and Degraded Condition Precursor Subgroup Trends

A review of the data for FY 2001–2010 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 = 0.87) for the period from FY 2001–2010, as shown in Figure 4.

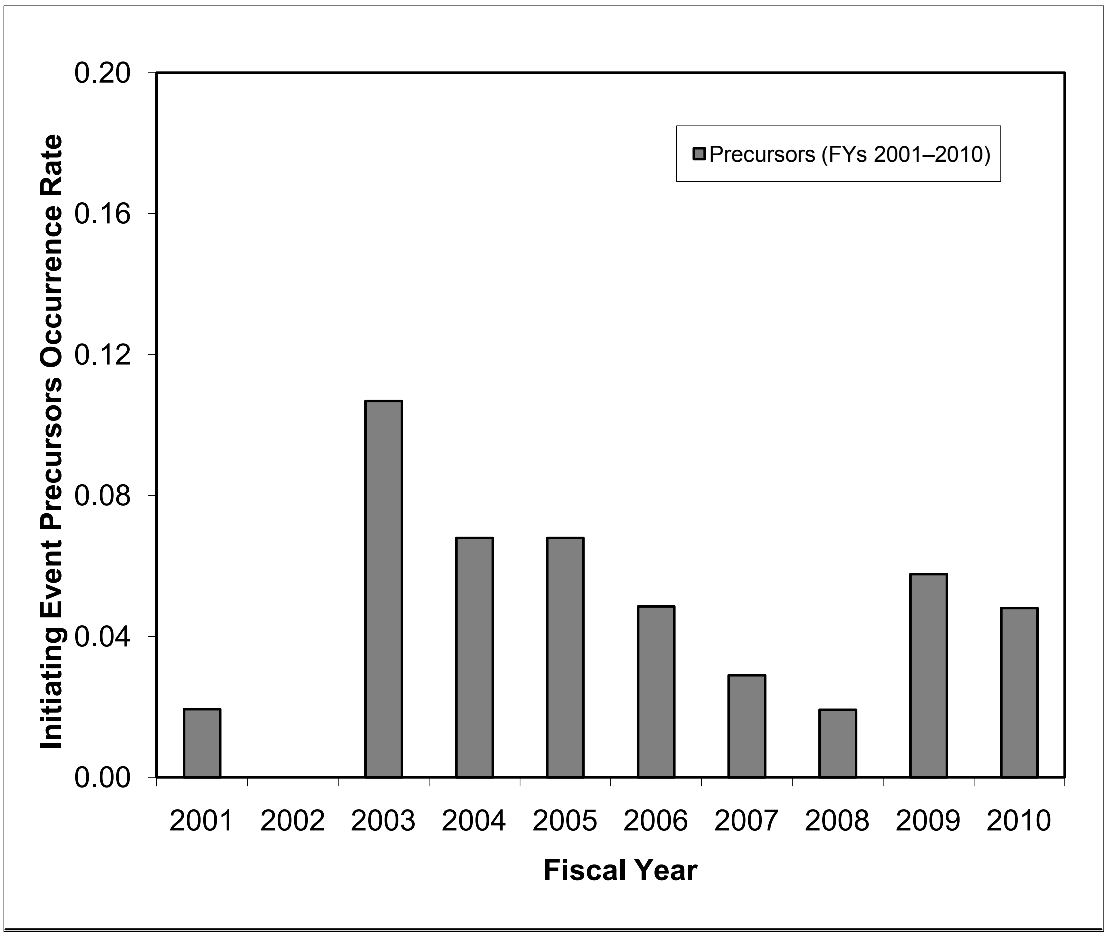

Figure 4. Precursors Involving Initiating Events.

- Of the 48 precursors involving initiating events during FY 2001–2010, 52 percent were LOOP events.

Degraded Conditions

- The mean occurrence rate of precursors involving degraded conditions does not exhibit a trend that is statistically significant (p-value = 0.11) during FY 2001–2010, as shown in Figure 5.

- Over the past 10 years, precursors involving degraded conditions outnumbered initiating events (71 percent compared to 29 percent, respectively). This predominance was most notable in FY 2001 and FY 2002 when degraded conditions contributed to 91 percent and 100 percent of the identified precursors, respectively.

- From FY 2001–2010, 29 percent of precursors involving degraded conditions existing for a decade or longer.[9] Of these precursors, 56 percent involved degraded conditions with condition start dating back to initial plant construction.

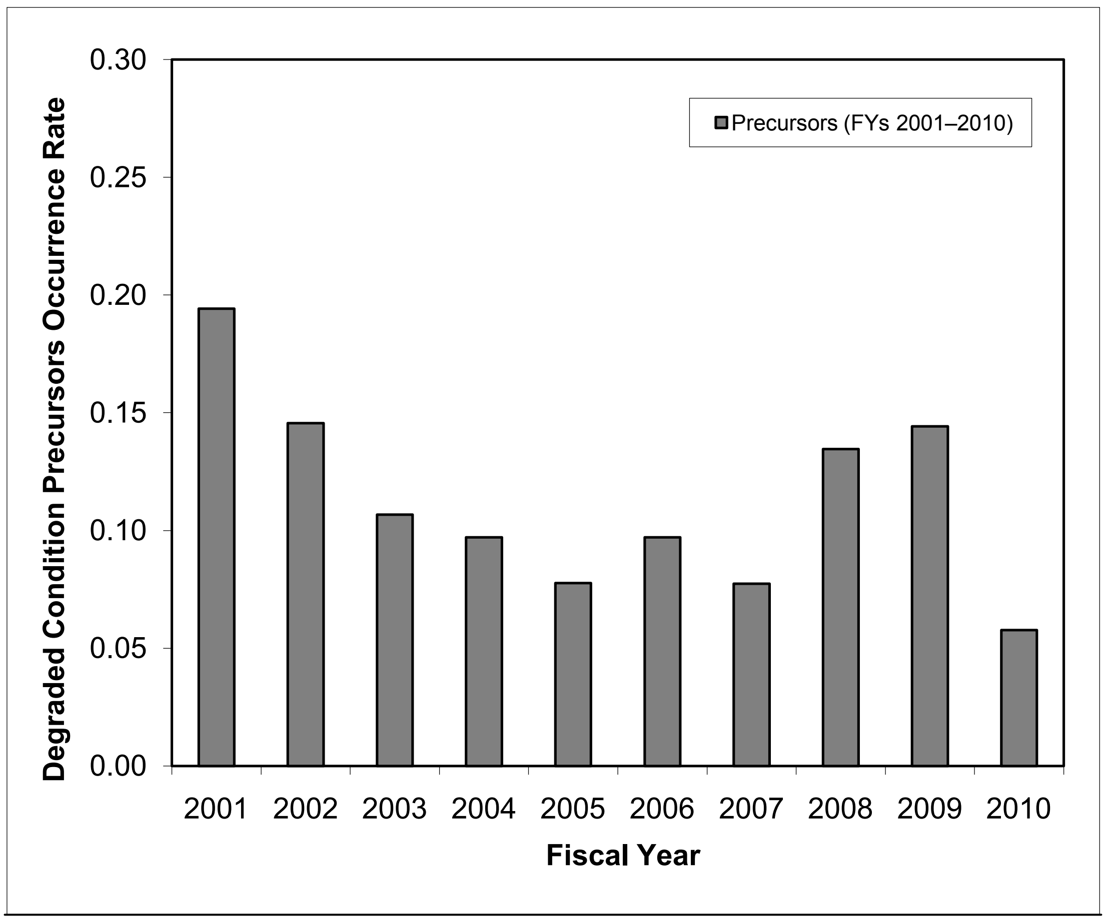

Figure 5. Precursors Involving Degraded Conditions.

9 Note that although these degraded conditions lasted for many years, ASP analyses limit the exposure period to one year.

5.2 Precursors Involving a Complete Loss of Offsite Power Initiating Events

No FY 2010 precursor resulted from a complete LOOP initiating event. Typically, all complete LOOP events meet the precursor threshold.

Results. A review of the data for FY 2001–2010 leads to the following insights:

- The mean occurrence rate of precursors resulting from a complete LOOP does not exhibit a trend that is statistically significant (p-value = 0.33) for the period from FY 2001–2010, as shown in Figure 6.
- Of the 25 complete LOOP events that occurred during FY 2001–2010, 44 percent resulted from a degraded electrical grid outside of the NPP boundary. Eight of the 11 grid-related complete LOOP precursors were the result of the 2003 Northeast Blackout.
- A simultaneous unavailability of an emergency power system train was involved in 2 of the 25 complete LOOP precursor events during FY 2001–2010.

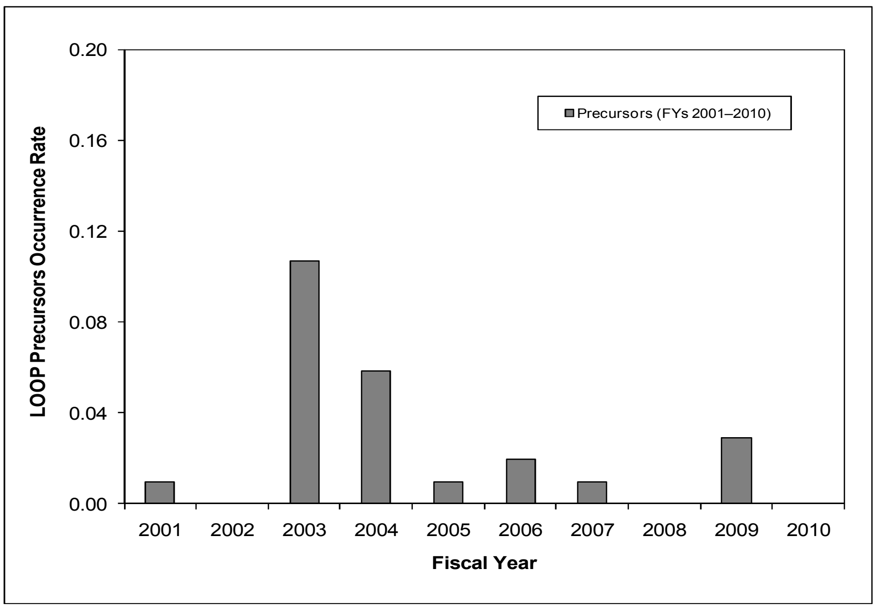

Figure 6. Precursors Involving LOOP Events.

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

A review of the data for FY 2001–2010 reveals the results for boiling-water reactors (BWRs) and pressurized-water reactors (PWRs) described below.[10]

[10] The sum of percentages in this section does not always equal 100 percent because some precursors involve multiple equipment availabilities.

BWRs

- The mean occurrence rate of precursors that occurred at BWRs does not exhibit a trend that is statistically significant (p-value = 0.94) for FY 2001–2010, as shown in Figure 7.

- LOOP events contributed to 58 percent of precursors involving initiating events at BWRs.

- Of the 30 precursors involving the unavailability of safety-related equipment that occurred at BWRs during FY 2001–2010, most were caused by failures in the emergency power system (40 percent), emergency core cooling systems (37 percent), electrical distribution system (13 percent), or safety-related cooling water systems (10 percent).

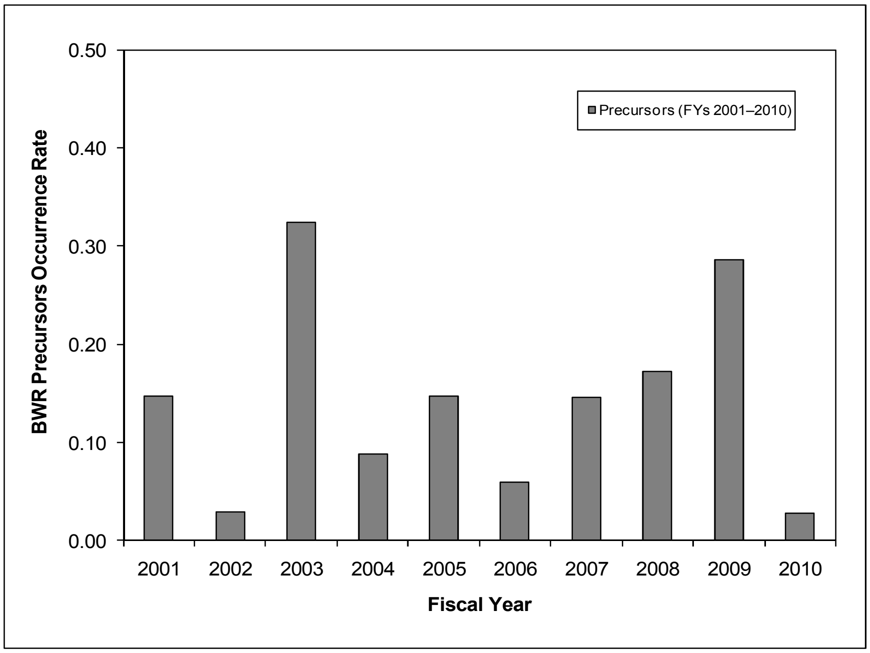

Figure 7. Precursors Involving BWRs.

PWRs

- The mean occurrence rate of precursors that occurred at PWRs exhibits a statistically significant decreasing trend (p-value = 0.01) during FY 2001–2010, as shown in Figure 8.

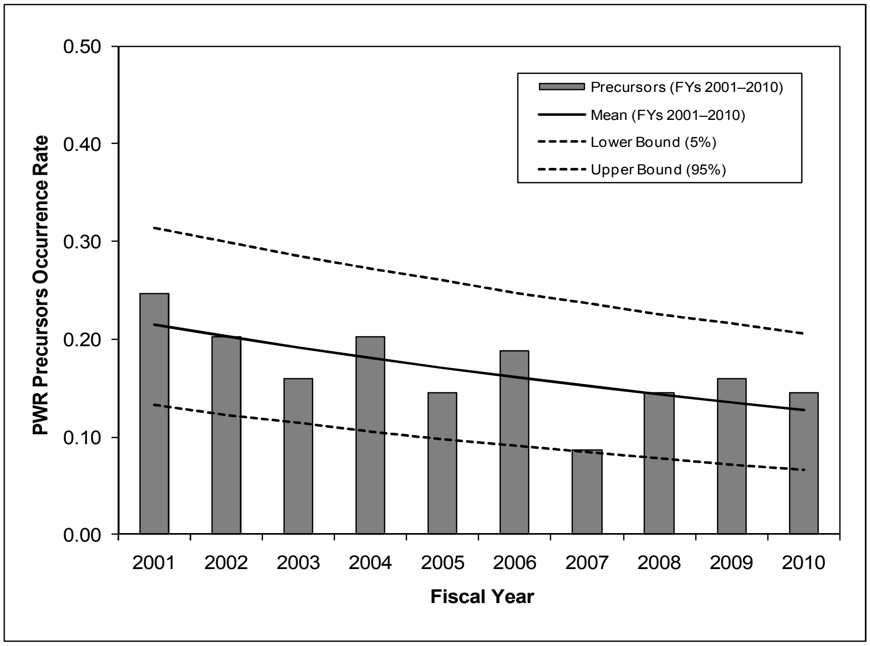

Figure 8. Precursors Involving PWRs.

- LOOP events contribute to 48 percent of precursors involving initiating events at PWRs.

- Of the 87 precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2001–2010, most were caused by failures in the emergency core cooling systems (29 percent), auxiliary feedwater system (20 percent), emergency power system (21 percent), or safety-related cooling water systems (17 percent).

  – Of the 25 precursors involving failures in the emergency core cooling systems, 18 precursors (72 percent) were due to conditions affecting sump recirculation during postulated loss-of coolant accidents of varying break sizes. Design errors were the cause of most of these precursors (89 percent).

  – Of the 17 precursors involving failures of the auxiliary feedwater system, random hardware failures (47 percent) and design errors (35 percent) were the largest failure contributors. Fifteen of the 17 precursors (88 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 44 percent of all precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2001–2010.

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 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-calendar 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 2003 and has a ΔCDP of 5×10^{-6}. A review of the LER reveals that the degraded condition has existed since a design modification performed in FY 2001. In the integrated ASP index, the ΔCDP of 5×10^{-6} is included in FYs 2001, 2002, and 2003 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 2003, only FY 2003 includes the CCDP from this precursor.

Results. Figure 9 depicts the integrated ASP indices for FY 2001–2010. A review of the ASP indices leads to the following insights:

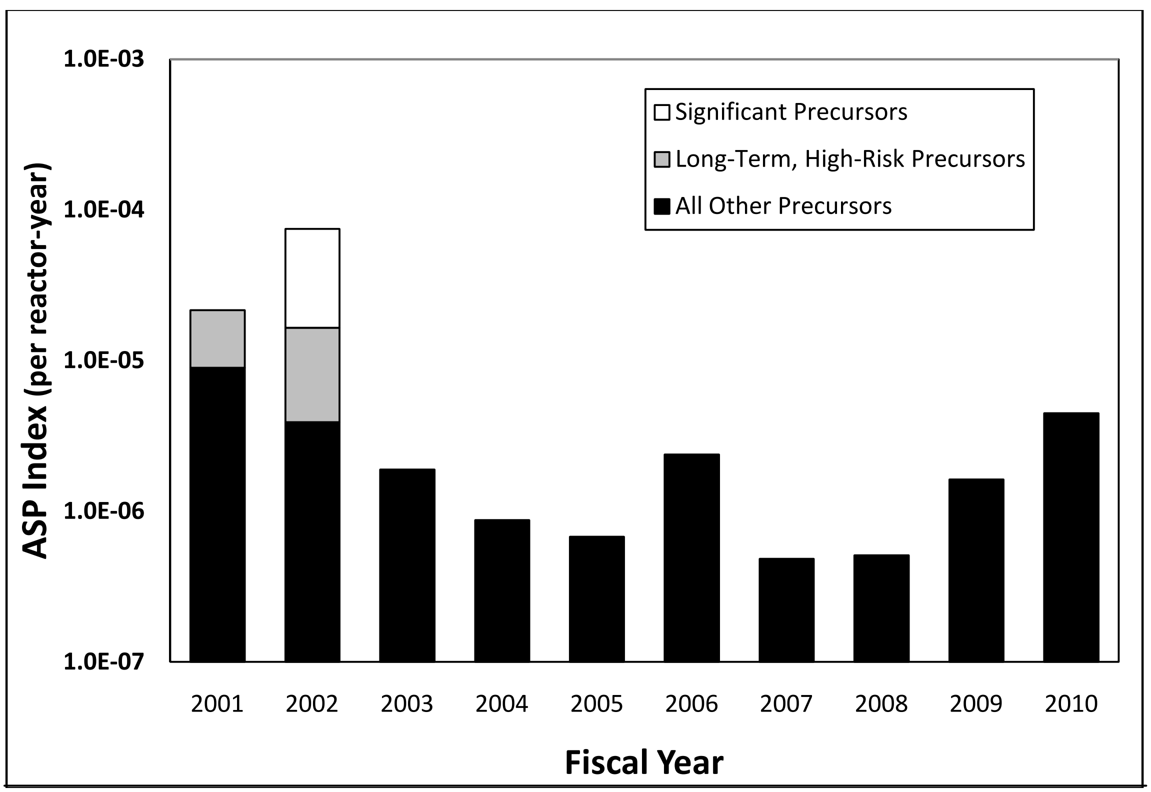

Figure 9. Integrated ASP Index.

- Based on the order of magnitude (10^{-5}), the average integrated ASP index for the period from FY 2001–2010 is consistent with the CDF estimates from the SPAR models and industry PRAs.

- Precursors over the FY 2001–2010 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 53 percent of the average integrated ASP index. The *significant* precursor (Davis-Besse, FY 2002) existed for 1 year.

  – Two precursors involving long-term degraded conditions at Point Beach Units 1 and 2 contributed 23 percent of the average integrated ASP. The degraded conditions were discovered in FY 2002 and involved potential common-mode failure of all auxiliary feedwater pumps. The associated ΔCDPs of these two precursors were high (7×10^{-4}) and the degraded conditions had existed since plant construction.

  – The remaining 24 percent of the average integrated ASP index resulted from contributions from the 162 precursors.

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 ASME/ANS RA-S-2008, "Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications," as endorsed in Regulatory Guide 1.200. None of the events indicated an inadequacy in the state of PRA practice as described in ASME/ANS RA-S-2008 (Reference 9).

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 2010. The staff did not identify any *significant* precursors in FY 2011. 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." These results will be provided in the FY 2011 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 2001–2010. 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 2011 Performance and Accountability Report.

- ***Additional Trend Results.*** During the same period, statistically significant decreasing trends were detected for two subgroups of precursors—precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4} and precursors that occurred at PWRs. No trends were observed in other precursor subgroups.

7.0 References

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3. Final ASP Report, “H. B. Robinson, Unit 2 (IR 50-261/10-09),” U.S. Nuclear Regulatory Commission, Washington, D.C., August 2011.

4. NRC Inspection Report 05000261/2010009, “H. B. Robinson Steam Electric Plant–Augmented Inspection Team Report,” U.S. Nuclear Regulatory Commission, Washington, D.C., July 2, 2010.

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8. SECY-10-0125, “Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models,” U.S. Nuclear Regulatory Commission, Washington, D.C., September 29, 2010.

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Status of the Standardized Plant Analysis Risk Models

1.0 Background

The objective of the Standardized Plant Analysis Risk (SPAR) Model Program is to develop standardized risk analysis models and tools that staff analysts use in many 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 a new, improved loss of offsite power (LOOP)/station blackout module; an improved reactor coolant pump seal failure model; and updated estimates of accident initiator frequencies and equipment reliability based on more recent operating experience data.

The SPAR models consist of a standardized, plant-specific set of risk models that use the event-tree/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. The system fault trees contained in the SPAR models generally are not as detailed as those contained in licensee probabilistic risk assessments (PRAs). To date, the staff has completed 78 SPAR models representing all 104 commercial operating units and benchmarked them against licensee PRAs during the onsite quality assurance reviews of these models.

The staff initiated the risk assessment standardization project (RASP) in February 2004. The primary focus of RASP is to standardize risk analyses in SDP Phase 3, ASP, and Management Directive (MD) 8.3, "NRC Incident Investigation Program." Under this project, the staff initiated the following activities:

- Enhancing SPAR models to be more plant specific and enhancing the codes used to manipulate the SPAR models.

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

- Providing 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, MD 8.3 evaluations, and the Mitigating Systems Performance Index involve the use of SPAR models. New SPAR models are under development in response to staff needs for assessing plant risk during shutdown operations and external events 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-10-0125, "Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models," dated September 29, 2010) as described below.

Technical Adequacy of SPAR Models

The staff implemented an updated SPAR Model Quality Assurance Plan covering the SPAR models in 2006. The main objective of this plan is to ensure the SPAR models continue to 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. 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.

In addition, the staff (with the cooperation of industry experts) performed a peer review of a representative boiling-water reactor (BWR) SPAR model and pressurized-water reactor SPAR model in accordance with American National Standard, ASME RA-S-2002, "Standard for 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. This effort is planned to be completed in 2013.

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

Currently, 16 SPAR models have all-hazard scenarios (previously labeled as "external event" scenarios) as well as internal event scenarios. Based on a user need from the Office of Nuclear Reactor Regulations (NRR) to the Office of Nuclear Regulatory Research (RES), further work is in progress to add more models, and update the current ones. One significant ongoing activity is the incorporation of internal fire scenarios from the National Fire Protection Association 805, "NFPA-805 Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants," for one of the pilot applications into the SPAR models. Existence of SPAR models with fire and external hazard capabilities allows the U.S. Nuclear Regulatory Commission (NRC) risk analysts to estimate the overall risk from a range of initiating events, including (i) fire risk based on up-to-date NFPA-805 considerations, and (ii) extremely low frequency but high consequence scenarios, such as non-recoverable station blackout scenarios that could arise from seismic events and external floods.

SPAR Models for Analysis of Internal Initiating Events during Shutdown Operation

The staff places a priority on creating methods and guidance for the risk assessment of shutdown events, with emphasis on SDP Phase 3 analyses. For this purpose, seven SPAR models that contain selected shutdown event scenarios, as well as internal event scenarios, have been developed. These models are supported by a handbook for the analysts, a model maker's guideline for the construction of other models and scenarios, an event tree template library, and a human error probability library. Currently, there are no plans to make further SPAR shutdown models after quality assurance reviews for the eighth and final model are completed. Currently available models, together with the supporting documents can be used to support SDP Phase 3 evaluations of shutdown events and degraded conditions for other plants, by generating further models from the existing templates.

MELCOR Thermal Hydraulic Analysis for SPAR Model Success Criteria

The staff has performed MELCOR analyses, using input decks developed under the State-of-the-Art Reactor Consequence Analysis Project, 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.

To date, calculations have been performed for a number of sequences for the Peach Bottom and Surry plants. These results have been incorporated in the technical bases supporting the Surry and Peach Bottom SPAR models. The results have been extended to include an additional 19 BWR SPAR models and 8 pressurized-water reactor (PWR) SPAR models. RES is continuing to pursue opportunities for broadening the scope of this effort in terms of the types of sequences being investigated, as well as the applicability of the work to more plants. This includes the planned development of additional MELCOR input models; the investigation of Level-1 PRA end-state characterization (e.g., realism of core damage surrogates); and planned interactions with the Electric Power Research Institute (EPRI).

This effort directly supports the agency's goal of using state-of-the-art tools that promote effectiveness and realism. Project plans and results are being communicated to internal and external stakeholders via mechanisms such as the Regulatory Information Conference and the industry’s Modular Accident Analysis Program Users’ Group.

3.0 Additional SPAR Model Activities

SAPHIRE Version 8 Maintenance and Improvements

The staff continues to maintain and improve the SAPHIRE Version 8 software to support the SPAR Model Program. The SAPHIRE Version 8 software is periodically reviewed and tested for the purposes of making it more efficient, reliable, and maintainable. Many of the software error fixes and modifications are developed in response to user requests, and user feedback will continue to be addressed. All SAPHIRE Version 8 maintenance activities, modifications, and improvements are performed in accordance with the documented SAPHIRE software quality assurance practices.

In fiscal year (FY) 2011, new features and capabilities have been implemented in SAPHIRE Version 8 to better support NRC regulatory activities. SAPHIRE Version 8 has been modified to run on multicore (multiple processors internal to a single computer) computers. The effective use of multicore computers has decreased the overall analysis time needed to quantify SPAR model results. SAPHIRE Version 8 also has been modified to better support its use in SDP Phase 2 analyses and inspection planning activities. SAPHIRE Version 8 now includes user-friendly links to SPAR model documentation and new risk insights reports, which summarize a plants’ risk information for NRC resident inspectors. The staff has also provided training on SAPHIRE Version 8 to those resident inspectors that are participating in the piloting of a new process for significance determination process (SDP) Phase 2 analyses using SPAR models.

Companion documentation for the SAPHIRE Version 8 software has recently been completed and has been published as NUREG/CR-7039, Volumes 1 through 7, in FY 2011. The documentation includes an overview of SAPHIRE Version 8 features, a tutorial, a users’ guide, and a technical reference. The completion of the SAPHIRE Version 8 documentation provides a valuable resource for the software users.

On September 19, 2011, the Office of the Inspector General (OIG) issued audit report OIG-11-A-18, "Memorandum Report: Audit of NRC's SAPHIRE 8 System." Although the OIG concluded that SAPHIRE 8 meets its operational capabilities and there is limited security risk to the software, the OIG recommended several additional measures relating to software distribution policies and website access controls to ensure that the software was properly managed. The staff is currently evaluating corrective actions for the three recommendations identified by the OIG in the audit report.

Evaluation of Extensive Damage Mitigation Strategies and Guidance

This project is in support of Staff Requirements Memorandum COMGBJ-06-0004 "Potential Closure of the Issues Surrounding the February 25, 2002, Security Orders to Nuclear Power Plants", dated April 14, 2006. The objective of this project is to evaluate the change in risk of the 104 NRC-licensed commercial nuclear power plants (NPPs) based on the implementation of extensive damage mitigation strategies and guidance required by 10 CFR 50.54(hh) if those strategies and guidance are used by the licensee to mitigate reactor accidents typically modeled in the SPAR models. An evaluation of the 78 SPAR models was completed in October 2010. The results of this study, which are designated as Official Use Only – Security Related Information and have not been publically released, were forwarded to the Office of Nuclear Reactor Regulation to support an assessment of the effectiveness of the 10 CFR 50.54(hh) security enhancements implemented by licensees and the potential credit of these enhancements in the Significance Determination Process.

New Reactor SPAR Models

Prior to new plant operation, the staff may need to perform risk assessments to confirm PRA results provided in licensing submittals or to evaluate risk-informed applications. Once the plants begin operation, the results from licensee PRAs or independent assessments using SPAR models may be used by the NRC staff for the evaluation of operational findings and events similar to the assessments performed for current operating reactors.

During FY 2011, the staff developed two design-specific internal events SPAR models for the Advanced Boiling Water Reactor (ABWR)—one for the ABWR/Toshiba reactor design and one for the ABWR/GE design. As part of the SPAR model development, the requisite supporting documentation also was completed. The first draft of the ABWR/Toshiba model was provided to the Office of New Reactors (NRO) for review and comments are being resolved. The ABWR/GE SPAR model has been completed and will be transitioned to a routine maintenance status.

The staff also has initiated work on developing a design-specific internal events SPAR model for the U.S. Advanced Pressurized-Water Reactor (U.S. APWR). The SPAR model fault tree and event tree development for the U.S APWR is in progress.

Although the AP1000 model was completed in February 2010, a modification was made to the SPAR model to include an external events seismic model. This modification has been completed and will be submitted to NRO for review.

The staff plans to continue developing new reactor SPAR models including external events 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.

Cooperative Research for PRA

The staff has executed an addendum to the memorandum of understanding (MOU) with 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. The staff also continues to work with the National Aeronautical and Space Administration to address PRA issues of mutual interest. In addition, NRC has used the cooperative agreement and grant program to establish collaborative PRA research projects with the University of Maryland and the Massachusetts Institute of Technology. The objective of this effort is to work with the broader PRA community to facilitate resolution of PRA issues and to develop PRA methods, tools, data, and technical information useful to both NRC and industry.

Initial cooperative efforts under the EPRI MOU have focused on the following:

- Support system initiating event analysis.
- Treatment of LOOP in PRAs.
- Treatment of uncertainty in risk analyses.
- Standard approach for injection following BWR containment failure.
- Standard approach for containment sump recirculation during small and very small loss-of-coolant accidents.
- Human reliability analysis.
- Digital instrumentation and control risk methods.
- Advanced PRA methods.
- Advanced reactor PRA methods.

Significant efforts have been made in the past year in the areas of support system initiating event analysis, treatment of LOOP in PRAs, and treatment of uncertainty in risk analysis. For example, in the area of support system initiating event analysis, the staff and industry have come to agreement on a common approach to modeling support system initiators and worked together to resolve common cause issues that significantly affect model quantification results. The staff plans to use the support system initiating event methodology and the improved treatment of LOOP events to further enhance the realism and accuracy of the SPAR models. These methodologies are planned to be implemented in the SPAR models as one of the activities associated with addressing the peer review comments. The staff plans to continue these cooperative efforts with EPRI and other stakeholders to address the remaining issues over the next several years.