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}.

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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 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.

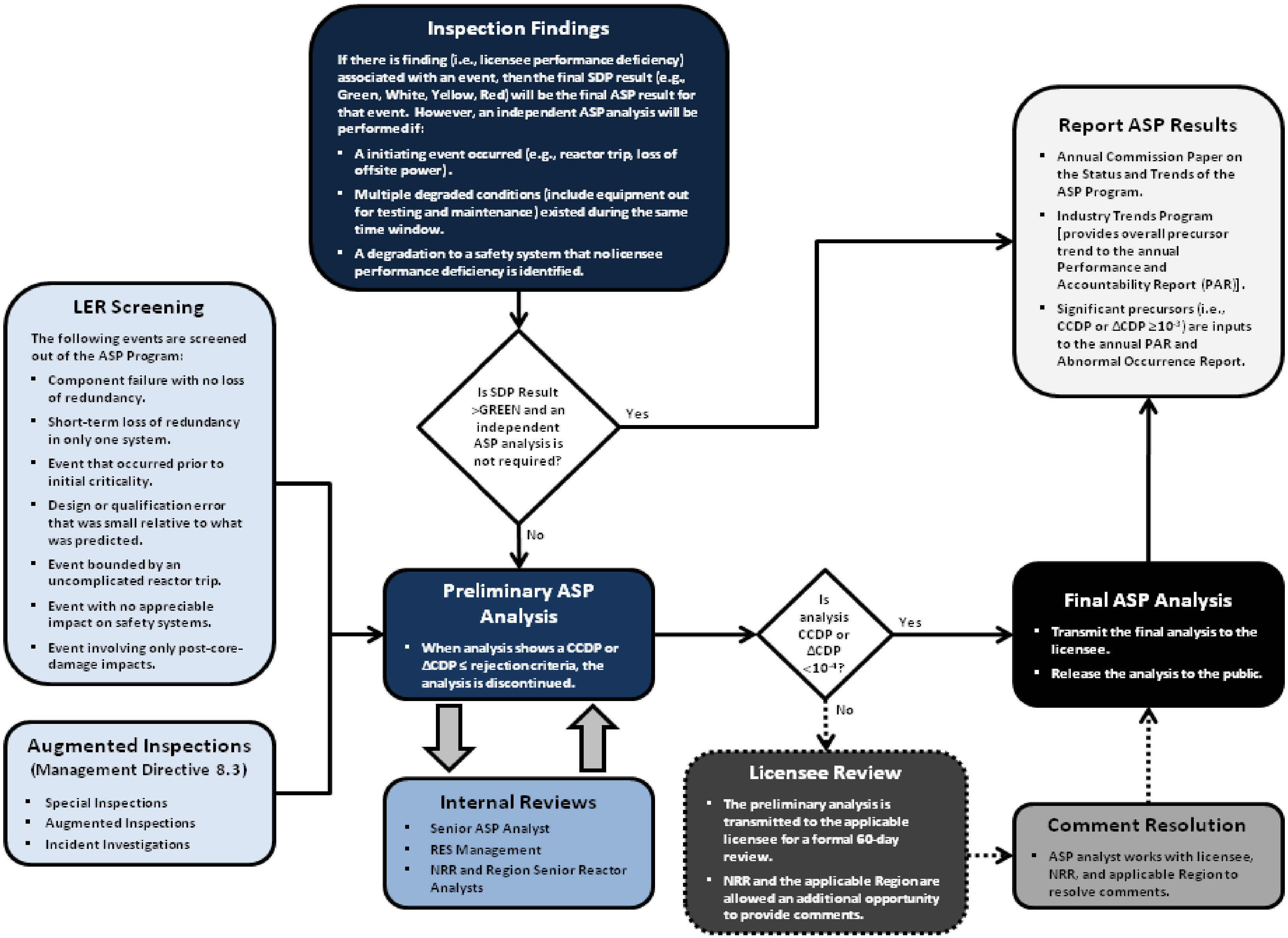

Figure 1. ASP Process Diagram.

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).

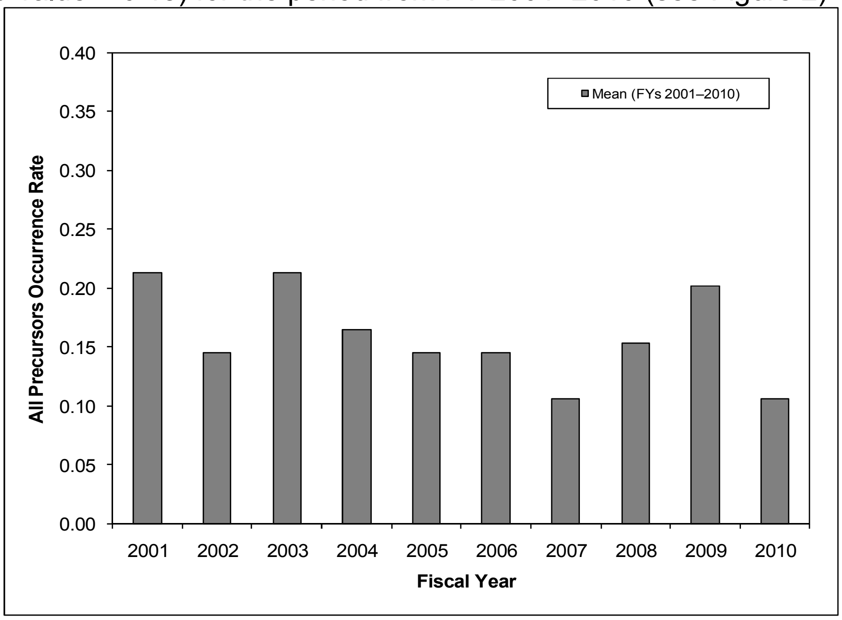

Figure 2. Total Precursors.

- 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).

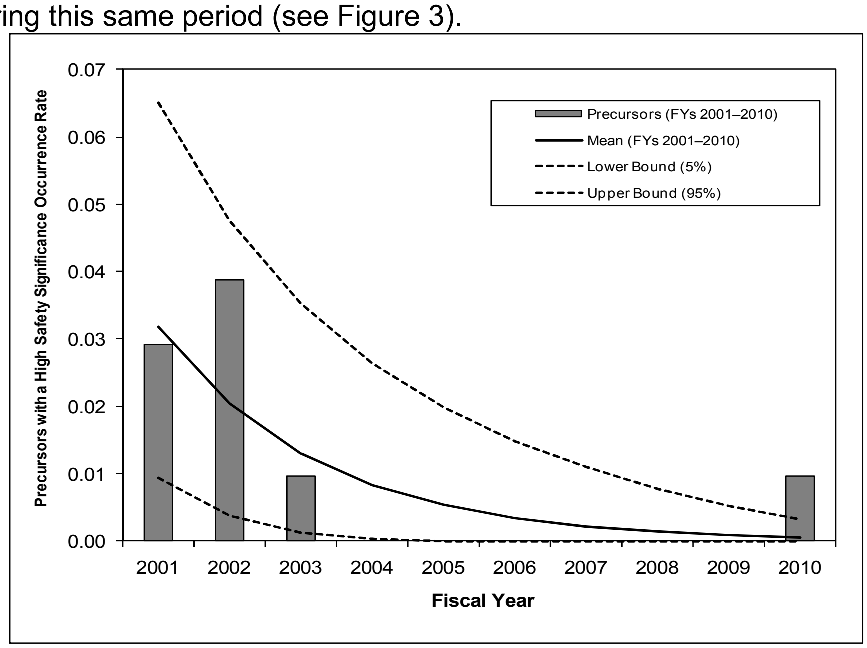

Figure 3. Precursors with High Safety Significance.

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.

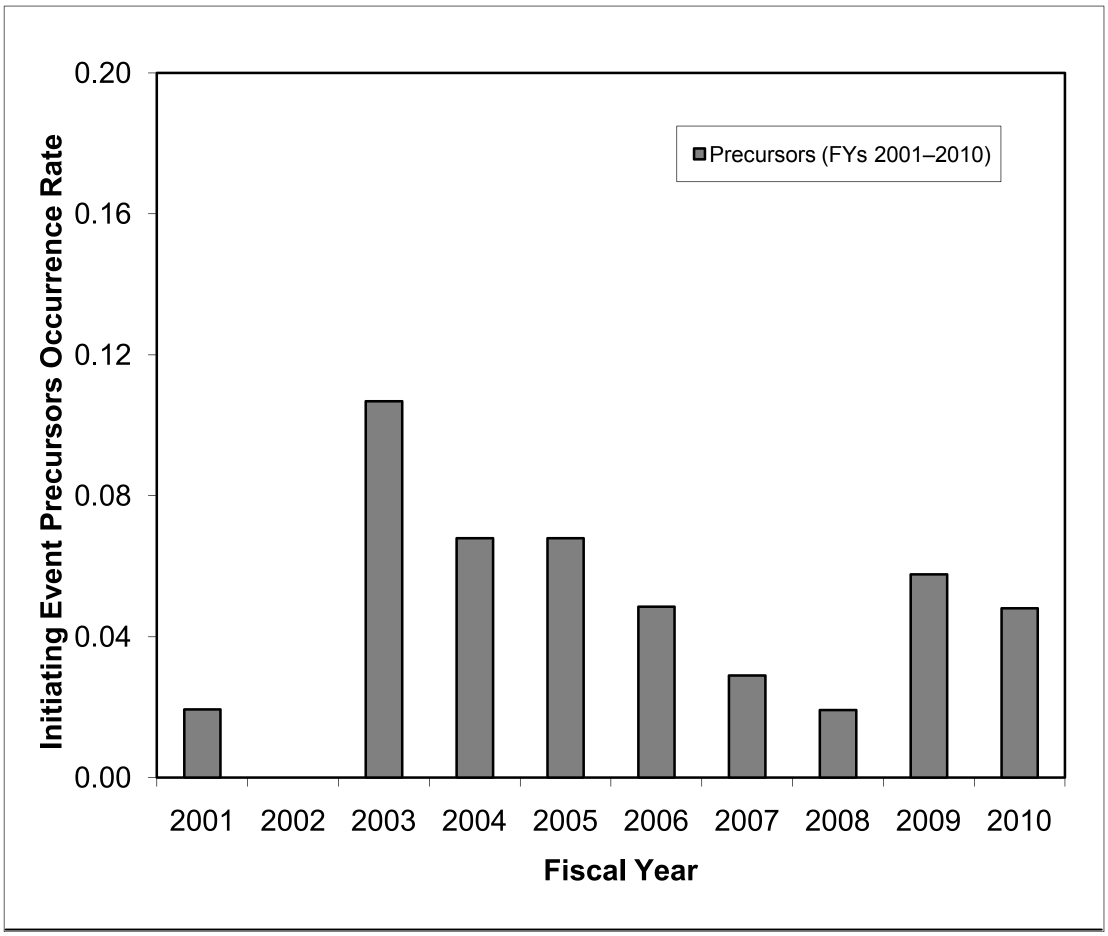

Figure 4. Precursors Involving Initiating Events.

- 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.

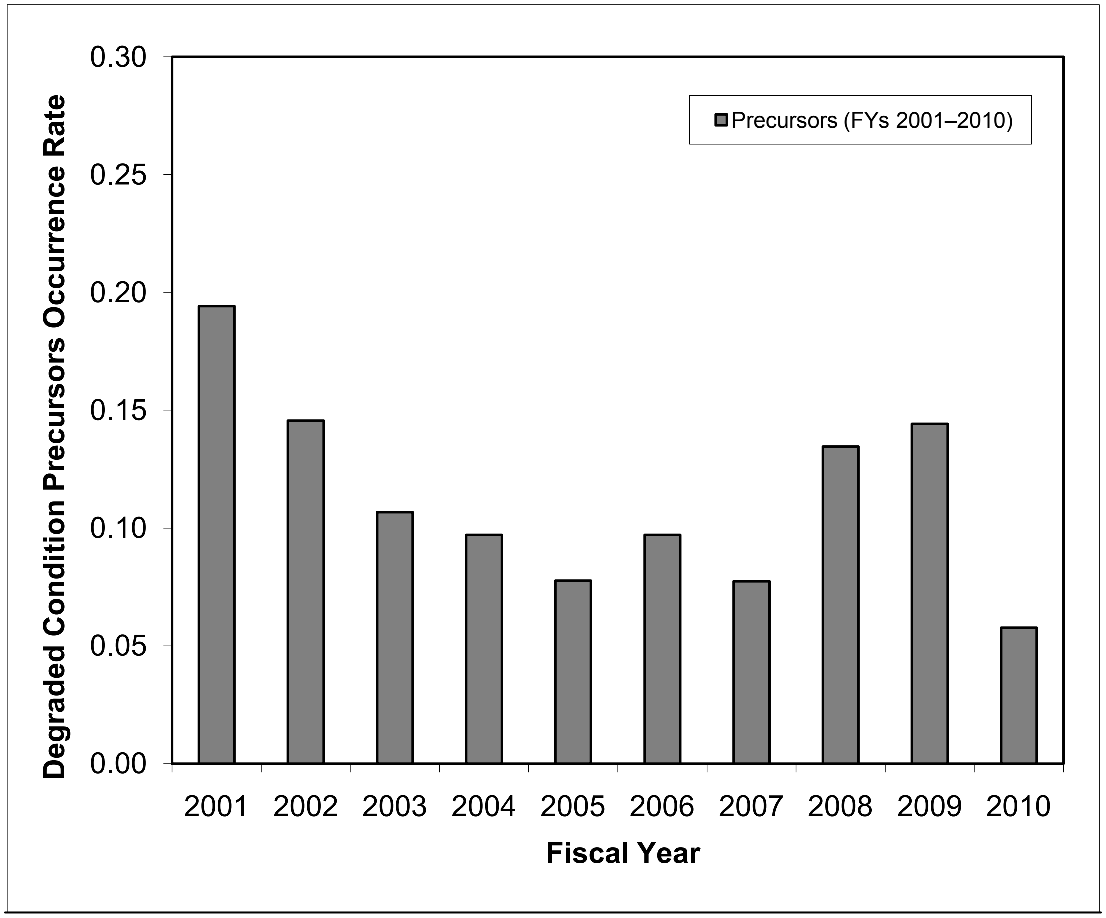

Figure 5. Precursors Involving Degraded Conditions.

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.

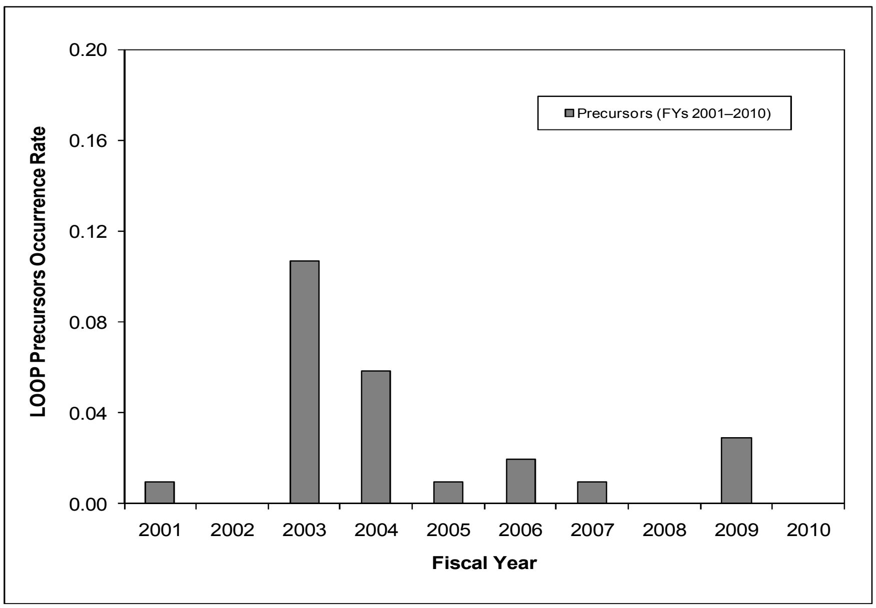

Figure 6. Precursors Involving LOOP Events.

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]

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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).

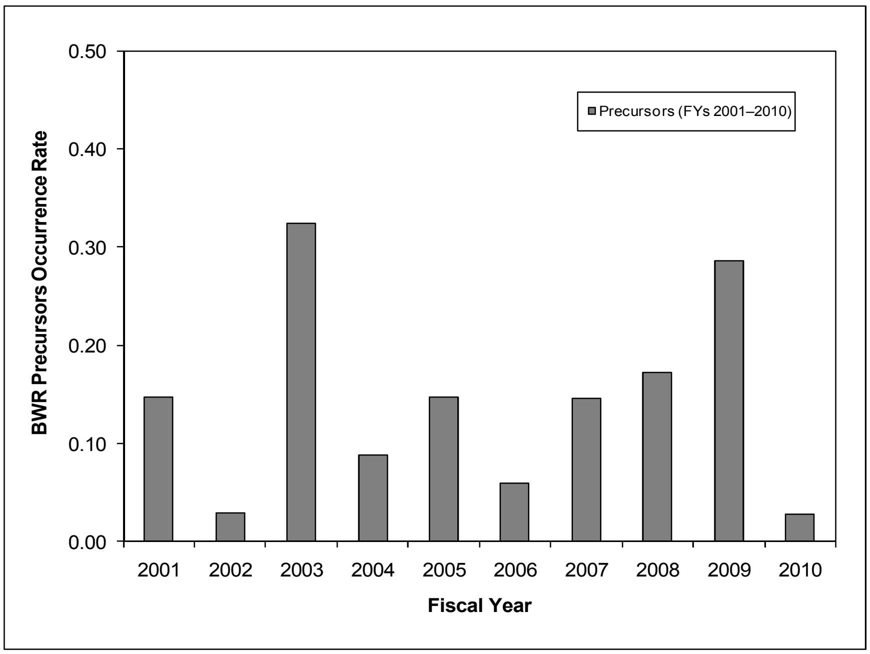

Figure 7. Precursors Involving BWRs.

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.

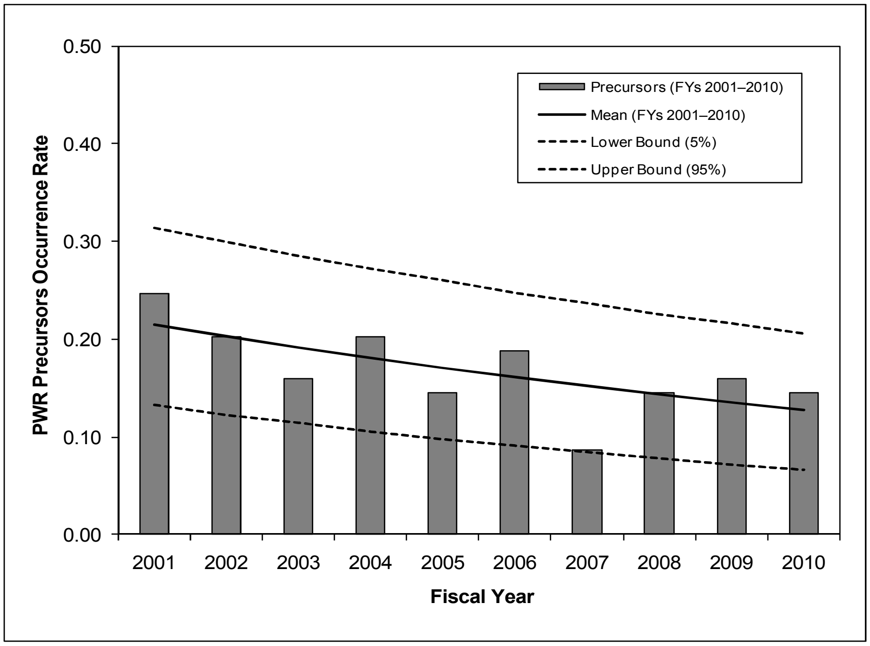

Figure 8. Precursors Involving PWRs.

- 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:

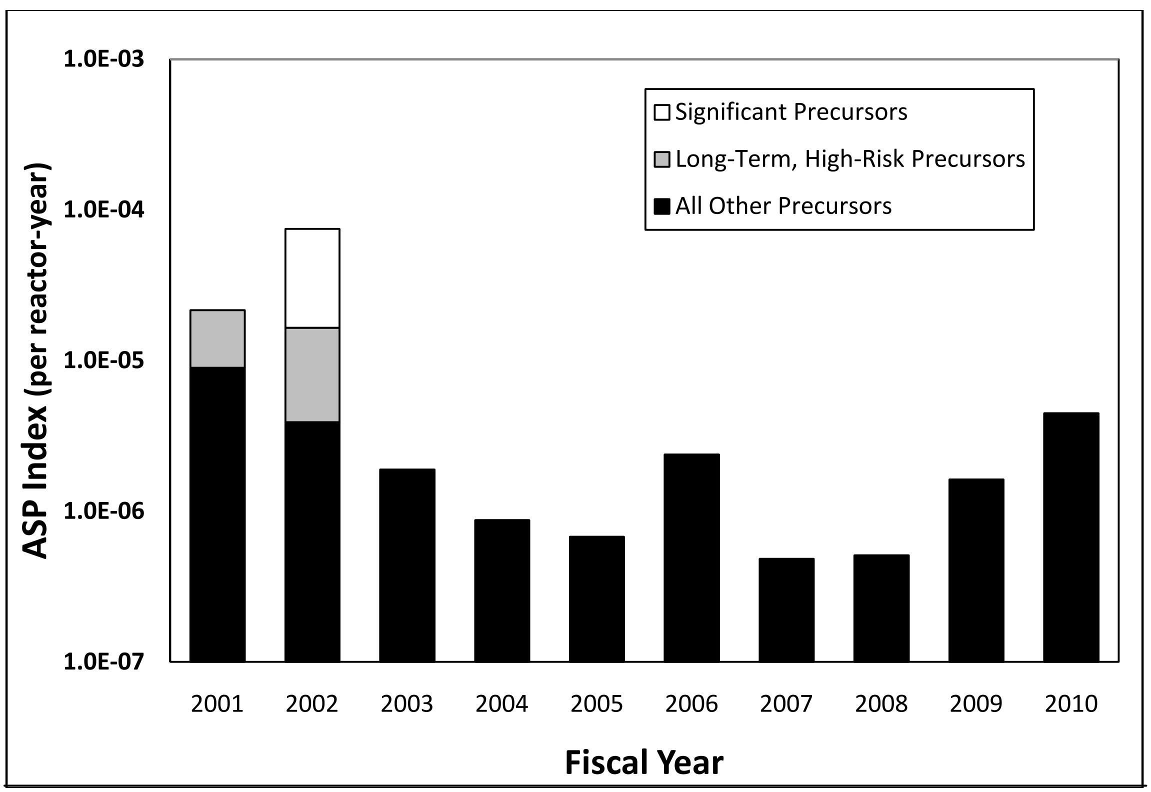

Figure 9. Integrated ASP Index.

- 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

1. NUREG-1100, Vol. 27, "Performance Budget: Fiscal Year 2012," U.S. Nuclear Regulatory Commission, Washington, D.C., February 2011.

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

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.

5. NRC Inspection Report 05000261/2010004 and 05000261/2010501, "H.B. Robinson Steam Electric Plant– Integrated Inspection Report and Assessment Follow-Up Letter," U.S. Nuclear Regulatory Commission, Washington, D.C., November 12, 2010.

6. NRC Inspection Report 05000261/2010013, "H. B. Robinson Steam Electric Plant– Preliminary White Findings," U.S. Nuclear Regulatory Commission, Washington, D.C., December 27, 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.

9. ASME/ANS RA-S-2008, "Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications," Revision 1 RA-S-2002, ASME, New York, NY, April 2008.