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

1.0 Introduction

This enclosure discusses the results of accident sequence precursor (ASP) analyses conducted by the U.S. Nuclear Regulatory Commission (NRC) staff as they relate to events that occurred during fiscal years (FYs) 2014 and 2015. Based on those results, this document also discusses the staff's analysis of historical ASP trends and the evaluation of the related insights.

2.0 Background

The NRC established the ASP Program in 1979 in response to recommendations made in NUREG/CR-0400, "Risk Assessment Review Group Report," issued September 1978 (Ref. 1).[1] The ASP Program systematically evaluates U.S. nuclear power plant (NPP) operating experience to identify, document, and rank the operational events that have a conditional core damage probability (CCDP) or an increase in core damage probability (ΔCDP) greater than or equal to 1×10^{-6}. That is, for any given operational event analyzed, the likelihood of inadequate core cooling and severe core damage was greater than or equal to one in one million.

Program Process. To identify potential precursors, the staff reviews operational events, including the impact of external events (e.g., fires, floods, and seismic events), from licensee event reports (LERs) and inspection reports (IRs) on a plant 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. The analyses of operational events are conducted using the NRC's Standardized Plant Analysis Risk (SPAR) models and the Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) software. The SPAR models are a plant-specific set of risk models that rely on a set of standardized modeling conventions (e.g., naming scheme, modeling approaches, and logic structure). Figure 1 illustrates the complete ASP analysis process.

Program Metrics. An operational event can be one of two types: (1) an occurrence of an initiating event, such as a reactor trip or a loss of offsite power (LOOP), with or without any subsequent equipment unavailability or degradation, or (2) a degraded plant condition characterized by the unavailability or degradation of equipment without the occurrence of an initiating event.

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

[1] The NRC formed the Risk Assessment Review Group (commonly referred to as the Lewis Committee) in 1977 to perform an independent evaluation of the Reactor Safety Study (WASH-1400) that was completed 3 years earlier. That committee made a number of recommendations in 1978, including that more use be made of operational data to assess the risk from nuclear power plants. The review group's report stated, "It is important, in our view, that potentially significant (accident) sequences, and precursors, as they occur, be subjected to the kind of analysis contained in WASH-1400." The first major report of the ASP program, "Precursors to Potential Severe Core Damage Accidents: 1969–1979, A Status Report" (NUREG/CR-2497, Volume 1), was formally released in June 1982.

staff calculates a ΔCDP. This metric represents the increase in core damage probability for the

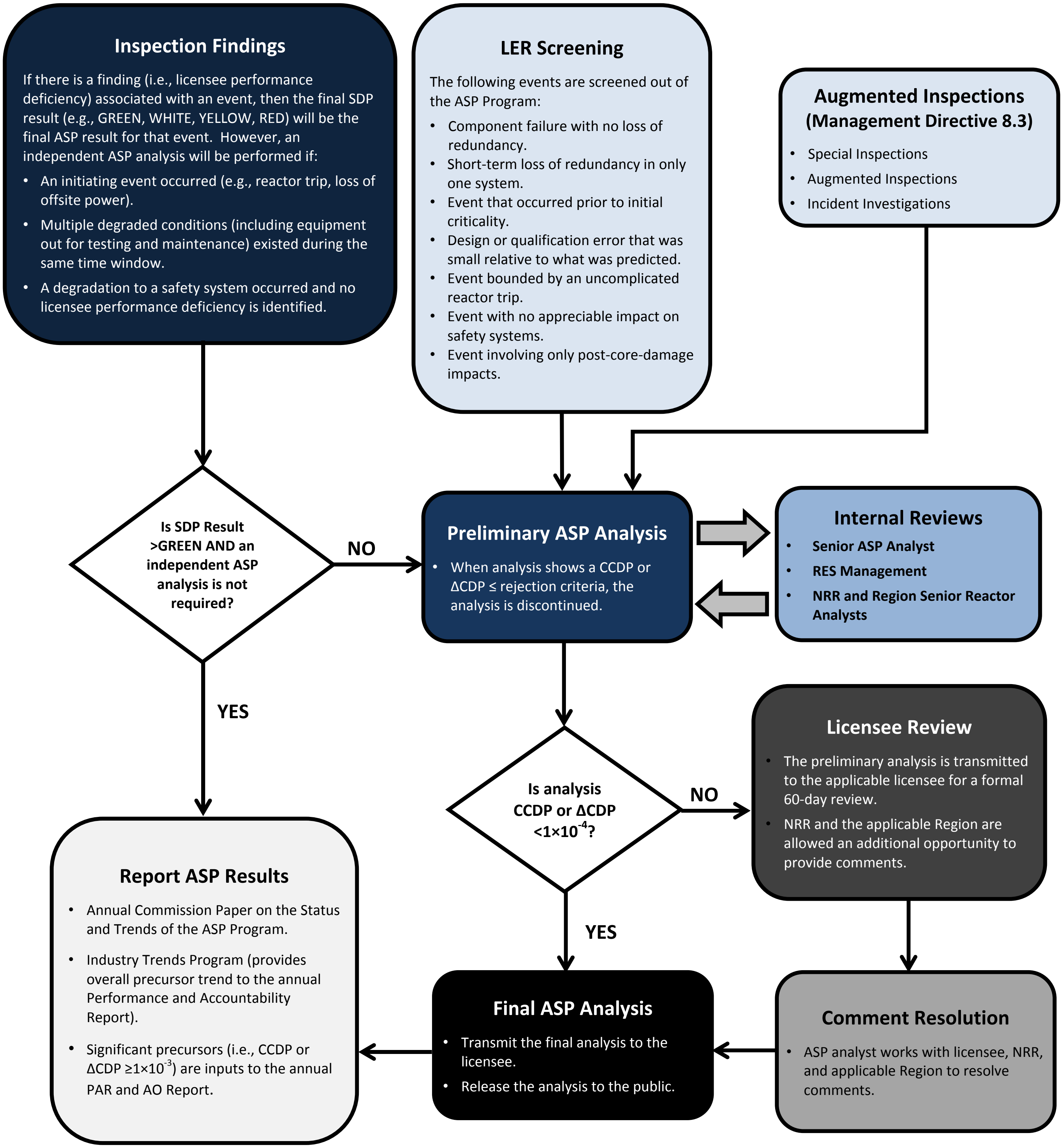

Figure 1. ASP Process Flowchart.

time period during which a component or multiple components were deemed unavailable or degraded.

Program Thresholds. The ASP Program defines an event with a CCDP or a ΔCDP greater than or equal to 1×10^{-6} to be a precursor. The ASP Program uses the plant-specific CCDP for the nonrecoverable loss of feedwater and condenser heat sink, with no degradation of safety-related equipment, as the initiating-event precursor threshold if it is greater than 1×10^{-6}. This ensures the more safety-significant events are analyzed. Since 1988, this initiating-event precursor threshold has screened out uncomplicated trips (reactor trips with no losses of safety-system equipment) from being precursors because of their relatively low risk significance. The ASP Program defines a *significant* precursor as an event with a CCDP or ΔCDP greater than or equal to 1×10^{-3}.

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 adequacy of current probabilistic risk assessment (PRA) standards and guidance.
- Provide feedback to regulatory activities.

The NRC also uses the ASP Program results to monitor performance against performance indicators in the agency's Congressional Budget Justification (Ref. 2) and Industry Trends Program (ITP) (Ref. 3), as well as in reports to Congress on events of high safety significance in accordance with "abnormal occurrence" criteria (Ref. 4). Specially, the ASP Program provides the following inputs to programs and reports:

- Number of *significant* precursor events for the annual Congressional Budget Justification. ASP Program results are used as one of several inputs to the performance indicator "Number of malfunctions, deficiencies, events, or conditions at commercial nuclear power plants (operating or under construction) that meet or exceed abnormal occurrence (AO) criteria II.A though II.D."
- Trend of all precursor events for the ITP.
- Number of precursor events with a CCDP or ΔCDP greater than or equal to 1×10^{-5} for the ITP. ASP program results are used, along with other inputs from other programs, in the ITP to evaluate the trend of the "significant events" industry-level indicator.
- Description of *significant* precursor events for the annual abnormal occurrence report to Congress in accordance with Criterion II.C of NUREG-0090, "Report to Congress on Abnormal Occurrences Fiscal Year 2014," Volume 37 (Ref. 4).

Program Scope. The ASP Program is one of three agency programs that assess the risk significance of events at operating NPPs. The other two programs are the Significance Determination Process (SDP) (Ref. 5) and the event-response evaluation process, as defined in Management Directive (MD) 8.3, "NRC Incident Investigation Program" (Ref. 6). The SDP evaluates the risk significance of a single licensee performance deficiency, while the risk assessments performed under MD 8.3 are used to determine, in part, the appropriate level of reactive inspection in response to an event. An SDP assessment has the benefit of information obtained from the inspection, whereas the MD 8.3 assessment is expected to be performed

within a day or two after the event notification.
In contrast to the other two programs, a comprehensive and integrated risk analysis under the ASP Program includes all anomalies observed at the time of the event or discovered after the event. These anomalies may include unavailable and degraded plant structures, systems, and components (SSCs); human errors; and an initiating event (reactor trip). In addition, an unavailable or degraded SSC does not have to be a performance deficiency (e.g., SSCs out for test and maintenance) or an analyzed condition in the plant design basis. The ASP Program has time to complete an analysis of a complex issue and thus produces a more refined estimate of risk. Analyses schedules provide time so that NRC or licensee engineering evaluations can be made available for review. State-of-the-art methods can be developed or current techniques can be refined for unique conditions when necessary. In addition, the SPAR model can be modified for special considerations (e.g., seismic, internal fires, flooding).

There are similarities in the risk assessments conducted by the three programs. All programs use SPAR models, the same documented methods and guidance, and similar analysis assumptions, except where program objectives deviate from one another. ASP and SDP analyses assumptions are typically the same for single performance deficiencies. To minimize overlap and improve efficiency, since 2006, SDP results have been used in lieu of independent ASP analyses to the extent practical and consistent with the overall objectives of both programs. Typically the SDP analyses are used in the ASP Program when the analysis performed addresses the major contributors to risk for the event based on a review conducted by an ASP Program risk analyst. Typically for initiating events, many of the modeling assumptions made for MD 8.3 analyses can be adopted by ASP analyses. However, some modeling assumptions are revised as detailed information about the event becomes available when inspection activities are completed. In addition, there are program differences on how certain modeling aspects are incorporated (e.g., SSCs out for testing or maintenance). These key similarities provide opportunities for significant ASP Program efficiencies. For a potential *significant* precursor, analysts from the three programs work together to provide a timely determination of plant risk. As such, duplication between programs is minimized to the extent practical within the program objectives.

In addition, the ASP Program provides integrated analyses of complex operating events that are not evaluated by the SDP or finalized by MD 8.3 evaluations. Two notable examples include the degraded reactor vessel head with multiple degraded conditions at Davis-Besse in FY 2003 (LERs 346/02-002, 346/02-005, and 346/03-002) and the complicated LOOP event at Byron Unit 2 in FY 2012 (LER 454/12-001).

The Davis-Besse precursor event involved (1) a potential loss-of-coolant accident (LOCA) due to reactor pressure vessel head erosion from the leakage of a circumferential cracked control rod drive mechanism nozzle, (2) the potential unavailability of sump recirculation due to screen plugging following a postulated LOCA from unqualified containment coatings and other debris (e.g., insulation) inside containment, and (3) the potential unavailability of high-pressure safety injection pumps during the recirculation phase of a postulated LOCA due to potential debris generated by certain postulated LOCAs and entrained in pumped fluid. The SDP cited three licensee performance deficiencies. Analyzed separately, the equivalent ΔCDP for the three deficiencies were 4×10^{-4}, 3×10^{-5}, and 3×10^{-6}, respectively. The ASP Program analysis integrated these deficiencies and aggregated the risk which resulted in a ΔCDP of 6×10^{-3} identifying this as a significant precursor that was reportable to Congress. The ASP analysis result confirmed the risk significance of this event following a systematic and repeatable process that, in part, undergirded the substantial regulatory response that was undertaken. The regulatory response included issuance of Order EA-03-009 requiring all licensees with plants susceptible to reactor pressure vessel head degradation to perform visual inspections for indications of degradation or boric acid leakage, working with the American Society of Mechanical Engineers (ASME) to incorporate reactor pressure vessel head inspections into the ASME code, adopting a new operating experience program, and enhancing the NRC's ability to detect declining plant performance by changing several NRC inspection and management programs.

The Byron Unit 2 precursor event resulted from a LOOP and unprotected under-voltage conditions on safety-related electrical buses for eight minutes. The loss of one of three phases (Phase "C") of 345 kilovolts offsite power to the two unit station auxiliary transformers (SATs) did not result in an automatic under-voltage protection signal, because the under-voltage protection scheme did not provide adequate protection from a single loss of Phases "A" and "C". As a result, all running safety equipment powered by the safety buses had tripped on over-current conditions. These conditions existed until operators manually opened (from the main control room) the SAT feeder breakers about eight minutes after the event had initiated. Following the opening of the SAT feeder breakers, both emergency diesel generators started and loaded supplying power to the safety buses, as designed. The MD 8.3 risk assessment of the event that was performed on the day of the event occurrence resulted in a CCDP of 7×10^{-6}. The assessment did not include the aspects of the under-voltage condition of the safety buses that was identified as the result of a special inspection. The inspection identified no performance deficiencies; therefore, no SDP assessment was required. The ASP analysis of this complicated LOOP event resulted in an aggregated plant risk CCDP of 1×10^{-4}. This realization contributed to the basis for the ongoing staff efforts on the system study of electrical system and component failures to risk. In addition, the NRC staff issued Bulletin 2012-01, "Design Vulnerability in Electric Power System," and Information Notice (IN) 2012-03, "Design Vulnerability in Electric Power System" highlighting the potential significance of a single-phase open circuit condition.

3.0 ASP Program Status

The following subsections summarize the status and results of the ASP Program (as of September 30, 2015).

FY 2014 Analyses. The staff completed its screening and review of 501 LERs and their associated inspection findings for FY 2014. On the basis of that review, 36 events were selected and analyzed for potential precursors. Of these, the ASP analyses have identified 6 precursors (initiating events) and the SDP identified 10 precursors (degraded conditions). For 10 of the 16 precursors, the performance deficiency identified under the Reactor Oversight Process documented the risk-significant aspects of the event completely. In these cases, the SDP significance category (i.e., the "color" of the finding) is reported in the ASP Program. For the remaining events, an independent ASP analysis was performed to determine the risk significance of three LOOP initiating events, two electrical transformer failures, and a 13 kilovolts bus failure.

Table 1 presents the results of the staff's ASP analyses for FY 2014 precursors that involved initiating events. Table 2 presents the analysis results for FY 2014 precursors that involved degraded conditions.

FY 2015 Analyses. The staff performs an initial review of all events to determine if they have the potential to be *significant* precursors. Specifically, the staff reviews LERs (reported by licensees in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) 50.73, "Licensee Event Report System") and daily event-notification reports (reported by licensees in accordance with 10 CFR 50.72, "Immediate Notification Requirements for Operating Nuclear Power Reactors") to identify potential *significant* precursors. The staff has completed the initial review of FY 2015 events and identified no potentially *significant* precursors (as of September 30, 2015). The staff will inform the Commission if a *significant* precursor is identified during the more detailed evaluations of events.

Table 1. FY 2014 Precursors Involving Initiating Events

Event Date	Plant	Description	CCDP
10/14/13	Pilgrim	LOOP and Reactor Scram. ***LER 293/13-009***	3×10^{-5}
12/9/13	Arkansas Nuclear One, Unit 2	Fire and Explosion of the Unit Auxiliary Transformer. ***LER 368/13-004***	2×10^{-6}
1/18/14	Shearon Harris	Manual Reactor Trip due to Indications of a Fire. ***LER 400/14-001***	6×10^{-6}
1/21/14	Calvert Cliffs 2	Reactor Trip due to Inadequate Protection Against Weather-Related Water Intrusion. ***LER 318/14-001***	5×10^{-6}
5/25/14	Millstone 2	Dual Unit LOOP and Reactor Scram. ***LER 336/14-006***	1×10^{-5}
5/25/14	Millstone 3	Dual Unit LOOP and Reactor Scram. ***LER 336/14-006***	2×10^{-5}

Table 2. FY 2014 Precursors Involving Degraded Conditions

Condition Duration	Plant	Description	ΔCDP/ SDP Color
39 years[5]	Fort Calhoun	Harsh Environment Due to Postulated High-Energy Line Breaks Could Lead to the Failure of Equipment Needed to Safely Shutdown the Plant. ***Enforcement Action (EA)-14-187***	WHITE[2]
31 years[5,6]	Ginna	Unanalyzed Condition for Potential Floodwater Intrusion into Vital Battery Rooms. ***EA-13-247***	WHITE
10 years[5]	Oconee 1	High Cycle Fatigue Resulted in Reactor Coolant Leak and Unit Shutdown. ***EA-14-091***	WHITE
36 years[5,6]	St. Lucie 1	Internal Reactor Auxiliary Building Flooding During Heavy Rain Due to Degraded Conduits Lacking Internal Flood Barriers. ***EA-14-131***	WHITE
40 years[5,6]	Arkansas Nuclear One, Unit 1	Inadequate External Flood Protection for Safety-Related Equipment Located Below the Design Basis Flood Elevation. ***EA-14-088***	YELLOW[3]
40 years[4,5]	Arkansas Nuclear One, Unit 2	Inadequate External Flood Protection for Safety-Related Equipment Located Below the Design Basis Flood Elevation. ***EA-14-088***	YELLOW

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

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

Condition Duration	Plant	Description	ΔCDP/ SDP Color
1 year	Millstone 3	Turbine Driven Auxiliary Feedwater Pump Operability Impacted by Incorrect Bearing. ***EA-14-092***	WHITE
23 years[5]	Oyster Creek	Technical Specification Prohibited Condition Caused by Two Electromagnetic Relief Valves Inoperable for Greater Than Allowed Outage Time. ***EA-14-178***	YELLOW
9 years[5]	Oyster Creek	Technical Specification Prohibited Condition Caused by Emergency Diesel Generator Inoperable for Greater than Allowed Outage Time. ***EA-14-186***	WHITE
109 days	Clinton	Failure of a Shutdown Cooling Water Pump Due to Damaged Bushing. ***EA-15-064***	WHITE

4.0 Trends and Insights

This section defines a statistically significant trend, defines the data period used in trending analyses, and discusses the results of trending analyses and insights 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.[6] A p-value less than or equal to 0.05 indicates that there is 95 percent confidence that a trend exists in the data (i.e., leading to a rejection of the null hypothesis that there is no trend).

Data Coverage. The data period for the ASP trending analyses is a rolling 10-year period, which is aligned with the rolling 10-year period used in the ITP.

4.1 Occurrence Rate of All Precursors

The NRC's ITP evaluates trends in licensee safety performance using industry-level indicators. The mean occurrence rate of all precursors identified by the ASP Program is one indicator used by the ITP to assess industry performance.[7]

Results. The mean occurrence rate of all precursors does not exhibit a statistically significant trend (p-value = 0.59) for the 10-year period from FY 2005 through FY 2014 (see Figure 2).

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

5 These four events were identified from the efforts undertaken by licensees and NRC inspectors as part of the Fukushima Near-Term Task Force Recommendation 2.3 walkdown inspections (Ref. 7).

6 For the purposes of this analysis, the null hypothesis is based on a constant-rate Poisson process producing the observed data set. A lower p-value indicates a lower likelihood that the observed data could be produced by this constant-rate process.

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

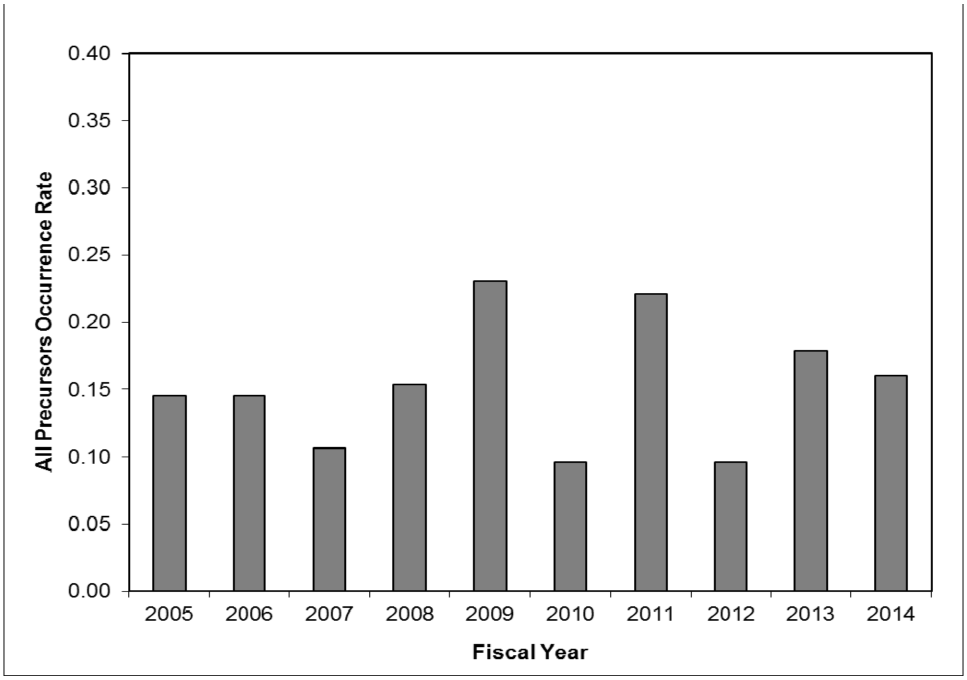

Figure 2. Occurrence Rate of All Precursors.

4.2 *Significant* Precursors

The NRC's Congressional Budget Justification (NUREG-1100, Volume 31) provides performance indicators used to measure and evaluate performance as part of the NRC's planning, budget, and performance management process. The number of *significant* precursors identified by the ASP program is one of several inputs to a performance indicator used to monitor the agency's strategic safety goal (Ref. 2).

Results. A review of the data for the 10-year period from FY 2005 through FY 2014 reveals the following insights:

- No *significant* precursors have been identified during FY 2005 through FY 2014. The staff has completed the initial review of FY 2015 events and identified no potentially *significant* precursors (as of September 30, 2015).
- The last *significant* precursor was identified in FY 2002 and involved concurrent, multiple degraded conditions at the Davis-Besse nuclear power plant.[8]

4.3 Occurrence Rate of Precursors with a CCDP or ΔCDP $\geq 1\times10^{-4}$

Precursors with a CCDP or ΔCDP $\geq 1\times10^{-4}$ are considered important in the ASP Program because they generally have a CCDP higher than the annual CDP estimated by most plant-specific PRAs.
Results. A review of the data for the 10-year period from FY 2005 through FY 2014 reveals the

[8] Commission Paper SECY-10-0125, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models" (Ref. 8), provides a complete list of all *significant* precursors from 1969 through 2010.

following trend and insights:

- The staff did not identify any precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4} for FY 2013 or FY 2014.
- 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 trend (p-value = 0.11; see Figure 3).

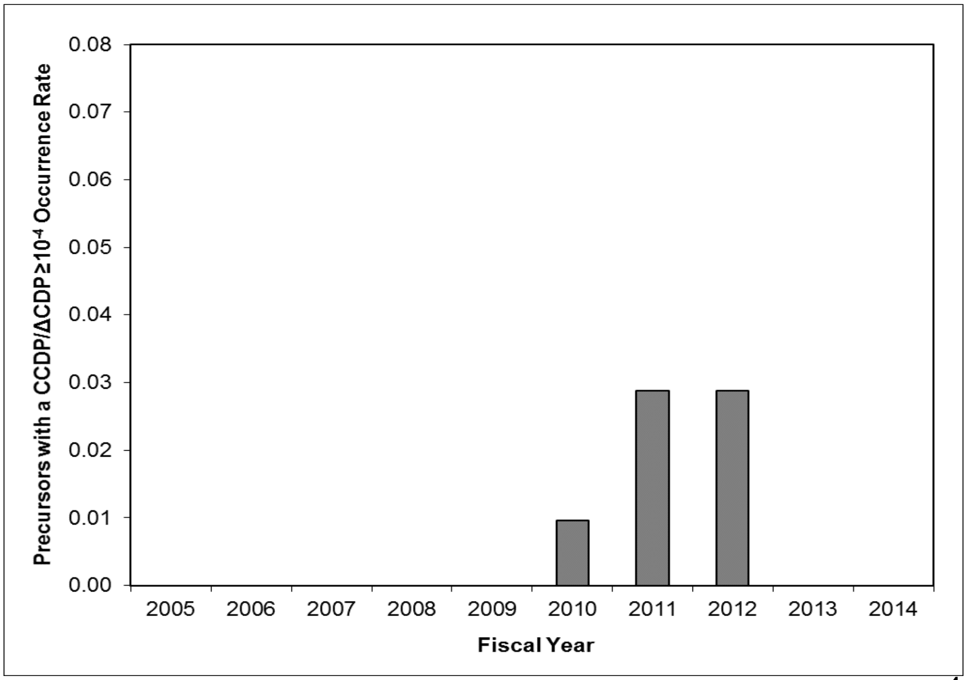

Figure 3. Occurrence Rate of Precursors with a CCDP/ΔCDP ≥ 1×10^{-4}.

- For FY 2012 and FY 2013, statistically significant increasing trends were observed in each respective 10-year period (FY 2003 through FY 2012 and FY 2004 though FY 2013, respectively). However, with no additional precursors observed in FY 2013 and FY 2014, the trend is no longer statistically significant.
- Over the past 10-year period (FY 2005 through FY 2014), a total of 7 precursors with CCDP or ΔCDP greater than or equal to 1×10^{-4} were identified: in FY 2010 (1 precursor), FY 2011 (3 precursors), and FY 2012 (3 precursors). As reported to the Commission last year, 6 of the 7 precursors involved electrical events in electrical distribution systems. See Enclosure 1 to SECY-14-0107, “Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models,” for a listing of these precursor events and a summary of insights (Ref. 9).

4.4 Precursors Involving Initiating Events and Degraded Conditions

A review of the data for the 10-year period from FY 2005 through FY 2014 reveals the following insights for precursors involving initiating events and degraded conditions.

Initiating Events

- The mean occurrence rate of precursors involving initiating events does not exhibit a statistically significant trend (p-value = 0.26) (see Figure 4).

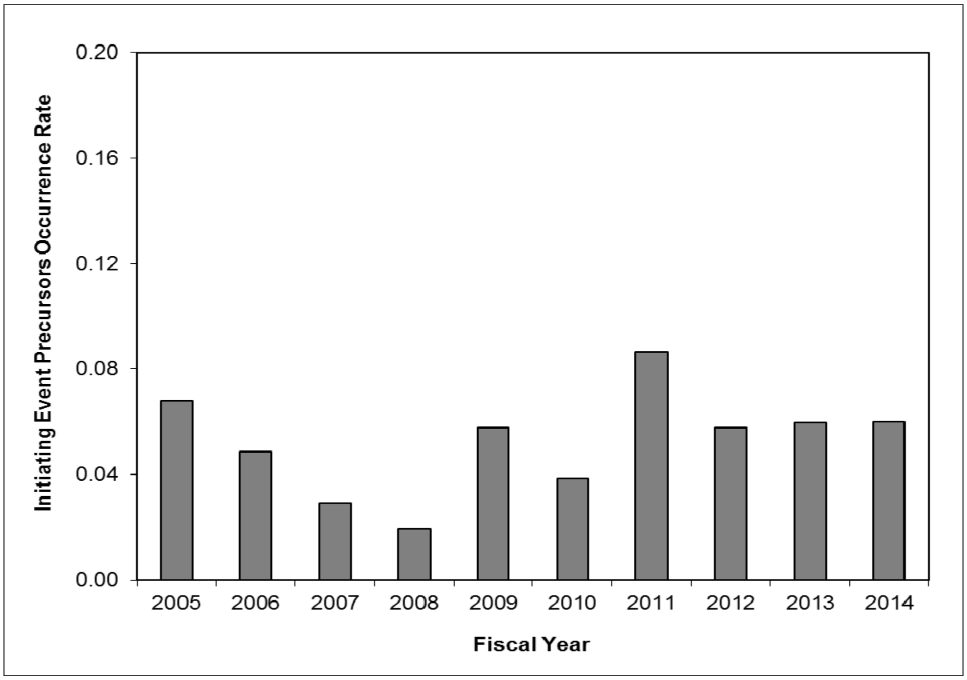

Figure 4. Occurrence Rate of Precursors Involving an Initiating Event.

- Of the 54 precursors involving initiating events, 27 precursors (50 percent) were LOOP events. While the frequency of complicated trips[9] (27 precursors) is about the same as the frequency of LOOPs (27 precursors), the CDP estimates for LOOPs are somewhat higher.

Degraded Conditions

- The mean occurrence rate of precursors involving degraded conditions does not exhibit a statistically significant trend (p-value = 0.94) (see Figure 5).
- Over the past 10 years, precursors involving degraded conditions (104 precursors) outnumbered initiating events (54 precursors) by 93 percent.
- Of the 104 precursors involving degraded conditions, 35 precursors (34 percent) involved degraded conditions existing for a decade or longer.[10] Of these 35 precursors, 15 precursors involved degraded conditions dating back to initial plant construction.

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9 A complicated trip is a reactor trip with a concurrent loss of safety-system equipment.

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

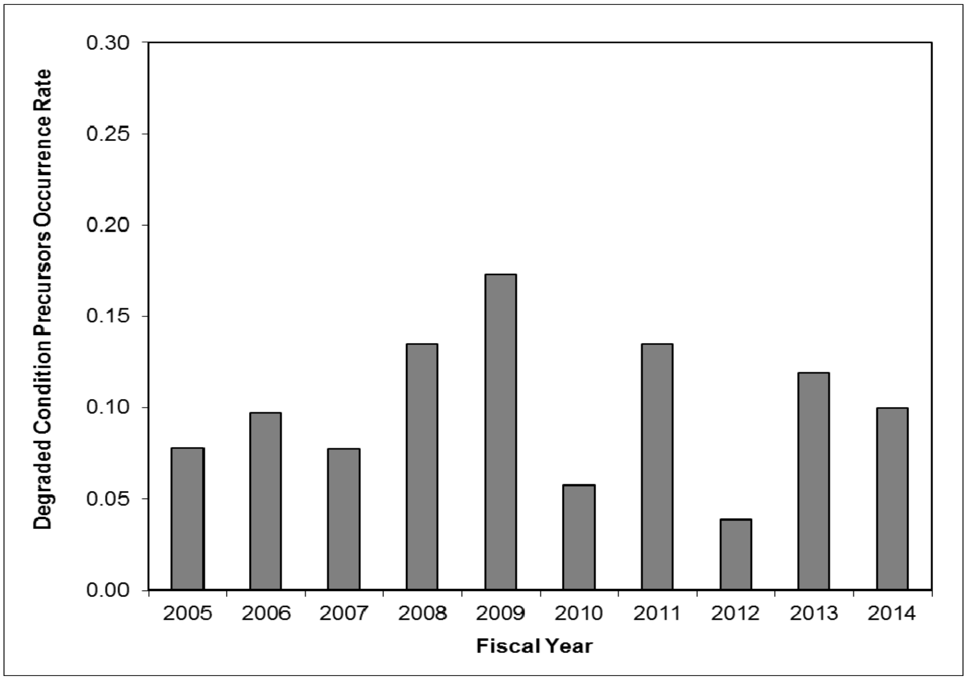

Figure 5. Occurrence Rate of Precursors Involving Degraded Conditions.

4.5 Precursors Involving a Complete Loss of Offsite Power Initiating Event

In FY 2014, 3 precursors from 2 NPP sites resulted from a complete LOOP initiating event.[11] In FY 2015, 3 complete LOOP initiating events occurred at 2 NPP sites.[12] Typically, all complete LOOP initiating events meet the precursor threshold.

Results. A review of the data for the 10-year period from FY 2005 through FY 2014 reveals the following insights:

- *Trend*. The mean occurrence rate of precursors involving LOOP precursor events exhibited a statistically significant increasing trend (p-value = 0.01; see Figure 6). The increasing trend of LOOP precursor events became significant in FY 2014 when 6 LOOP precursor events dropped out of the rolling 10-year trend period and 3 LOOP precursor events occurred in FY 2014.
- *Precursor Counts.* Of the 158 precursors that occurred during the FY 2005 through FY 2014 period, 27 precursors (17 percent) were LOOP precursor events that occurred at 19 NPP sites. Of the 27 LOOP precursor events, 20 precursors occurred during the last 4 years (FY 2011 through FY 2014).
- *Concurrent Unavailability of an Emergency Power Train*. Of the 27 LOOP precursor events,

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[11] A LOOP initiating event involves a reactor trip and the simultaneous loss of electrical power to all unit safety buses (also referred to as emergency buses, Class 1E buses, and/or vital buses) requiring all emergency power generators to start and supply power to the safety buses. The non-safety buses may (or may not) be deenergized as a result of the LOOP initiating event. (Ref. 10)

[12] Precursor analyses of events occurring in FY 2015 are not final. Three LOOP initiating events occurred in FY 2015 and will most likely meet the ASP threshold (i.e., CCDP $\geq 1 \times 10^{-6}$). These events are not included in the trending analysis. These FY 2015 LOOP events occurred at Pilgrim on January 27, 2015 (LER 293/15-002) and Calvert Cliffs Units 1 and 2 on April 7, 2015 (LER 317/15-002).

2 (7 percent) precursors involved a concurrent unavailability of an emergency power system train during the FY 2005 through FY 2014 period. One precursor involved an emergency diesel generator (EDG) failure to run due to a leak in the EDG coolant system and 1 precursor involved an EDG out of service due to maintenance. In FY 2015, a LOOP initiating event (and potential precursor) occurred involving an EDG failure to start due to a fault in the EDG startup circuity and the shutdown sequencer failure for the other EDG to automatically restart selected equipment (see Calvert Cliffs LER 317/15-002).

- *External Hazards.* Of the 27 LOOP precursor events, 12 (44 percent) precursors resulted from external hazards, including: 2 tornados (5 precursors), Hurricane Katrina (1 precursor), 3 other weather-related events (4 precursors), and the 2011 Virginia earthquake (2 precursors). All units at the 5 multi-unit NPP sites involved in these events were affected by the external events. Of these 12 LOOP precursor events, 7 (58 percent) occurred in FY 2011.[13]
- *Outside Plant Boundary*. Of the 27 LOOP precursor events, 3 (11 percent) precursors resulted from an electrical fault either in the plant switchyard or offsite power transmission line to the switchyard.
- *Multi-unit NPP Sites*. Of the 27 LOOP precursor events, 15 precursors occurred at all units at a multi-unit NPP site, 5 precursors occurred at a single unit at a multi-unit site, and 7 precursors occurred at a single-unit site.

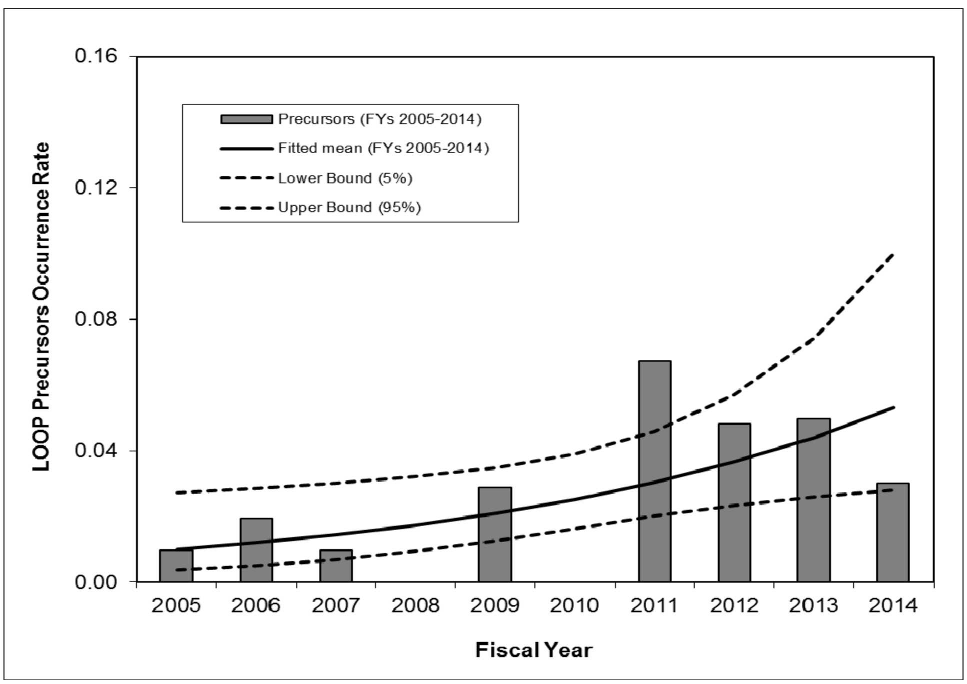

Figure 6. Occurrence Rate of Precursors Involving a Complete LOOP.

4.6 Precursors at BWRs and PWRs

A review of the data for the 10-year period from FY 2005 through FY 2014 reveals the following

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

insights for boiling-water reactors (BWRs) and pressurized-water reactors (PWRs).

BWRs

- The mean occurrence rate of precursors that occurred at BWRs does not exhibit a statistically significant trend (p-value = 0.41; see Figure 7).

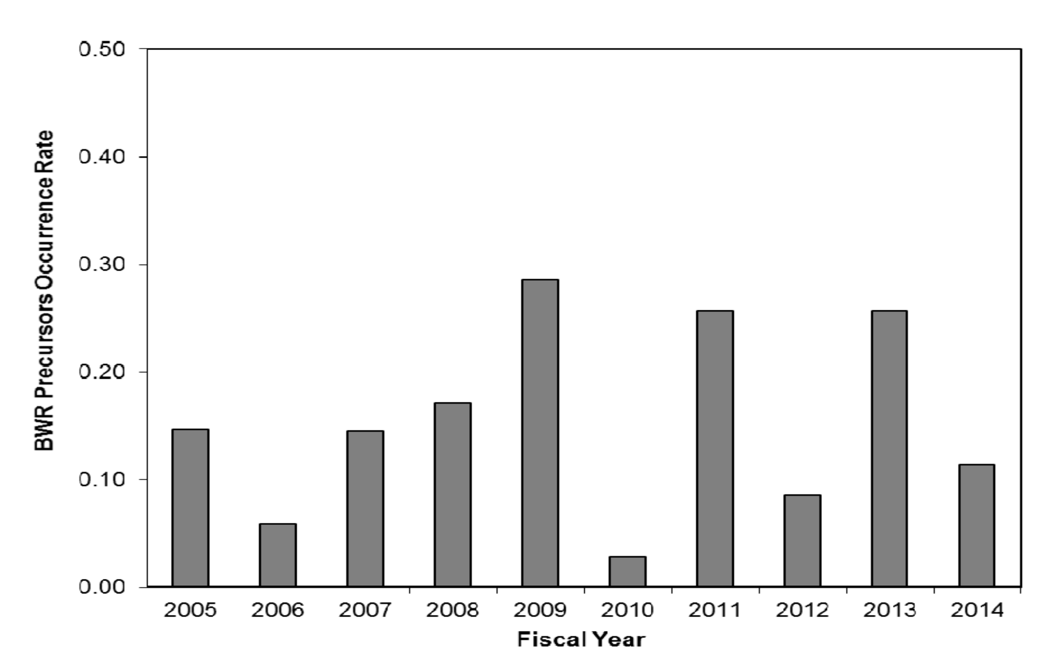

Figure 7. Occurrence Rate of BWR Precursors.

- Of the 21 precursors involving initiating events at BWRs, 11 precursors (52 percent) were complete LOOP events.
- Of the 33 precursors involving the unavailability of safety-related equipment that occurred at BWRs, most were caused by failures in the emergency power system (12 precursors or 36 percent), emergency core cooling systems (7 precursors or 21 percent), electrical distribution systems (2 precursors or 6 percent), or safety-related cooling water systems (1 precursor or 3 percent).

PWRs

- The mean occurrence rate of precursors that occurred at PWRs does not exhibit a statistically significant trend (p-value = 0.95; see Figure 8).
- Of the 33 precursors involving initiating events at PWRs, 16 precursors (48 percent) were complete LOOP events.
- Of the 71 precursors involving the unavailability of safety-related equipment that occurred at PWRs, most were caused by failures in the emergency power system (17 precursors or 24 percent), auxiliary feedwater system (10 precursors or 14 percent), electrical distribution system (10 precursors or 14 percent), safety-related cooling water systems (7 precursors or 10 percent), or emergency core cooling systems (5 precursors or 7 percent).
- Of the 5 precursors involving failures in the emergency core cooling systems, 3 precursors (60 percent) were because of conditions affecting sump recirculation during postulated loss-of-cooling accidents of varying break sizes.

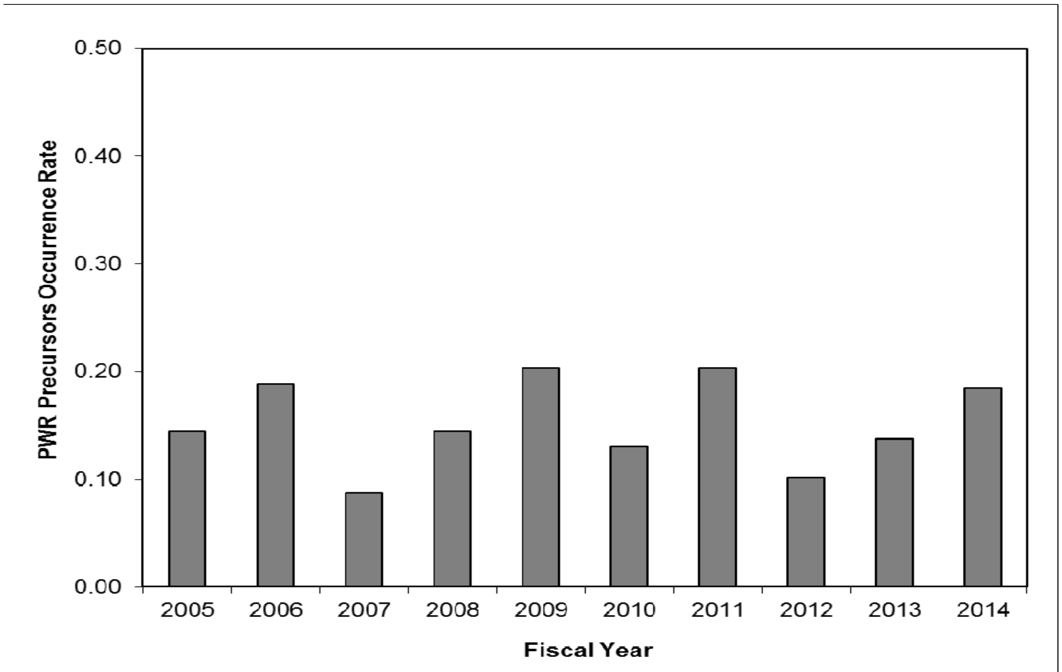

Figure 8. Occurrence Rate of PWR Precursors.

- Of the 10 precursors involving failures of the auxiliary feedwater system, random hardware failures (7 precursors or 70 percent) and design errors (2 precursors or 20 percent) were the largest failure contributors. Nine of the 10 precursors (90 percent) involved the unavailability of the turbine-driven auxiliary feedwater pump train.
- Of the 17 precursors involving failures in the emergency power system, 14 precursors (82 percent) were from hardware failures.
- Design errors contributed to 2 precursors involving the unavailability of safety-related equipment that occurred at PWRs.

4.7 Operating Experience Insights Feedback for PRA Standards and Guidance

One objective of the ASP Program is to provide insights into the adequacy of current PRA standards and guidance. ASP event analyses, both precursors and events that did not exceed the ASP Program threshold, from FY 2014 were reviewed against the PRA elements described in the American Society of Mechanical Engineers (ASME)/American Nuclear Society (ANS) RA-Sa-2009, "Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications" (Ref. 11), as endorsed in Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities" (Ref. 12). This review sought to identify aspects of the event analyses for which the risk-significant ASME/ANS PRA Standard did not provide adequate guidance.

Results. None of the FY 2014 event analyses indicated an inadequacy in the PRA elements as described in ASME/ANS RA-Sa-2009. The staff continues to work with ASME/ANS on refining the standard to ensure that it provides sufficient guidance.

5.0 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 2014. The staff identified no potentially *significant* precursors in FY 2015 (as of September 30, 2015).
- ***Occurrence Rate of All Precursors.*** The occurrence rate of all precursors does not exhibit a trend that is statistically significant from FY 2005 through FY 2014.
- ***Additional Trend Results.*** During the same period, a statistically significant increasing trend was observed in precursors involving LOOP precursor events. No statistically significant trend was observed in precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4}, precursors involving initiating events or degraded conditions, or precursors at BWRs or PWRs.

6.0 References

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