POLICY ISSUE
INFORMATION

October 1, 2008 SECY-08-0145

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 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, including development of associated risk models (e.g., SPAR models). The ASP Program systematically evaluates U.S. nuclear power plant 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 the safety goal established in the agency's Strategic Plan (see NUREG-1100, Volume 24, "Performance Budget: Fiscal Year 2009," issued February 2008).

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The SPAR Model Program develops and improves independent risk-analysis tools and capabilities to support the use of probabilistic risk assessment (PRA) in the agency's risk-informed regulatory activities. 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. The staff also uses SPAR models to perform analyses in support of risk-informed reviews of license amendments and the State-of-the-Art Reactor Consequence Analysis project.

DISCUSSION:

This section summarizes the status, accomplishments, and results of the ASP Program and SPAR Model Program since the previous status report, SECY-07-0176, "Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models," dated October 3, 2007.

ASP Program

The staff has completed the analyses of all precursor events that were identified in fiscal year (FY) 2007 (nine precursors). Precursors are events with a conditional core damage probability (CCDP) or increase in core damage probability (ΔCDP) that is greater than or equal to 1×10^{-6}. In addition, the staff has completed the screening for FY 2008 events for *significant* precursors. *Significant* precursors have a CCDP or ΔCDP greater than or equal to 1×10^{-3}. The staff identified no *significant* precursors in FY 2008. The last *significant* precursor identified was the Davis-Besse event in FY 2002. The ASP Program provides input to the agency's safety-performance measure of zero events per year identified as a *significant* precursor of a nuclear reactor accident.

The staff evaluated precursor data during the period of FY 2001 through FY 2007 to identify statistically significant adverse trends for the Industry Trends Program (ITP). The staff detected a statistically significant decreasing trend for all precursors during this 7-year period. The ASP Program provides the ITP an input to the agency's safety-performance measure of no more than one significant adverse trend in industry safety performance. In addition to the decreasing trend of all precursors, the staff detected a statistically significant decreasing trend during this same period for precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4}.

The staff has begun analyzing potential precursors occurring in FY 2008. Thus far, the staff has identified six precursors in FY 2008.

SPAR Model Program

The staff continued to enhance the Revision 3 SPAR models for internal events during power operations. This effort primarily involves comparing the SPAR models against the respective licensee's plant PRA models. Any differences between the two models are discussed between the staff and the licensee. Once the differences are understood, the staff will revise the SPAR models if necessary to properly represent the as-built, as-operated plant. In addition, the staff will document unresolved technical issues. The staff completed a total of 75 plant model comparisons (out of 77 models representing 104 operating nuclear plants). This includes the development of a Browns Ferry Unit 1 SPAR model.

The staff continued to expand the SPAR model capability beyond internal events at full power operation. The staff previously completed a total of 15 SPAR external event models (e.g., fires, floods, and seismic events). The staff initiated model development of low-power and shutdown scenarios for two plants. The staff also initiated a project to extend SPAR models for three plants to include the modeling of containment systems and plant damage states. This project will provide the capability to assess accident progression to the level of containment damage.

The SPAR Model Quality Assurance Plan was formerly established in 2006 for SPAR model development activities. In addition to internal quality assurance efforts, the staff is working with industry representatives to ensure that the models and risk assessment techniques continue to be improved and updated. The staff and the Electric Power Research Institute executed an Addendum to the Memorandum of Understanding to conduct cooperative research for PRA. Several of the initiatives in this effort are intended to resolve technical issues that account for differences between NRC's SPAR models and the licensees' PRAs.

UPCOMING ACTIVITIES:

- The staff will continue the screening, review, and analysis (preliminary and final) of potential precursors, including *significant* precursors, for FY 2008 and FY 2009 events to support the agency's Strategic Plan goals for monitoring performance.

- For the SPAR Model Program, the staff will continue to implement enhancements to the Revision 3 internal event models for full power operations. 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 to resolve PRA technical issues common to both licensee PRA and SPAR models. This cooperative effort is expected to span the next 3 years.

- The staff will continue to add additional modeling capability (e.g., external events, low-power and shutdown scenarios, and containment systems) into SPAR models. The staff will use information obtained as part of the National Fire Protection Association 805 pilot application process to update and enhance the SPAR fire models. The staff plans to complete several models, spanning the different plant types, that contain external events, low-power and shutdown scenarios, and the modeling of containment systems by 2009.

- The staff will evaluate the need for additional plant models after the use and assessment of this representative set of models in the SDP, ASP, and Management Directive 8.3, "NRC Incident Investigation Program."

- The staff initiated the development of new reactor SPAR models to allow performance of risk assessments to confirm licensee PRA results, comparisons of the effects of design differences, and evaluation of risk-informed applications prior to new plant operation. In addition, the new reactor SPAR models will be required for evaluating operational findings and events.

In summary, the ASP Program continues to evaluate the safety significance of operating events at nuclear power plants and to provide insights to the NRC's risk-informed and performance-based regulatory programs. The staff identified no *significant* precursors in FY 2008. The staff detected a statistically significant decreasing trend for all precursors during the FY 2001 through

FY 2007 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/

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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 (FY) 2007–2008. 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 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 from licensee event reports (LERs) and inspection reports. The staff then analyzes any identified potential precursors by calculating a 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 any subsequent equipment unavailability or degradation, or (2) a degraded plant condition depicted by 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 the probability of reaching a core damage state for the period that a piece of equipment or a combination of equipment is deemed unavailable or degraded from a nominal core damage probability for the same period for which the nominal failure or unavailability probability is assumed for the subject equipment.

The ASP Program considers an event with a CCDP or a ΔCDP greater than or equal to 1×10^{-6} to be a precursor. 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-based view of nuclear power plant operating experience and a measure for trending nuclear power plant core damage risk.
- Provide a partial check on dominant core damage scenarios predicted by probabilistic risk assessments (PRAs).
- Provide feedback to regulatory activities.

The NRC also uses the ASP Program to monitor performance against the safety goal established in the agency's Strategic Plan (see Reference 1). Specifically, the program provides input to the following performance measures:

- Zero events per year identified as a *significant* precursor of a nuclear reactor accident (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-3}).
- No more than one significant adverse trend in industry safety performance (determination principally made from the Industry Trends Program (ITP) but supported by ASP results).

Program Scope. The ASP Program is one of three agency programs that assess the risk significance of issues and 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"). Compared to the other two programs, the ASP Program assesses additional scope of operating experience at U.S. nuclear power plants. For example, compared to the SDP, 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

Table 1 summarizes the status of NRC's ASP analyses as of September 30, 2008. Specifically, the table identifies ASP analyses that the staff has completed for events that occurred during FY 2007–2008. (Note that, as of September 30, 2008, the staff had not yet screened all of the FY 2008 events.) The following subsections summarize the results of these analyses, which are further detailed in the associated Tables 1–4.

FY 2007 Analyses. The ASP analyses for FY 2007 identified nine precursors. All nine precursors occurred while the plants were at power. The staff used SDP and MD 8.3 analysis results to identify seven of the nine precursors.

None of the FY 2007 analyses exceeded 1×10^{-4}; therefore, in accordance with the streamlined review process (see Reference 2), the staff issued these ASP analyses as final after completion of internal reviews.

Table 2 presents the results of the staff's ASP analyses for FY 2007 precursors that involved initiating events, while Table 3 presents the analysis results for precursors that involved degraded conditions.

FY 2008 Analyses. The staff has completed all screening and reviews for potential *significant* precursors (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-3}) through September 30, 2008. In particular, the staff reviewed a combination of LERs (as required by Title 10, Section 50.73, "Licensee Event Report System," of the *Code of Federal Regulations* [10 CFR 50.73]) and daily event notification reports (as required by 10 CFR 50.72, "Immediate Notification Requirements for Operating Nuclear Power Reactors") to identify potential *significant* precursors. The staff did not identify any *significant* precursors in FY 2008.

The staff is still screening and reviewing LERs concerning other potential precursor events that occurred during FY 2008.[1] Six FY 2008 precursors have been identified thus far. The staff plans to complete all FY 2008 analyses by September 2009.

4.0 Industry Trends

This section discusses the results of trending analyses for all precursors and *significant* precursors.

Statistically Significant Trend. The trending method used in this analysis is consistent with those methods used in the staff's risk studies (see Appendix E to Reference 3). The trending method uses the p-value approach for determining the probability of observing a trend as a result of chance alone. A trend is considered statistically significant if the p-value is smaller than 0.05. The figures at the end of this enclosure show the p-value for each trend.

Data Coverage. Based on insights gained in SECY-06-028, "Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models," dated October 5, 2006, the staff chose FY 2001 as the trend analyses' starting point to provide a data period with a consistent ASP Program scope and to align it with the first full year of the Reactor Oversight Process (ROP). ASP Program changes that occurred in FY 2001 (e.g., inclusion of SDP findings and external initiated events) resulted in a step increase in the number of precursors identified compared to those identified in previous years. The data period for trending analyses ends in FY 2007 (the last full year of completed ASP analyses) but will become a shifting 10-year period in the future.

The following exception applies to the data coverage of the trending analyses:

- ***Significant Precursors.*** The trend of *significant* precursors includes events that occurred during FY 2008. The results for FY 2008 are based on the staff's screening and review of a combination of LERs and daily event notification reports.[2] The staff analyzes all potential *significant* precursors immediately.
- ***Integrated ASP Index.*** The integrated ASP index is not used for trending; therefore, older data may be used. A data period of 10 years (FYs 1998–2007) is used when reporting this index.

4.1 Occurrence Rate of All Precursors

The NRC's ITP provides the basis for addressing the agency's safety-performance measure on the "number of statistically significant adverse trends in industry safety performance" (one measure associated with the safety goal established in NRC's Strategic Plan). The mean occurrence rate of all precursors identified by the ASP Program is one indicator used by the ITP to assess industry performance.

Results. Figure 1 depicts the occurrence rate for all precursors by fiscal year during the period of FY 2001–2007. A review of the data for that period reveals the following insights:

[1] Licensees have a 60-day grace period after an event or discovery of a degraded condition to submit an LER.

[2] The staff has completed all screening and reviews through September 30, 2008.

- The mean occurrence rate of all precursors exhibits a statistically significant decreasing trend for the period from FY 2001–2007 (see Figure 1).
- The analysis detected a statistically significant decreasing trend for precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4} during this same period (see Figure 2).

4.2 *Significant* Precursors

The ASP Program provides the basis for the safety-performance 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 Strategic Plan). Specifically, the Strategic Plan defines a *significant* precursor as an event that has a probability of at least 1 in 1000 (greater than or equal to 1×10^{-3}) of leading to a reactor accident (see Reference 1).

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

- The mean occurrence rate of *significant* precursors does not exhibit a statistically significant trend for the period from FY 2001–2008.
- No *significant* precursors were identified in FY 2008.
- The staff has identified only one *significant* precursor since FY 2001. In FY 2002, the staff identified a *significant* precursor involving multiple degraded conditions at Davis-Besse. The specific conditions included cracking of control rod drive mechanism (CRDM) nozzles, degradation of the reactor pressure vessel (RPV) head, potential clogging of the emergency sump, and potential degradation of the high-pressure injection (HPI). Reference 4 provides a complete list of all *significant* precursors from 1969–2006, including event descriptions.
- Over the past 20 years, *significant* precursors have occurred, on average, about once every 5 years. The events in this group involve differing failure modes, causes, and systems.

5.0 Insights and Other Trends

The following sections provide additional ASP trends and insights from the period FY 2001–2007.

5.1 Initiating Events vs. Degraded Conditions

A review of the data for FY 2001–2007 yields insights described below.

Initiating Events

- Over the past 7 years, precursors involving degraded conditions outnumbered initiating events (70 percent compared to 30 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.
- The mean occurrence rate of precursors involving initiating events is not statistically significant for the period from FY 2001–2007, as shown in Figure 3.
- Of the precursors involving initiating events during FY 2001–2007, 63 percent were LOOP events.

Degraded Conditions

- The mean occurrence rate of precursors involving degraded conditions exhibits a statistically significant decreasing trend during the FY 2001–2007 period, as shown in Figure 4.
- From FY 2001–2007, 41 percent of precursors involving degraded conditions had a condition start date before FY 2001.

5.2 Precursors Involving Loss of Offsite Power Initiating Events

Only one LOOP event occurred in FY 2007 (Brunswick, Unit 2).

Results. A review of the data for FY 2001–2007 leads to the following insights:

- The mean occurrence rate of precursors resulting from a LOOP does not exhibit a trend that is statistically significant for the period from FY 2001–2007, as shown in Figure 5.
- Of the LOOP events that occurred during the FY 2001–2007 period, one-half resulted from a degraded electrical grid outside of the nuclear power plant boundary.
- A simultaneous unavailability of an emergency power system train was involved in 2 of the 22 LOOP precursor events during FY 2001–2007.

5.3 Precursors at Boiling-Water Reactors Versus Pressurized-Water Reactors

A review of the data for FY 2001–2007 reveals the results for boiling-water reactors (BWRs) and pressurized-water reactors (PWRs) described below.[3]

BWRs

- The mean occurrence rate of precursors that occurred at BWRs does not exhibit a trend that is statistically significant for the period from FY 2001–2007, as shown in Figure 6.
- LOOP events contributed to 67 percent of precursors involving initiating events at BWRs.
- Of the 17 precursors involving the unavailability of safety-related equipment that occurred at BWRs during FY 2001–2007, most were caused by failures in the emergency core cooling systems (59 percent), emergency power system (35 percent), electrical distribution system (24 percent), or essential service water system (18 percent).

PWRs

- The mean occurrence rate of precursors that occurred at PWRs exhibits a statistically significant decreasing trend during the FY 2001–2007 period, as shown in Figure 7.
- LOOP events contribute to 60 percent of precursors involving initiating events at PWRs.
- Of the 63 precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2001–2007, most were caused by failures in the emergency core cooling systems (38 percent), auxiliary feedwater system (22 percent), emergency power system (19 percent), or electrical distribution system (10 percent).

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

- Of the 24 precursors involving failures in the emergency core cooling systems, 17 precursors (71 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 (88 percent).
- Of the 14 precursors involving failures of the auxiliary feedwater system (AFW), random hardware failures (43 percent) and design errors (43 percent) were the largest failure contributors. Twelve of the 14 precursors involved the unavailability of the turbine-driven auxiliary feedwater pump train.
- Of the 12 precursors involving failures of the emergency power system, 10 precursors (83 percent) were from random hardware failures.
- Design errors contributed 53 percent of all precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2001–2007.

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.

For an initiating event occurring in FY 2003, only FY 2003 includes the CCDP from this precursor.

Results. Figure 8 depicts the integrated ASP indices for FY 1998–2007. A review of the ASP indices leads to the following insights:

- Based on order of magnitude (10^{-5}), the average integrated ASP index for the period from FY 1998–2007 is consistent with the CDF estimates from the SPAR models and industry PRAs.
- Precursors over the 10-year period (FY 1998–2007) made the following contributions to the average integrated CDF:
  - The one *significant* precursor (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-3}) contributed to 26 percent of the average integrated CDF from precursors over the 10-year period. The *significant* precursor (Davis-Besse, FY 2002) existed for a 1-year period.

- Four precursors contribute 40 percent of the average integrated CDF from precursors over the 10-year period. Specifically, long-term degraded conditions at Point Beach Units 1 and 2 (discovered in 2001) involved potential common-mode failure of all AFW pumps, while long-term degraded conditions at D.C. Cook Units 1 and 2 (discovered in 1999) involved a number of locations in the plant where the effects of postulated high-energy line break events would damage safety-related components. The associated ΔCDPs of the degraded conditions at Point Beach and D.C. Cook were high (7×10^{-4} and 4×10^{-4}, respectively) and the degraded conditions had existed since plant construction.
- The remaining 34 percent of the average integrated CDF from precursors over the 10-year period resulted from contributions from 137 precursors.

Limitations. Using CCDPs and ΔCDPs from ASP results to estimate CDF is difficult because (1) the mathematical relationship 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 Consistency with Probabilistic Risk Assessments and Individual Plant Examinations

A secondary objective of the ASP Program is to provide a partial validation of the dominant core damage scenarios predicted by PRAs and individual plant examinations (IPEs). Most of the identified precursor events are consistent with failure combinations identified in PRAs and IPEs.

However, a review of the precursor events for FY 2001–2007 reveals that approximately 30 percent of the identified precursors involved event initiators or failure modes that were not explicitly modeled in the PRA or IPE for the specific plant where the precursor event occurred. Table 4 lists these precursors. The occurrence of these precursors does not imply that explicit modeling is needed; however, such modeling could yield insights that could be incorporated in future revisions of the PRA.

6.0 Summary

This section summarizes the ASP results, trends, and insights:

- ***Significant Precursors.*** The staff did not identify any *significant* precursors (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-3}) in FY 2008. The ASP Program provides the basis for the safety-performance measure of zero “number of significant accident sequence precursors of a nuclear reactor accident.” The NRC’s Performance and Accountability Report for FY 2008 and the NRC Performance Budget for FY 2010 will report these results.

- ***Occurrence Rate of All Precursors.*** A statistically significant decreasing trend was detected in the occurrence rate of all precursors during the FY 2001–2007 period. This

ASP trend provides the basis for one performance indicator used by the ITP to assess industry performance. The NRC's Performance and Accountability Report for FY 2008 and the NRC Performance Budget for FY 2010 will report the overall performance indicator results.

- ***Additional Trend Results.*** During the same period, statistically significant decreasing trends were detected for three groups of precursors—precursors with a CCDP or ΔCDP greater than or equal to 10^{-4}, precursors involving degraded conditions, and precursors that occurred at PWRs.

7.0 References

1. NUREG-1100, Vol. 24, "Performance Budget, Fiscal Year 2009," U.S. Nuclear Regulatory Commission, Washington, DC, February 2008.

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

3. NUREG/CR-5750, "Rates of Initiating Events at U.S. Nuclear Power Plants: 1987–1995," U.S. Nuclear Regulatory Commission, Washington, DC, February 1999.

4. SECY-06-0208, "Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models," U.S. Nuclear Regulatory Commission, Washington, DC, October 2006.

Table 1. Status of ASP Analyses

Status	FY 2007	FY 2008[a]
Analyzed events that were determined not to be precursors	76	28
Events to be further analyzed	—	24
ASP precursor analyses	2	—
SDP (or MD 8.3) results used for ASP program input	7	6
Total precursors identified	9	6

a. As of September 30, 2008, the staff has not yet screened all of the FY 2008 initiating events and degraded conditions.

Table 2. FY 2007 Precursors Involving Initiating Events

Event Date	Plant	Description	CCDP
10/11/06	Surry 2	Partial loss of offsite power with subsequent reactor trip. ***50-280/06-11***	2×10^{-6}
10/19/06	River Bend	Automatic reactor scram due to inadvertent isolation of main feedwater. ***LER 458/06-007***	3×10^{-6}
11/1/06	Brunswick 2	Loss of startup auxiliary transformer results in Unit 2 manual reactor protection system actuation. ***LER 324/06-001***	6×10^{-6}

Table 3. FY 2007 Precursors Involving Degraded Conditions

Event Date[a]	Condition Duration[b]	Plant	Description	ΔCDP/ SDP Color
10/10/06	454 days	Fort Calhoun	Faulty maintenance causes the inoperability of a containment spray train for 454 days. ***EA-07-047***	WHITE
11/2/06	9 days	Brunswick 1	Emergency diesel generator inoperable due to failure of foreign material exclusion practices. ***EA-07-024***	WHITE
1/5/07	85 days	Farley 2	Residual heat removal containment sump suction valve inoperable for 85 days. ***EA-07-173***	YELLOW
1/18/07	57 days	Cooper	Inadequate procedures result in failure of emergency diesel generator voltage regulator. ***EA-07-090***	WHITE
2/14/07	14 days	Fort Calhoun	Emergency diesel generator failure during test due to degraded field flash contacts. ***EA-07-194***	WHITE
6/14/07	10 years	Cooper	Inadequate post-fire procedure could have prevented achieving safe shutdown. ***EA-07-204***	WHITE

a. ASP event date is the discovery date for a precursor involving a degraded condition.
b. Condition duration is the time period when the degraded condition existed. The ASP Program limits the analysis exposure time of degraded condition to 1 year.

Table 4. Precursors Involving Failure Modes and Event Initiators that Were Not Explicitly Modeled in the PRA or IPE Concerning the Specific Plant at Which the Precursor Event Occurred

Plant	FY	Event Description
Cooper	2007	Inadequate post-fire procedure could have prevented achieving safe shutdown. ***EA-07-204***
Clinton	2006	Potential air entrapment of high-pressure core spray because of incorrect suction source switchover set point. ***EA-06-291***
Oconee 1, 2, & 3	2006	Failure to maintain design control for the standby shutdown facility flooding boundary. ***EA-06-199***
Kewaunee	2005	Design deficiency could cause unavailability of safety-related equipment during postulated internal flooding. ***EA-05-176***
LaSalle 1 & 2 Crystal River 3	2005	Single-failure vulnerability of safety bus protective relay schemes caused by common power metering circuits. ***EA-05-103, EA-05-114***
Watts Bar	2005	Component cooling backup line from essential raw cooling water was unavailable because silt blockage. ***50-390/04-05***
Watts Bar	2005	Low-temperature, overpressure valve actuations while shut down. ***EA-05-169***
Calvert Cliffs 2	2004	Failed relay causes overcooling condition during reactor trip. ***LER 318/04-001***
Palo Verde 1, 2, & 3	2004	Containment sump recirculation potentially inoperable because of pipe voids. ***LER 528/04-009***
Shearon Harris	2003	Postulated fire could cause the actuation of certain valves, which could result in a loss of the charging pump, reactor coolant pump seal cooling, loss of reactor coolant system inventory, and other conditions. ***LER 400/02-004***
St. Lucie 2	2003	RPV head leakage because of cracking of CRDM nozzles. ***LER 389/03-002***
Kewaunee	2003	Failure to provide a fixed fire-suppression system could result in a postulated fire that propagates and causes the loss of control cables in both safe-shutdown trains. ***50-305/02-06***
Crystal River 3 Three Mile Island 1 Surry 1 North Anna 1 & 2	2002	RPV head leakage because of cracking of CRDM nozzle(s). ***LER 302/01-004, LER 289/01-002, LER 280/01-003, LER 339/02-001***
Columbia	2002	Common-cause failure of breakers used in four safety-related systems. ***50-397/02-05***
Davis-Besse	2002	Cracking of CRDM nozzles and RPV head degradation, potential clogging of the emergency sump, and potential degradation of the pumps. ***LER 346/02-002***
Callaway	2002	Potential common-mode failure of all AFW pumps because of foreign material in the condensate storage tank caused by degradation of the floating bladder. ***LER 483/01-002***
Point Beach 1 & 2	2002	Potential common-mode failure of all AFW pumps because of a design deficiency in the AFW pumps' air-operated minimum flow recirculation valves. The valves fail closed on loss of instrument air, which could potentially lead to pump deadhead conditions and a common-mode, non-recoverable failure of the AFW pumps. ***LER 266/01-005***
Shearon Harris	2002	Potential failure of Residual Heat Removal Pump A and Containment Spray Pump A because of debris in the pumps' suction lines. ***LER 400/01-003***
Oconee 1, 2, & 3 Arkansas 1 Palisades	2001	RPV head leakage because of cracking of CRDM nozzle(s). ***LER 269/03-002, LER 270/02-002, LER 287/03-001, LER 313/02-003, LER 255/01-004***

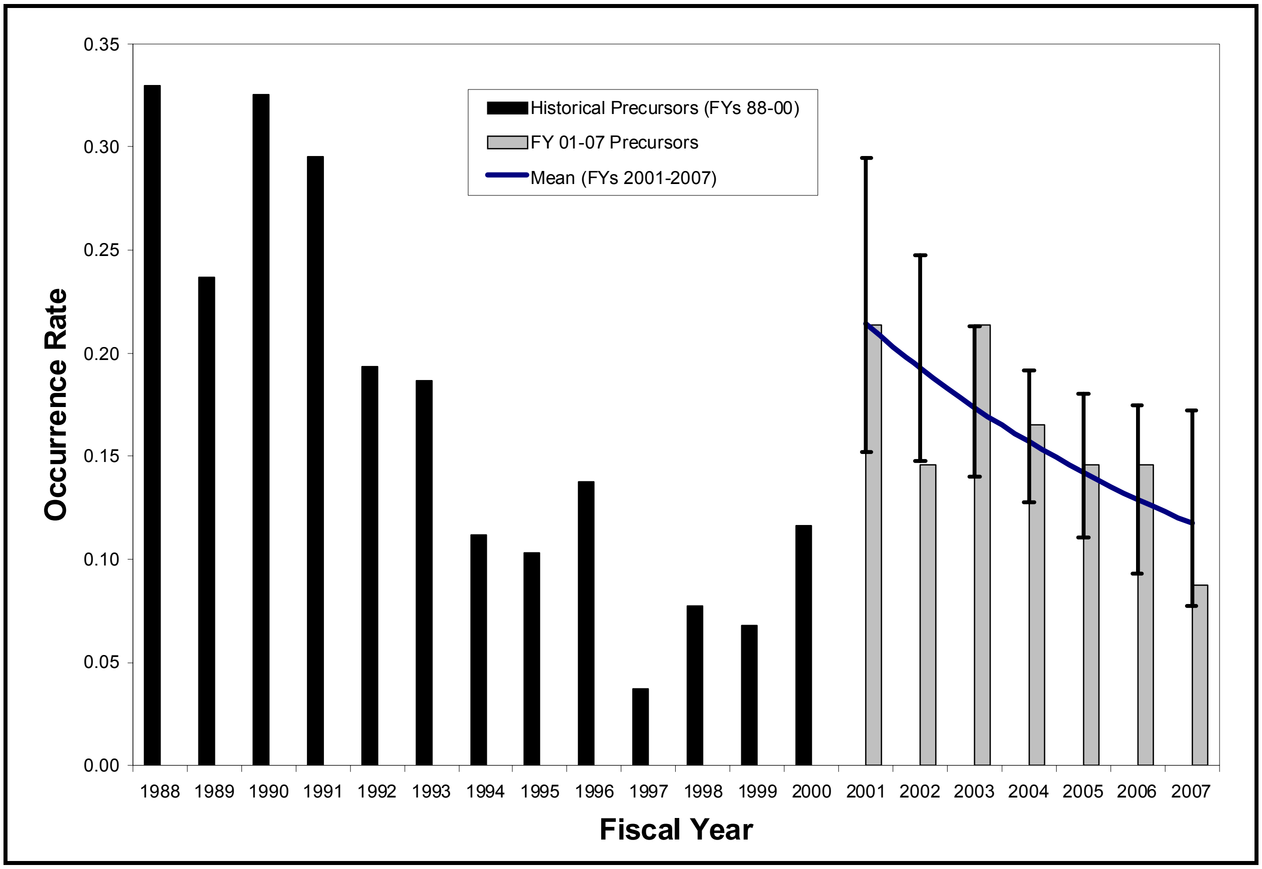

Figure 1. Total precursors—occurrence rate, by fiscal year. Data for FY 1988–2000 are shown for historical perspective. A statistically significant decreasing trend (p-value = 0.03) is detected for the FY 2001–2007 period.

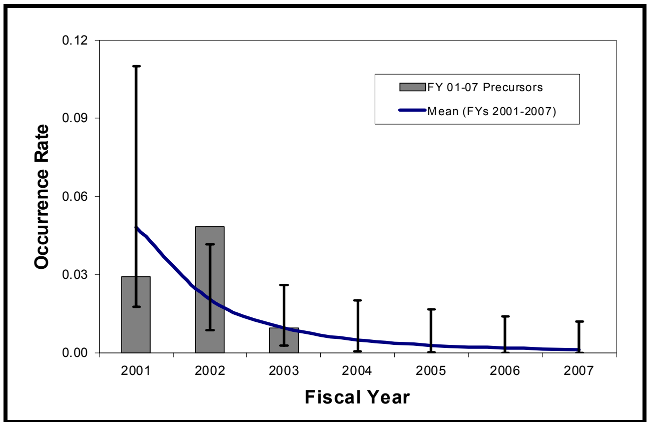

Figure 2. Precursors with a CCDP or ΔCDP ≥10^{-4}—occurrence rate by fiscal year. A statistically significant decreasing trend (p-value = 0.0005) is detected for the FY 2001–2007 period.

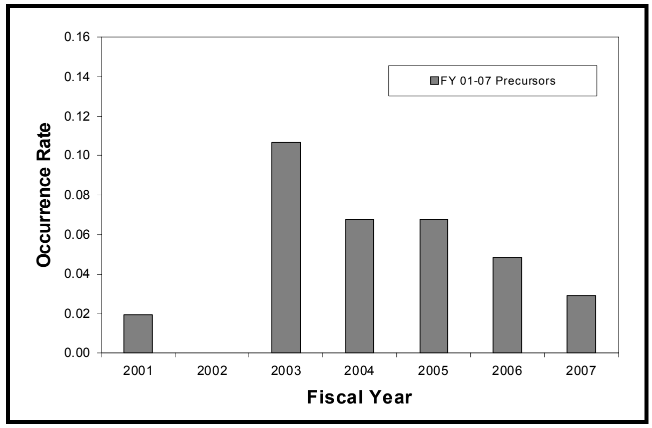

Figure 3. Precursors involving initiating events—occurrence rate by fiscal year. No trend line is shown because no statistically significant trend (p-value = 0.45) is detected for the FY 2001–2007 period.

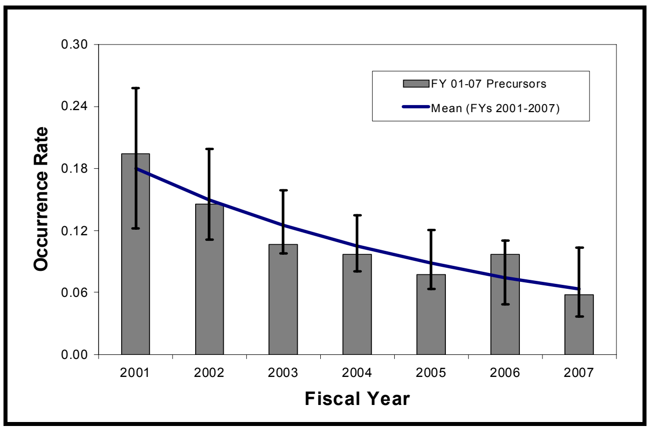

Figure 4. Precursors involving degraded conditions—occurrence rate by fiscal year. A statistically significant decreasing trend (p-value = 0.002) is detected for the FY 2001–2007 period.

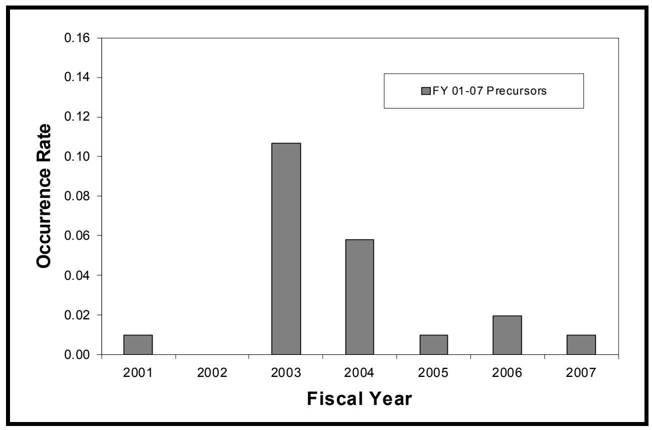

Figure 5. Precursors involving LOOP events—occurrence rate by fiscal year. No trend line is shown because no statistically significant trend (p-value = 0.52) is detected for the FY 2001–2007 period.

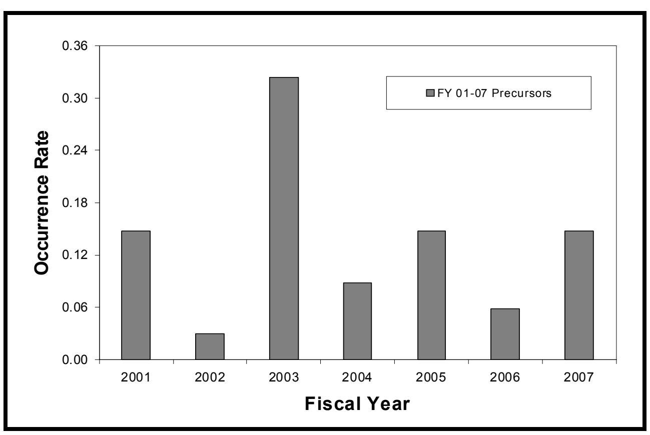

Figure 6. Precursors involving BWRs—occurrence rate by fiscal year. No trend line is shown because no statistically significant trend (p-value = 0.70) is detected for the FY 2001–2007 period.

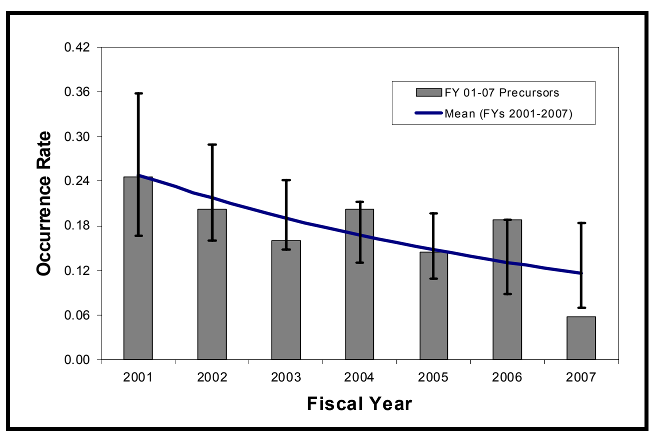

Figure 7. Precursors involving PWRs—occurrence rate by fiscal year. A statistically significant decreasing trend (p-value = 0.02) is detected for the FY 2001–2007 period.

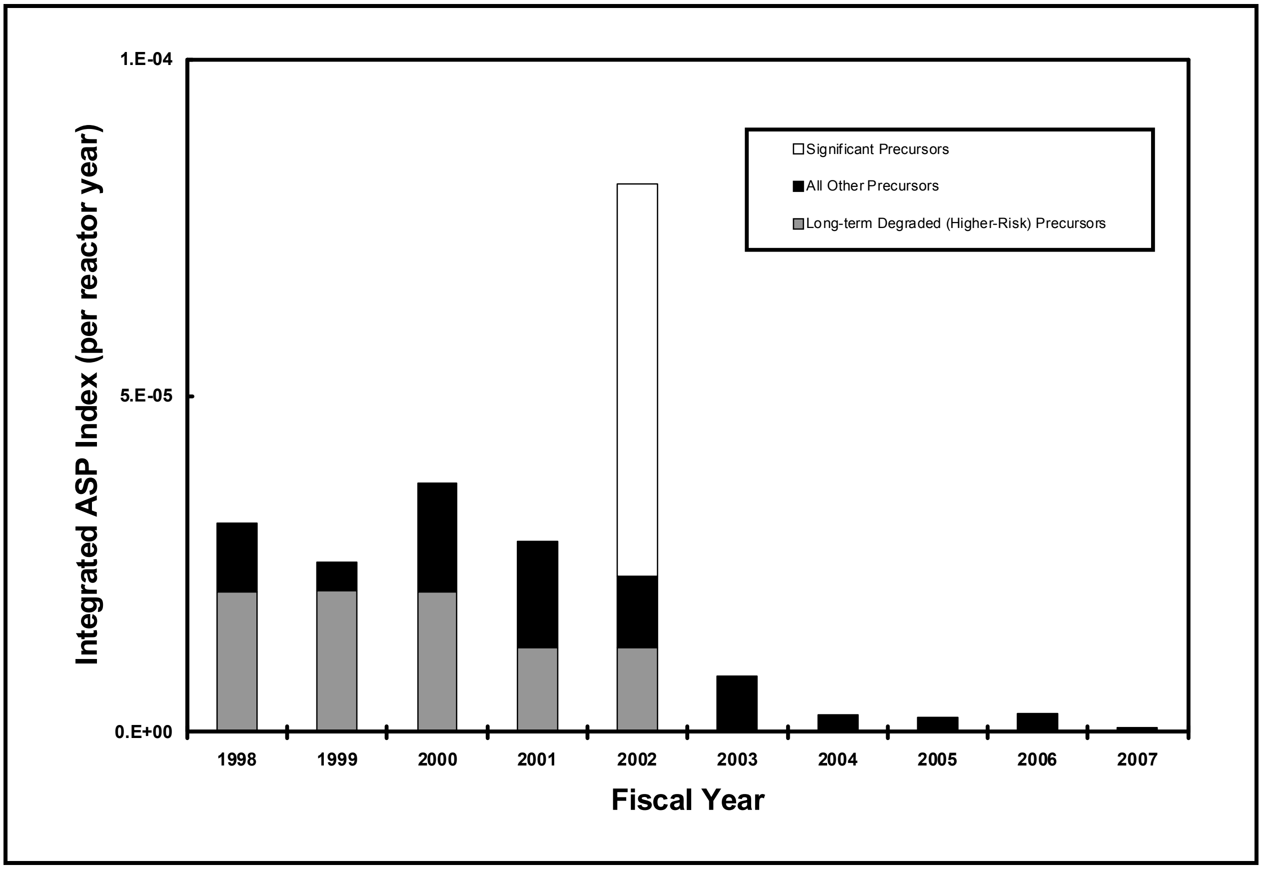

Figure 8. Integrated ASP index—risk contribution from precursors per fiscal year. The risk contribution from precursors involving degraded conditions is included in <u>all</u> fiscal years when the degraded condition existed. The risk contribution from precursors involving initiating events is included in the fiscal year in which the event occurred. The multiple, short-term degraded conditions at Davis-Besse contributed to the single significant precursor in FY 2002.

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 Level 1, Revision 3, 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 Level 1, Revision 3, 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 are not as detailed as those contained in licensees' probabilistic risk assessments (PRAs). To date the U.S. Nuclear Regulatory Commission (NRC) staff has completed Revision 3 SPAR models to represent all 104 commercial operating units and benchmarked them against licensee PRAs during the onsite quality-assurance reviews of these models.

In August 2000, the staff developed the SPAR model development plan to address the following models:

- Internal initiating events during full-power operation (Revision 3 SPAR models).
- Internal initiating events during low-power and shutdown operations.
- External initiating events (including fires, floods, and seismic events).
- Calculation of large early release frequency (LERF).

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 8.3. Under this project, the staff is working to complete the following activities:

- Enhance SPAR models to be more plant specific and enhance the codes used to manipulate the SPAR models.
- Document 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), internal events during low-power and shutdown operations, and LERF sequences.
- Provide on-call technical support for licensing and inspection issues.

2.0 SPAR Model Development 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, MD 8.3 evaluations, licensing actions, and the Mitigating Systems Performance Index (MSPI), involve the use of SPAR models. New SPAR models are under development in response to staff needs for modeling internal initiating events during low-power and shutdown operations, external initiating events, and for assessing accident progression to the plant damage state level.

The staff currently uses SPAR models to support the State-of-the-Art Reactor Consequence Analysis Project. The staff uses Revision 3 SPAR models for the plants selected, along with other sources of PRA information, to identify accident sequences that will be evaluated for their potential offsite consequences. The staff plans to update the SPAR models as appropriate, based on insights gained through this project.

In conformance with the SPAR model development plan, the staff has completed the following activities in model and method development since the previous status report (SECY-07-0176, "Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models," dated October 3, 2007) as described below.

SPAR Models for Analysis of Internal Initiating Events During Full-Power Operation

The staff developed enhanced Revision 3 SPAR models. This effort involved (1) performing a cut-set-level review against the respective licensee's plant PRA model for each of the Revision 3 SPAR models and (2) incorporating into the Revision 3 SPAR models the resolution of the PRA modeling issues that were identified during the onsite quality assurance reviews of the Revision 3 SPAR models, during the MSPI pilot program reviews, and based on feedback from model users. The staff completed enhanced Revision 3 SPAR models for 75 of the 77 Revision 3 SPAR models.

Completion of the cut-set-level reviews at two plants (Nine Mile Point Unit 2 and Watts Bar) have been delayed because of holdups experienced by the licensees in updating their PRA and completing an American Society of Mechanical Engineers (ASME) standard peer review of their revised PRA. Nine Mile Point Unit 2 anticipates completion by February 2009. At this time, Watts Bar is unable to provide an anticipated completion date.

The staff developed a Browns Ferry Unit 1 SPAR model, which includes performing a cut-set-level review.

The staff completed updating the enhanced Revision 3 SPAR models with data published in NUREG/CR-6928, "Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants," issued February 2007.

The staff has identified important plant differences at some multiunit sites. To address these plant differences, applicable SPAR models are being split into single-unit models. The staff has developed single-unit SPAR models for Peach Bottom Units 2 and 3, Brunswick Units 1 and 2, Calvert Cliffs Units 1 and 2, and Susquehanna Units 1 and 2.

In addition to the above model enhancements, the staff completed SPAR model reevaluations of the eight MSPI pilot plants and nine enhanced Revision 3 SPAR models because of changes to licensee PRAs that occurred during the implementation of MSPI.

SPAR Models for the Analysis of External Events

The staff previously completed a total of 15 SPAR external event models. The staff is developing a plan to define and direct the activities for the next 3-year time period. One significant upcoming activity is the incorporation of internal fire event scenarios from the National Fire Protection Association 805 PRA studies into the SPAR models.

SPAR Models for Analysis of Internal Initiating Events during Low-Power and Shutdown Operation

In FY 2008, the activities were completed for five second-generation SPAR low-power and shutdown models to support SDP Phase 3 analyses. The staff is developing a plan to define and direct the activities for the next 3-year time period. The staff places a priority on creating a RASP Handbook on PRA analysis of low-power and shutdown events, with emphasis on SDP Phase 3 analyses.

The staff completed one SPAR model that contains internal, external, and shutdown events. The task of integration and configuration control of various event models (internal, external, and shutdown) has been assigned a high priority to manage and control costs of these integrated models and their maintenance.

Extended SPAR Models for the Analysis of Accident Progression to the Plant Damage State Level

The staff initiated a project to develop extended Level I SPAR models covering different reactor technologies. In addition to the plant systems needed to mitigate core damage, these extended SPAR models will include containment systems that are needed to mitigate potential radionuclide release. These models will provide the capability to assess accident progression to the containment damage state level. The staff completed extended Level I SPAR models for five plants: Surry, Peach Bottom, Sequoyah, Grand Gulf, and Susquehanna. In addition, the staff completed Level II SPAR models for Surry, Peach Bottom, and Sequoyah. The staff anticipates integration of the Level II SPAR models with their respective extended Level I SPAR models to be completed in CY 2009.

This activity enhances prior NRC research that was directed at the evaluation of accident sequences to determine if they contributed to large early releases. This task also will provide the capability to further extend the models for other modes of radionuclide release should the need arise in the future.

3.0 Additional SPAR Model Activities

Audit by the NRC Office of Inspector General

The NRC Office of the Inspector General (OIG) completed an audit report, OIG-06-A-24, “Evaluation of the NRC's Use of Probabilistic Risk Assessment in Regulating the Commercial

Nuclear Power Industry," dated September 29, 2006, which made the following three recommendations:

(1) Develop and implement a formal, written process for maintaining PRA models that is sufficiently representative of the as-built, as-operated plant to support model uses.

(2) Develop and implement a fully documented process to conduct and maintain configuration control of PRA software (i.e., SAPHIRE, GEM).

(3) Conduct a full verification and validation of SAPHIRE Version 7.2 and GEM.

The corrective actions required to resolve recommendations 1 and 2 have been completed.

In follow-up discussions, OIG acknowledged that performing a full verification and validation of SAPHIRE Version 7 would not be justified at this time because of the development schedule of SAPHIRE Version 8. The staff is implementing four improvements to the SAPHIRE project software verification and validation. These improvements are consistent with the Institute of Electrical and Electronics Engineers Standard for Software Verification and Validation 1012-1998. Subsequent discussions with the OIG staff indicated that the addition of these four recommendations, combined with code testing, would satisfy full verification and validation of SAPHIRE Version 8.

The staff will implement these improvements in the SAPHIRE Version 8 statement of work and anticipates its general release date in CY 2009. OIG considers this issue resolved, and the issue will be closed with the release of SAPHIRE Version 8.

<u>Technical Adequacy of SPAR Models</u>

The staff implemented an updated SPAR Model Quality Assurance Plan covering the Revision 3 SPAR models in 2006. 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 Revision 3 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. The staff documented its processes in the RASP handbook.

<u>New Reactor SPAR Models</u>

The staff has begun the development of new reactor SPAR models. Prior to new plant operation, the staff may need to perform risk assessments to confirm PRA results provided in combined operating license (COL) submittals or to evaluate risk-informed applications after COL issuance.

The main objective of this work is to develop a design-specific internal events SPAR model for the Advanced Passive 1000 Reactor based on the SAPHIRE computer code. As part of the SPAR model development, the requisite supporting documentation also will be developed. Because design standardization is a key aspect of the new plants, it will only be necessary to develop one SPAR model for each of the new designs.

Because some of the new reactor designs rely on passive systems and components to mitigate accident scenarios, the first model will be a proof-of-concept to ensure that the necessary technical capabilities are in fact available and the state-of-the art of the SPAR models is sufficient to complete the models. Upon successful completion of the first model the remaining models will be developed.

Cooperative Research for PRA

The staff has executed an addendum to the memorandum of understanding with the Electric Power Research Institute (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 objective of this effort is to work with the broader PRA community to resolve PRA issues and to develop PRA methods, tools, data, and technical information useful to both NRC and industry. The agency has established working groups that include support from the Office of Nuclear Regulatory Research, Office of Nuclear Reactor Regulation, Office of New Reactors, and the regional offices. Initial cooperative efforts include the following:

- Support system initiating event analysis.
- Treatment of LOOP in PRAs.
- Initiating event guideline development.
- Treatment of uncertainty in risk analyses.
- Aggregation of risk metrics.
- Standard approach for injection following containment failure (boiling-water reactors).
- Standard approach for containment sump recirculation during small and very small loss-of-coolant accident.
- 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, treatment of uncertainty in risk analysis, and aggregation of risk metrics. 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 continue this cooperative effort with EPRI to address the remaining issues over the next 3 years.

SAPHIRE Version 8 Development

SAPHIRE Version 8 includes features and capabilities that are new or improved over the current Version 7 to address new requirements for risk-informed programs. User interfaces were developed for performing:

- SDP Phase 2 analyses with the SPAR models.
- Event assessments.
- Other types of PRA analyses.

Features and capabilities also have been improved for SPAR model development and use. Level 1 SPAR models were updated to run in the new SDP Phase 2 analysis interface. External events models required a new data input method and code improvements to develop and run them. New requirements for LERF models have been incorporated, including the capability to perform phase mission time analysis which also is useful for low power and shutdown modeling. In addition, SAPHIRE Version 8 has been designed with unique capabilities to use the SPAR models in an integrated manner (i.e., different model types such as internal and external events models combined into one model). Improved PRA methods also have been implemented for common cause failure modeling and for sequence solving. Finally, the software's general functionality has been enhanced, and the layout has been made more user-friendly.

Version 8 is currently in beta testing. In addition to beta testing, independent verification and validation activities and the staff's peer review are planned. SAPHIRE Version 8 is anticipated to be ready for general use by the end of CY 2009.