POLICY ISSUE
INFORMATION

September 29, 2009 SECY-09-0143

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 25, "Performance Budget: Fiscal Year 2010," issued May 2009). 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

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Program, the Incident Investigation Program event assessment process, and the Generic Issue Program resolution process.

DISCUSSION:

This section summarizes the status, accomplishments, and results of the ASP Program and SPAR Model Program since the previous status report, SECY-08-0145, "Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models," dated October 1, 2008.

ASP Program

The staff has completed the analyses of all precursor events that were identified in fiscal year (FY) 2008 (15 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 of FY 2009 events for *significant* precursors. *Significant* precursors have a CCDP or ΔCDP greater than or equal to 1×10^{-3}. No *significant* precursors were identified in either FY 2008 or FY 2009 and the staff continues to complete the review, analysis, and documentation of all potential precursors. 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 2008 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 8-year period. The ASP Program results are trended in the ITP to provide 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 2009. Thus far, two precursors have been identified in FY 2009.

SPAR Model Program

The staff completed an enhancement of the internal event SPAR models representing the 104 operating commercial nuclear power plants. This effort primarily involved comparing the SPAR models against the respective licensee's plant PRA models. Differences between the two models were discussed between the staff and the licensee. The staff revised the SPAR models as necessary to properly represent the as-built, as-operated plant and documented additional technical issues to be addressed through continuing NRC and industry efforts.

In addition to the above model enhancements, the staff completed an evaluation of the risk reduction associated with the severe accident mitigation strategies related to core damage for about two-thirds of the licensees. The evaluations of the remaining licensees are scheduled to be completed by October 2010.

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 shutdown scenarios for two plants. The staff also completed 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 staff also completed the development of a new reactor SPAR model (AP1000) to allow confirmation of PRA results presented in licensing submittals and evaluation of risk-informed applications prior to new plant operation, and assessment of operational findings and events once operation commences.

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. In addition, the staff, with the cooperation of industry experts, performed a peer review of a typical boiling-water reactor SPAR model in accordance with American National Standard ASME RA-S-2002, "Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications," and Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities." A peer review of a typical pressurized-water reactor SPAR model is scheduled to be completed in October 2009.

UPCOMING ACTIVITIES:

- The staff will continue the screening, review, and analysis (preliminary and final) of potential precursors for FY 2009 and FY 2010 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 internal event SPAR 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 NRC SPAR models. This cooperative effort is expected to span the next 2 years.

- As part of a broader, ongoing initiative among internal stakeholders to enhance risk tools used in reactor oversight, the staff is identifying additional enhancements to the SPAR models based on specific needs of end users. These enhancements are planned to be incorporated into the models.

- The staff will use information obtained as part of the National Fire Protection Association 805 pilot application process to create two new SPAR fire models with updated fire scenarios.

- The staff will continue to evaluate the need for additional SPAR model capability (beyond full power internal events) based on experience gained from SDP, ASP, and Management Directive 8.3, "NRC Incident Investigation Program Assessments."

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

In summary, the ASP Program continues to evaluate the safety significance of operating events at nuclear power plants and to provide insights to NRC's risk-informed and performance-based regulatory programs. The staff identified no *significant* precursors in FY 2009. The staff detected a statistically significant decreasing trend for all precursors during the FY 2001 through FY 2008 period. The SPAR Model Program is continuing to develop and improve independent risk analysis tools and capabilities to support the use of PRA in the agency's risk-informed regulatory activities.

COORDINATION:

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

/RA/

Brian W. Sheron, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Results, Trends, and Insights of the ASP Program
2. Status of the SPAR Models

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

1.0 Introduction

This enclosure discusses the results of accident sequence precursor (ASP) analyses conducted by the staff as they relate to events that occurred during fiscal years (FY) 2008–2009. 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 or without 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 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}.

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.

[1] For initiating event analyses, the precursor threshold is a CCDP $\geq1\times10^{-6}$ or the plant-specific CCDP for a non-recoverable loss of feedwater, whichever is greater. This initiating event precursor threshold prevents reactor trips with no losses of safety system equipment from being precursors.

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 partially 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, 2009. Specifically, the table identifies ASP analyses that the staff has completed for events that occurred during FY 2008–2009. (Note that, as of September 30, 2009, the staff had not yet screened all of the FY 2009 events.) The following subsections summarize the results of these analyses, which are further detailed in the associated Tables 1–4.

Table 1. Status of ASP analyses.

Status	FY 2008	FY 2009
Analyzed events that were determined not to be precursors	67	14
Events to be further analyzed	—	9
ASP precursor analyses	2	—
SDP (or MD 8.3) results used for ASP program input	13	2
Total precursors identified	15	2

FY 2008 Analyses. The ASP analyses for FY 2008 identified 15 precursors. Fourteen of the 15 precursors occurred while the plants were at power. The staff used SDP analysis results to identify 13 of the 15 precursors.

None of the FY 2008 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 2008 precursors that involved initiating events. Table 3 presents the analysis results for FY 2008 precursors that involved degraded conditions.

Table 2. FY 2008 precursors involving initiating events.

Event Date	Plant	Description	CCDP/ SDP Color
04/15/08	Oconee 1	Procedure error leads to loss of reactor coolant system inventory while shutdown. ***Enforcement Action (EA)-08-324***	WHITE
09/11/08	Monticello	Trip with partial loss of offsite power to due to blown fuse. ***Inspection Report (IR) 50-263/08-09***	1E-05

Table 3. FY 2008 precursors involving degraded conditions.

Event Date	Condition Duration	Plant	Description	ΔCDP/ SDP Color
10/19/07	1 year	Byron 1	Corrosion of equipment cooling water system piping. ***EA-08-046***	WHITE
10/19/07	1 year	Byron 2	Corrosion of equipment cooling water system piping. ***EA-08-046***	WHITE
11/21/07	20 days	Comanche Peak 1	Emergency diesel generator failed to activate during testing. ***EA-08-028***	WHITE
01/15/08	125 days	Cooper	Failure to establish procedural controls for maintenance of electrical connections on essential equipment. ***EA-08-124***	WHITE
01/15/08	6.5 hours	Point Beach 2	Concurrent unavailabilities- station auxiliary transformer and 480V safety bus. ***IR 50-266/08-07***	7.E-06
03/13/08	38 days	Farley 1	Emergency diesel generator exhaust pipe failure. ***EA-08-192***	WHITE
03/25/08	4 years	San Onofre 2	Deficient electrical connections with potential to affect multiple safety systems. ***EA-08-296***	WHITE
07/12/08	183 days	Hatch 1	Degraded coupling leads to emergency diesel generator inoperability. ***EA-09-054***	WHITE
07/12/08	183 days	Hatch 2	Degraded coupling leads to emergency diesel generator inoperability. ***EA-09-054***	WHITE
07/31/08	138 days	Prairie Island 1	Turbine-driven auxiliary feedwater pump inoperable due to valve out-of-position. ***EA-08-272***	WHITE
07/31/08	34 years	Prairie Island 2	Potential unavailability of the component cooling water system during a postulated high-energy line break due to inadequate design. ***EA-09-167***	WHITE
08/19/08	1 year	Brunswick 1	All emergency diesel generators unable to be operated locally due to incorrect control relay wiring. ***EA-09-121***	WHITE
08/19/08	1 year	Brunswick 2	All emergency diesel generators unable to be operated locally due to incorrect control relay wiring. ***EA-09-121***	WHITE

FY 2009 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, 2009. 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 2009.

The staff is still screening and reviewing LERs concerning other potential precursor events that occurred during FY 2009.[2] Two FY 2009 precursors have been identified thus far. The staff plans to complete all FY 2009 analyses by September 2010.

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.

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 2008 (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 2009. The results for FY 2009 are based on the staff's screening and review of a combination of LERs and daily event notification reports (as of September 30, 2009). 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 1999–2008) 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. A review of the data for that period reveals the following insights:

- The mean occurrence rate of all precursors exhibits a statistically significant decreasing trend (p-value = 0.01) for the period from FY 2001–2008 (see Figure 1).

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

- The analysis detected a statistically significant decreasing trend (p-value = <0.0001) for precursors with a CCDP or ΔCDP greater than or equal to 1×10^{-4} during this same period (see Figure 2).

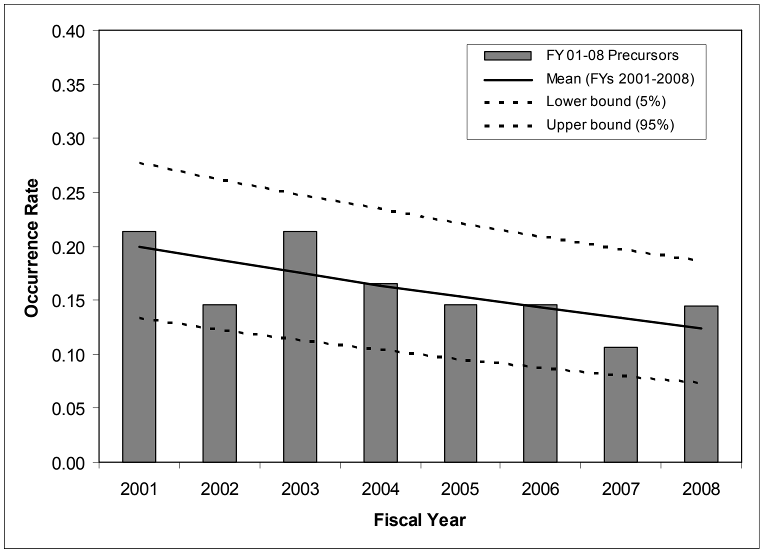

Figure 1. Total precursors.

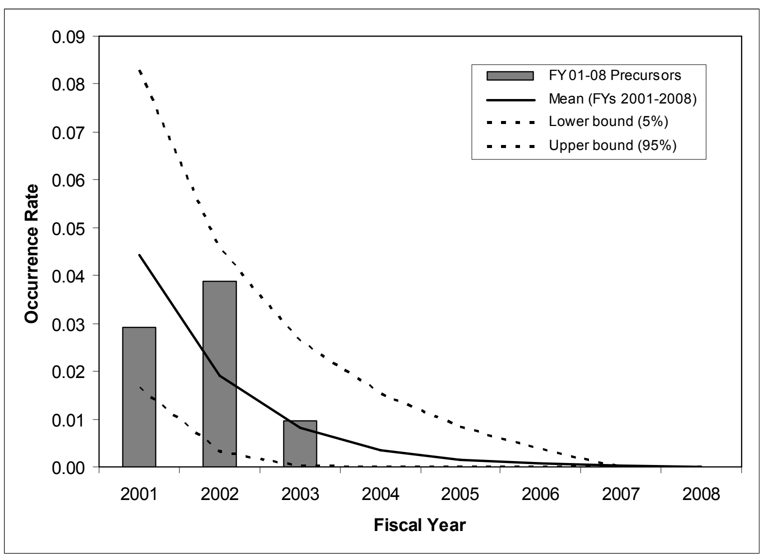

Figure 2. Precursors with a CCDP or ΔCDP ≥10^{-4}.

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:

- No *significant* precursors were identified in FY 2009.
- The staff has identified only one *significant* precursor since FY 2001. In FY 2002, the staff identified a *significant* precursor involving concurrent, 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 2001–2008.

5.1 Initiating Events vs. Degraded Conditions

A review of the data for FY 2001–2008 yields insights described below.

Initiating Events

- The mean occurrence rate of precursors involving initiating events is not statistically significant (p-value = 0.95) for the period from FY 2001–2008, as shown in Figure 3.

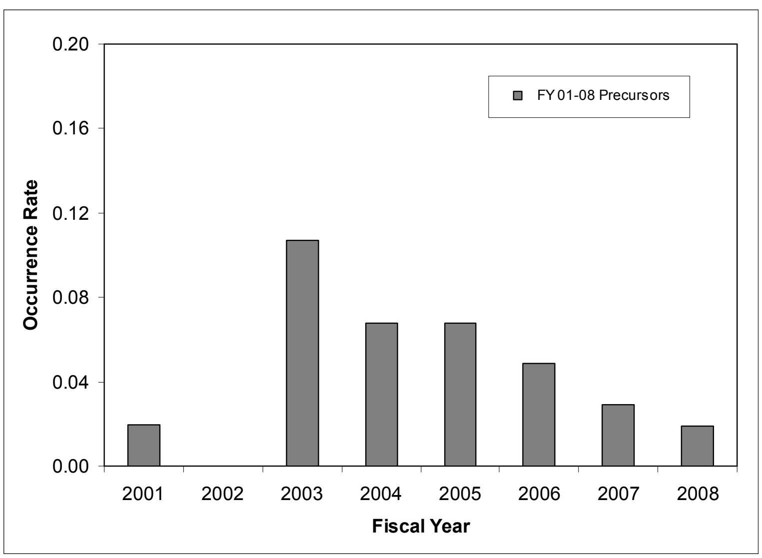

Figure 3. Precursors involving initiating events.

- Of the 37 precursors involving initiating events during FY 2001–2008, 59 percent were LOOP events.

Degraded Conditions

- The mean occurrence rate of precursors involving degraded conditions exhibits a statistically significant decreasing trend (p-value = 0.03) during the FY 2001–2008 period, as shown in Figure 4.
- Over the past 8 years, precursors involving degraded conditions outnumbered initiating events (72 percent compared to 28 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.

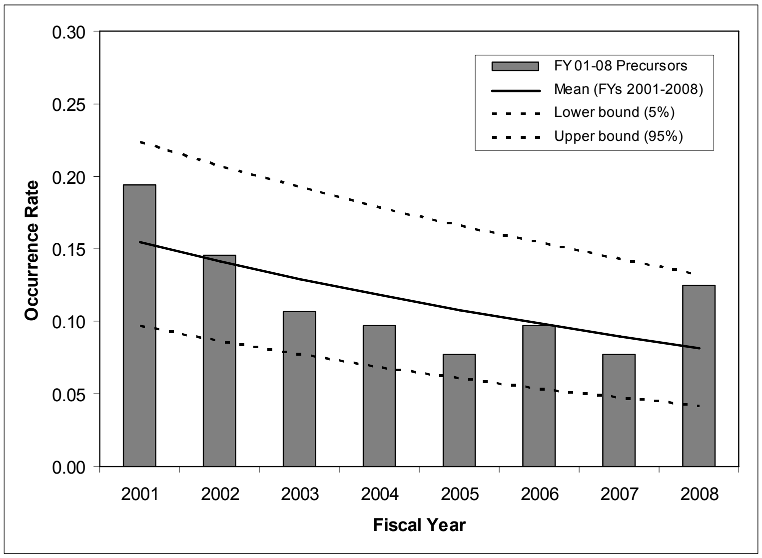

Figure 4. Precursors involving degraded conditions.

- From FY 2001–2008, 36 percent of precursors involving degraded conditions had a condition start date before FY 2001. Of these precursors, 53 percent involved degraded conditions with condition start dating back to initial plant construction.

5.2 Precursors Involving Loss of Offsite Power Initiating Events

None of FY 2008 precursors resulted from a loss of offsite power initiating event.

Results. A review of the data for FY 2001–2008 leads to the following insights:

- The mean occurrence rate of precursors resulting from a LOOP does not exhibit a trend that is statistically significant (p-value = 0.49) for the period from FY 2001–2008, as shown in Figure 5.
- Of the 22 LOOP events that occurred during the FY 2001–2008 period, one-half resulted from a degraded electrical grid outside of the nuclear power plant boundary. Eight of the 11 grid-related 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 22 LOOP precursor events during FY 2001–2008.

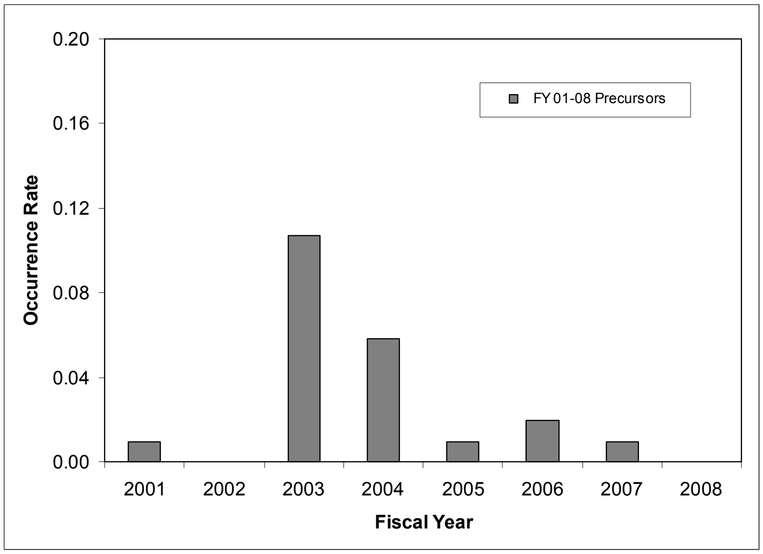

Figure 5. Precursors involving LOOP events.

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

A review of the data for FY 2001–2008 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 (p-value = 0.96) for the period from FY 2001–2008, as shown in Figure 6.

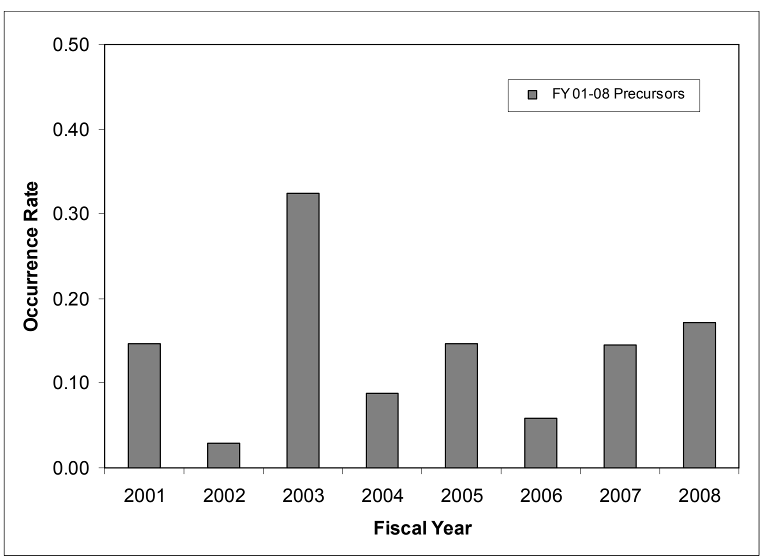

Figure 6. Precursors involving BWRs.

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

- LOOP events contributed to 63 percent of precursors involving initiating events at BWRs.
- Of the 22 precursors involving the unavailability of safety-related equipment that occurred at BWRs during FY 2001–2008, most were caused by failures in the emergency power system (50 percent), emergency core cooling systems (50 percent), electrical distribution system (18 percent), or safety-related cooling water systems (14 percent).

PWRs

- The mean occurrence rate of precursors that occurred at PWRs exhibits a statistically significant decreasing trend (p-value = 0.002) during the FY 2001–2008 period, as shown in Figure 7.

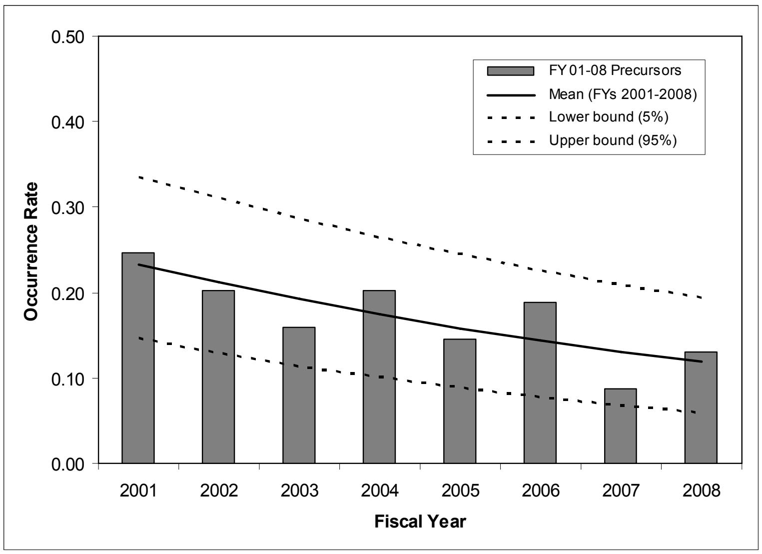

Figure 7. Precursors involving PWRs.

- LOOP events contribute to 57 percent of precursors involving initiating events at PWRs.
- Of the 73 precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2001–2008, most were caused by failures in the emergency core cooling systems (33 percent), auxiliary feedwater system (21 percent), emergency power system (19 percent), or safety-related cooling water systems (18 percent).
    - 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 15 precursors involving failures of the auxiliary feedwater system, random hardware failures (40 percent) and design errors (40 percent) were the largest failure contributors. Thirteen of the 15 precursors involved the unavailability of the turbine-driven auxiliary feedwater pump train.
    - Of the 14 precursors involving failures of the emergency power system, 12 precursors (86 percent) were from random hardware failures.

- Design errors contributed 48 percent of all precursors involving the unavailability of safety-related equipment that occurred at PWRs during FY 2001–2008.

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 1999–2008. A review of the ASP indices leads to the following insights:

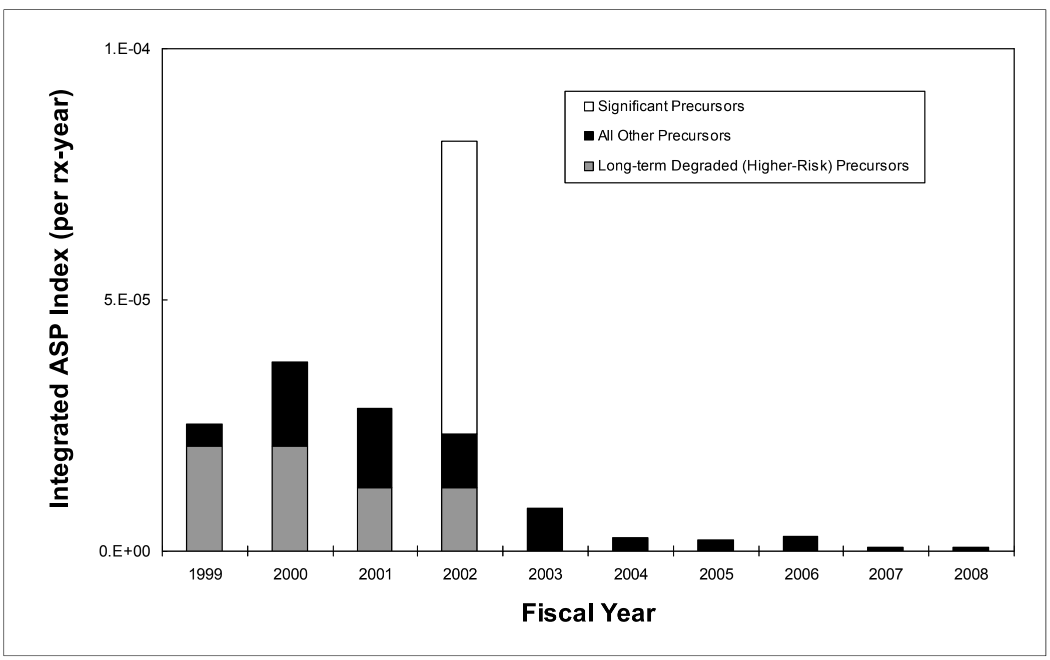

Figure 8. Integrated ASP index.

- Based on order of magnitude (10^{-5}), the average integrated ASP index for the period from FY 1999–2008 is consistent with the CDF estimates from the SPAR models and industry PRAs.
- Precursors over the 10-year period (FY 1999–2008) made the following contributions to the average integrated ASP index:
  - The one *significant* precursor (i.e., CCDP or ΔCDP greater than or equal to 1×10^{-3}) contributed to 31 percent of the average integrated ASP index over the 10-year period. The *significant* precursor (Davis-Besse, FY 2002) existed for a 1-year period.
  - Four precursors contribute 35 percent of the average integrated ASP index 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 (7×10^{-4}) and D.C. Cook (4×10^{-4}) were high and the degraded conditions had existed since plant construction.
  - The remaining 34 percent of the average integrated ASP index over the 10-year period resulted from contributions from 146 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 2001–2008 reveals that approximately 31 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 precursors that occurred over the past five years that were not explicitly modeled in a PRA or IPE. 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.

Table 4. Precursors involving failure modes or initiators not explicitly modeled in a PRA/IPE.

FY	Plant	Event Description
2008	Prairie Island 2	Potential unavailability of the component cooling water system during a postulated high-energy line break due to inadequate design. ***EA-09-167***
2008	Byron 1 & 2	Corrosion of equipment cooling water system piping. ***EA-08-046***
2008	San Onofre 2	Deficient electrical connections with potential to affect multiple safety systems. ***EA-08-296***
2008	Oconee 1	Procedure error leads to loss of reactor coolant system inventory while shutdown (Mode 6). ***EA-08-324***
2007	Cooper	Inadequate post-fire procedure could have prevented achieving safe shutdown. ***EA-07-204***
2007	McGuire 1 & 2	Potential inoperability of service water strainer backwash system during accident conditions. ***EA-08-220***
2006	Clinton	Potential air entrapment of high-pressure core spray because of incorrect suction source switchover set point. ***EA-06-291***
2006	Oconee 1, 2, & 3	Failure to maintain design control for the standby shutdown facility flooding boundary. ***EA-06-199***
2005	Kewaunee	Design deficiency could cause unavailability of safety-related equipment during postulated internal flooding. ***EA-05-176***
2005	LaSalle 1 & 2 Crystal River 3	Single-failure vulnerability of safety bus protective relay schemes caused by common power metering circuits. ***EA-05-103, EA-05-114***
2005	Watts Bar	Component cooling backup line from essential raw cooling water was unavailable because silt blockage. ***IR 50-390/04-05***
2005	Watts Bar	Low-temperature, overpressure valve actuations while shut down. ***EA-05-169***
2004	Calvert Cliffs 2	Failed relay causes overcooling condition during reactor trip. ***LER 318/04-001***
2004	Palo Verde 1, 2, & 3	Containment sump recirculation potentially inoperable because of pipe voids. ***LER 528/04-009***

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 2009. 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 FY 2009 Citizens' Report: FY 2009 Summary of Performance and Financial Results and the NRC Performance Budget: FY 2011 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 2001–2008 period. This ASP trend provides the basis for one performance indicator used by the ITP to assess industry performance. The NRC FY 2009 Citizens' Report: FY 2009 Summary of Performance and Financial Results and the NRC Performance Budget: FY 2011 will report these 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.

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 initiated 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 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 (MD) 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), and internal events during shutdown operations.
- 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, Management Directive (MD) 8.3, "NRC Incident Investigation Program," evaluations, 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 shutdown operations, external initiating events, and for assessing accident progression to the plant damage state level.

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-08-0145, "Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models," dated October 1, 2008) 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 the enhancement of the 77 Revision 3 SPAR models representing the 104 operating commercial nuclear power plants.

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 multi-unit sites. To address these plant differences, four SPAR models have been split into single-unit models. The staff has developed single-unit SPAR models for all units at Peach Bottom, Brunswick, Calvert Cliffs, and Susquehanna sites.

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 2-year time period. One significant upcoming activity is the incorporation of internal fire scenarios from the National Fire Protection Association 805 PRA studies into the SPAR models.

SPAR Models for Analysis of Internal Initiating Events during Shutdown Operation

The staff places a priority on creating methods and guidance for the risk assessment of shutdown events, with emphasis on SDP Phase 3 analyses. In FY 2009, the staff developed a detailed shutdown model maker guideline document to provide consistent guidance for the construction of shutdown SPAR models. Two SPAR models were developed using the modeling guidelines, resulting in a total of six shutdown SPAR models available to support SDP

Phase 3 analyses. The staff plans to complete three additional shutdown SPAR models in FY 2010.

MELCOR Thermohydraulic Analysis for SPAR Model Success Criteria

The staff is currently performing MELCOR analyses, using input decks developed under the State-of-the-Art Reactor Consequence Analysis project, to investigate success criteria associated with specific Level-1 PRA sequences. In some cases, these analyses confirm the existing technical basis and in other cases they support modifications that can be made to increase the realism of the agency's SPAR models.

To date, calculations have been performed for a number of sequences for both the Peach Bottom and Surry plants. These results will be incorporated in to the technical basis supporting the Surry and Peach Bottom SPAR models, and some results can be readily extended to other plants. The Office of Nuclear Regulatory Research (RES) is continuing to pursue opportunities for broadening the scope of this effort in terms of the types of sequences being investigated as well as the applicability of the work to more plants. This effort directly supports the agency's goal of using state-of-the-art tools that promote effectiveness and realism.

3.0 Additional SPAR Model Activities

SAPHIRE Version 8 Development

SAPHIRE Version 8, currently under development, 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.
- Condition assessments for SDP Phase 3 and ASP analyses, and MD 8.3 evaluations.
- Initiating event assessments for ASP analyses and MD 8.3 evaluations.
- Other types of PRA analyses requiring more significant modeling or data revisions.

Features and capabilities also have been improved for SPAR model development and use. Enhanced SPAR models for internal events during power operations have been developed to use the new SDP Phase 2 analysis interface. A new data input method and code improvements to develop and run the external events SPAR models was developed. 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 interface layout has been made more user-friendly.

Version 8 is currently in beta testing. In addition to beta testing, quality assurance activities include an independent verification and validation, an NRC internal peer review, and NRC software quality assurance audits. SAPHIRE Version 8 is anticipated to be ready for general use by April 2010.

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. The SPAR Model Quality Assurance Plan ensures that the SPAR models represent the as-built, as-operated plants. Idaho National Laboratory has implemented a Revision Control System to maintain configuration control of SAPHIRE.

In follow-up discussions on recommendation 3, 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 recommended improvements to the SAPHIRE Version 8 project software verification and validation. These recommendations were based on a comparison of the SAPHIRE testing, verification and validation to 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 is implementing these four recommendations and the code is being tested. OIG considers this issue resolved, and the issue will be closed with the release of SAPHIRE Version 8. SAPHIRE Version 8 is scheduled for release in April 2010.

Technical Adequacy of SPAR Models

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. In addition, the staff, with the cooperation of industry experts, performed a peer review of a representative boiling-water reactor (BWR) SPAR model in accordance with American National Standard, ASME RA-S-2002, "Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications," and Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities." A peer review of a representative pressurized-water reactor SPAR model is scheduled to be completed October 2009.

Evaluation of B.5.b Strategies to Mitigate Severe Accidents

This project is in support of Staff Requirements - COMGBJ-06-0004, dated April 14, 2006. The objective of this project is to establish the change in risk of the 104 NRC licensed commercial nuclear power plants based on the implementation of mitigation strategies required by Section B.5.b of Commission Order EA-02-026, dated February 25, 2002, if those mitigation strategies are used by the licensee to mitigate reactor accidents typically modeled in the SPAR models. An evaluation of 26 SPAR models has been completed as part of Phase 1 of this project. Two follow-on phases will result in the evaluation of the remaining SPAR models. This project is scheduled to be completed in October 2010.

New Reactor SPAR Models

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

The main objective of this work during FY 2009 was the development of a design-specific internal events SPAR model for the AP1000 reactor design. As part of the SPAR model development, the requisite supporting documentation also will be developed. During FY 2010, the staff plans to initiate development of a SPAR model for the Advanced Boiling-Water Reactor design. Because design standardization is a key aspect of the new plants, it should only be necessary to develop one SPAR model for each of the new designs.

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 RES, 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 (BWRs).

- 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 two years.