# POLICY ISSUE
(Information)

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FOR: The Commissioners

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SUBJECT: STATUS OF THE ACCIDENT SEQUENCE PRECURSOR PROGRAM AND THE DEVELOPMENT OF STANDARDIZED PLANT ANALYSIS RISK MODELS

PURPOSE:

To inform the Commission of the status of the Accident Sequence Precursor (ASP) Program, provide the annual quantitative ASP results, and communicate the status of the development 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 committed to report periodically to the Commission on the status of the ASP Program. In SECY-94-268, "Status of the Accident Sequence Precursor Program and Related Initiatives," dated October 31, 1994, the staff made two significant changes to this commitment. First, the staff committed to provide the report annually, and second, the staff began to provide annual quantitative ASP results. 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), contributing to the likelihood of additional failures.

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In SECY-02-0041, “Status of Accident Sequence Precursor and SPAR Model Development Programs,” dated March 8, 2002, the staff expanded the annual ASP SECY paper to include detailed information on the status of the SPAR Model Development Program. Through the SPAR Model Development Program, the staff developed standardized risk analysis models and tools that staff analysts can use in many regulatory activities.

## BACKGROUND

In fiscal year (FY) 2006, the staff streamlined the analysis and revised the review process and thus improved the timeliness of ASP analyses. The analysis process now includes results from the significance determination process (SDP) and Management Directive (MD) 8.3, “NRC Incident Investigation Program,” dated March 27, 2001, when practicable. By including these results, the staff prevented duplicate analyses for 13 precursors in FY 2006 and reduced unintended consequences of inconsistent outcomes. In addition, the revised review process has reduced administrative and review burdens to NRC staff and licensees since no formal peer reviews were required for FY 2006 analyses.

In SECY-04-0210, “Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models,” dated November 8, 2004, the staff informed the Commission of a plan to improve the timeliness of ASP analyses and complete the analyses of prior years’ precursor events.

## DISCUSSION:

This section summarizes the status, accomplishments, and results of the ASP Program and SPAR Model Development Programs since the previous status report, SECY-06-0208, “Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models,” dated October 5, 2006.

### *ASP Program*

The staff has completed the analyses of all precursor events that were identified in FY 2006 (14 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 $1\times10^{-6}$. In addition, the staff has completed the screening for FY 2007 events for *significant* precursors. *Significant* precursors have a CCDP or ΔCDP greater than or equal to $1\times10^{-3}$. The staff identified no *significant* precursors in FY 2007. The last *significant* precursor identified was the Davis-Besse event in FY 2002. The staff already has begun analyzing potential precursors occurring in FY 2007.

The staff evaluated precursor data during the period of FY 2001 through FY 2006 to identify statistically significant adverse trends for the Industry Trends Program. No statistically significant trend was detected for all precursors during this 6-year period. However, the staff noted a statistically significant decreasing trend for precursors with a CCDP or ΔCDP greater than or equal to $1\times10^{-4}$ during this same period.

*SPAR Model Development 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 probabilistic risk assessments (PRAs). Any differences identified between the two models are discussed with the licensee. Once the differences are understood, the SPAR models are revised if necessary to properly represent the as-built, as-operated plant, while unresolved technical issues are documented. A total of 52 plant models (out of 74 models) have been completed. In addition, the staff developed a preliminary Browns Ferry Unit 1 SPAR model and will review it against the licensee model when the licensee completes an American Society of Mechanical Engineers standard peer review of its PRA.

Also in FY 2006, the staff continued to expand the SPAR model capability beyond internal events at full power operation. External event scenarios (e.g., fires, floods, and seismic events) from the licensee submittals of the Individual Plant Examinations for External Events (IPEEEs) were incorporated into five additional SPAR external event models. To date, the staff has completed a total of 15 SPAR external event models. In response to a user need for SDP and ASP analyses, the staff initiated model development of low-power and shutdown (LP/SD) operation 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 through to the level of containment damage.

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 worked with the Office of the Inspector General (OIG) on an audit of the NRC's use of PRA and SPAR models in regulatory activities. The OIG made three recommendations to ensure that the models sufficiently represent the as-built, as-operated plants and that software used to run the models has been verified and validated. The staff implemented an updated SPAR model quality assurance plan and revised the risk assessment standardization project (RASP) handbook in response to the OIG recommendations. The staff has responded to all three OIG recommendations, and the OIG considers the issues resolved.

The staff also is working with industry representatives to improve the SPAR models. The Office of Nuclear Regulatory Research and the Electric Power Research Institute (EPRI) executed an Addendum to the Memorandum of Understanding (MOU) to conduct cooperative research for PRA. Several of the initiatives in this effort are intended to resolve technical issues that account for differences between the 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 2007 and FY 2008 events to support the agency's Strategic Plan goals for monitoring performance.

For the SPAR Model Development Program, the staff will continue to implement enhancements to the Revision 3 internal event models for full power operations. The staff plans to complete these enhanced models in 2008. The staff is also working with industry representatives to resolve PRA technical issues common to both licensee PRA and SPAR models. This effort is expected to span the next 3 years.

Additional modeling capability (e.g., external events, LP/SD scenarios, and containment systems) will continue to be added into SPAR models. The staff will utilize 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 representative sets of models that contain external events, LP/SD scenarios, and the modeling of containment systems by 2009. The staff will evaluate the need for additional plant models after the use of this representative set as part of the SDP, ASP, and MD 8.3 processes.

Standardized risk assessment guidelines as part of the RASP handbook will be revised by the end of calendar year 2007 to meet the needs of the SDP, and the staff will continue to work with industry representatives to better resolve differences in the use of risk models in event assessments.

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 SPAR Model Development 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. The staff uses SPAR models to support the Reactor Oversight Process, the ASP Program, the MD 8.3 evaluations, and the Generic Safety Issue resolution process. The staff also uses SPAR models to perform analyses in support of risk-informed reviews of license amendments.

COORDINATION:

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

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

# Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Model Development Program

## 1.0 Accident Sequence Precursor Program Background

The U.S. Nuclear Regulatory Commission (NRC) established the Accident Sequence Precursor (ASP) Program in 1979 in response to 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), contributing to the likelihood of additional failures.

To identify potential precursors, the NRC staff reviews plant events from licensee event reports (LERs), inspection reports, and special staff requests. 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 $1 \times 10^{-6}$ to be a precursor. The ASP Program defines a *significant* precursor as an event with a CCDP or ΔCDP greater than or equal to $1 \times 10^{-3}$.

<u>Program Objectives</u>

The ASP Program has the following objectives:

- provide a comprehensive, risk-informed 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 NUREG-1100, Volume 22, "Performance

Budget: Fiscal Year 2007," issued February 2006). 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 $1\times10^{-3}$)
- 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," dated March 27, 2001). Compared to the other two programs, the ASP Program assesses the significance of a different 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 there was no identified deficiency in the licensee's performance. The ASP Program scope also includes events with concurrent, multiple degraded conditions.

## 2.0 ASP Program Status

Analysis of ASP Events

Table 1 of Enclosure 2 to this paper provides the status of events identified as potential precursors under the ASP Program. The staff has completed all precursor analyses from fiscal year (FY) 2006. The analyses of FY 2007 events are in progress.

ASP Program Status

The staff plans to complete all FY 2007 analyses by September 2008. In addition, the ASP Program will give priority to analyses of potentially high-risk events when such events are identified during NRC inspections or in LERs.

ASP Streamlining

In June 2006, the staff implemented changes to streamline the ASP process and thus improve ASP timeliness and efficiency. The ASP Program gained efficiency by using results from the SDP and MD 8.3 evaluations. In FY 2006, the staff quantified 9 analyses (11 precursors) using the results of the SDP program, and the ASP team and Region II jointly prepared 1 analysis (2 precursors) as part of an MD 8.3 process.

As part of the new ASP process, lower risk events, specifically events with CCDP or ΔCDP of less than $1\times10^{-4}$, no longer receive formal review by the Office of Nuclear Reactor Regulation (NRR), regional office, or the licensee. None of the FY 2006 analyses exceeded $1\times10^{-4}$, so the staff issued these ASP analyses as final after completion of internal reviews.

The ASP Program continues to improve its timeliness. The staff completed the FY 2005 analyses and issued them in November 2006; it completed the FY 2006 analyses and issued them in July 2007, which is a 4-month improvement. Delays before FY 2005 were much longer.

## 3.0 Standardized Plant Analysis Risk Model Development Program Background

The objective of the Standardized Plant Analysis Risk (SPAR) Model Development Program is to develop standardized risk analysis models and tools that staff analysts use in many regulatory activities, including the ASP Program and Phase 3 of the 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/station blackout (LOOP/SBO) 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 an NRC-developed 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' PRAs. The staff completed the initial set of 72 Revision 3 SPAR models, representing all 103 units operating at the time, and benchmarked them against licensee PRAs during the onsite quality assurance reviews of these models. The preliminary SPAR model for Browns Ferry Unit 1 and the splitting of the Peach Bottom model into two separate models provide for 74 Revision 3 SPAR models, representing all 104 operating units.

In 1999, the SPAR Model Users Group (SMUG) assumed coordination of model development efforts that support the ASP Program and other risk-informed regulatory processes. This group consists of representatives from the Office of Nuclear Regulatory Research (RES), NRR, and the NRC's regional offices. In August 2000, SMUG completed the SPAR model development plan, which addresses the following models:

- internal initiating events during full-power operation (Revision 3 SPAR models)
- internal initiating events during low-power and shutdown (LP/SD) operations
- external initiating events (including fires, floods, and seismic events)
- calculation of large early release frequency (LERF)

In addition to SMUG, the NRC 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 MD 8.3. Under this project, the NRC 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 LP/SD operations, and LERF sequences
- provide on-call technical support to NRR and regional senior reactor analysts

## 4.0 SPAR Model Development Status

The SPAR Model Development Program continues to play an integral role in the ASP analysis of operating events. Many other agency activities, such as the ROP, 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 LP/SD operations and external initiating events and for assessing accident progression through to the plant damage state level.

The staff is currently using SPAR models to support the State-of-the-Art Reactor Consequence Analysis (SOARCA) project. The staff is using Revision 3.31 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.

The staff also plans to modify the SPAR models based on licensee B.5.b submittals and evaluate the reduction in risk realized from implementation of the mitigation strategies. Inspections planned to confirm implementation of Phases 2 and 3 of the B.5.b measures are scheduled to be completed at the end of calendar year (CY) 2008. The results of the inspections will provide a better understanding of the mitigation strategies to include in the SPAR model revisions, thus ensuring the models accurately reflect the as-built, as-operated plant. The FY 2009 budget includes resources for accomplishing the revisions to the SPAR models.

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-06-0208, "Status of the Accident Sequence Precursor Program and the Development of Standardized Plant Analysis Risk Models," dated October 5, 2006) as described below.

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

The staff developed enhanced Revision 3 SPAR models in response to NRR user needs. This effort involved (1) performing a cut-set-level review against the respective licensee's plant PRA for each of the Revision 3 SPAR models for 52 models that were not pilot plants in the MSPI program, 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 developed a preliminary Browns Ferry Unit 1 SPAR model. The staff will perform a cut-set-level review when the licensee completes an American Society of Mechanical Engineers standard peer review of its PRA model and provides the necessary information to the staff.

The staff is updating the enhanced 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. Future Revision 3 enhancements will use NUREG/CR-6928 data.

The staff has identified important plant differences at some multiunit sites. To address these plant differences, applicable SPAR models are being split into individual unit models. The staff has developed single-unit SPAR models for Peach Bottom Units 2 and 3. The staff also plans to develop single-unit SPAR models for four multiunit sites (Brunswick, Calvert Cliffs, Peach Bottom, and Susquehanna). This split will result in 77 version 3.31 enhanced SPAR models for 104 plants at the end of CY 2008.

In addition to the above model enhancements, the staff is scheduled to accomplish model reevaluations in 2008. These include reevaluations of the eight MSPI pilot plants and the nine version 3.31 enhanced SPAR models because of changes to licensee PRA models that occurred during the implementation of MSPI.

*SPAR Models for the Analysis of External Events*

The staff incorporated external initiating events (e.g., fires, floods, and seismic events) into the Revision 3 SPAR models for five additional plants and used available models to support the SOARCA project. The staff has completed 14 integrated (i.e., combined internal and external events) models. The internal and external event scenarios are modeled seamlessly and can be exercised by the existing experienced users with little additional effort. The staff will produce additional models as needed in coordination with the requirements of the SDP and ASP Program.

Currently available information is used to identify and incorporate external event sequences into the SPAR models. The SPAR models do not include the modeling of the phenomenology of the external events; instead, they model the accident sequences resulting from these phenomena. For example, the modeling of internal fire scenarios does not include the modeling of fire growth, fire spread, and equipment vulnerability; instead, SPAR fire scenarios are defined using information on accident scenario screening and accident scenario definitions from licensee submittals as part of the individual plant examination of external events. Generic information from available staff studies was also used where applicable. For example, much seismic model standardization is achieved by consistent modeling of seismic scenarios based on fragilities of key structures, systems, and components.

The staff is pursuing validation and update of the external events SPAR model scenarios as opportunities to do so arise. For example, the staff is making an effort to determine the feasibility of obtaining fire modeling and scenario information from the ongoing pilot projects for the National Fire Protection Association 805 application program to update and upgrade the existing fire scenarios in the SPAR models.

*SPAR Models for Analysis of Internal Initiating Events during LP/SD Operation*

The staff has implemented a second generation of model development in response to user interest for SDP and ASP analyses for initiating events during LP/SD operations. Currently, two

Revision 3 SPAR models have second-generation LP/SD scenarios. These integrated models were created under an updated LP/SD project plan. This activity supplements earlier work that had produced 11 simplified LP/SD models. The second-generation models are more detailed and more portable when compared to the original models.

The staff expects three more LP/SD models to be completed in early FY 2008. The staff will produce additional models as needed in coordination with the needs of the SDP and ASP Program.

The staff will enhance model validation to increase model fidelity by visiting sites and focusing on plants with models that are most likely to be used in the near future by NRC SDP analysts.

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

The agency initiated a project to develop three extended SPAR models covering different reactor technologies. In addition to the plant systems needed to mitigate core damage, these extended SPAR models will also include containment systems that are needed to mitigate potential radionuclide release. These models will provide the capability to assess accident progression through to the containment damage state level.

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 will also provide the capability to further extend the models for other modes of radionuclide release should the need arise in the future.

## 5.0 Additional SPAR Model Activities

<u>Audit by the Office of Inspector General</u>

The 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 are sufficiently representative of the as-built, as-operated plant to support model uses.

In the follow-up discussions with OIG and in its formal response, the staff stated that, over the years, the NRC staff has developed processes that ensure that risk-informed regulatory decisions are based on the as-built and as-operated plant. These processes include the following:

— use of the draft RASP Handbook that provides guidance on basic principles of risk assessment, appropriate methodology (i.e., a tool box of techniques), and documentation standards,

— internal review of the risk evaluations by experienced analysts, and

— consensus review for major decisions and high-risk events, which ensures that both the licensee and the NRC are using state-of-the-art approaches and complete plant information.

In summary, as discussed with OIG, the revised RASP Handbook will provide a formal, written process for maintaining PRA models that are sufficiently representative of the as-built, as-operated plant to support model use. Based on the staff's response, OIG considers this recommendation to be resolved. This issue will be closed when the next revision of the RASP Handbook is completed in CY 2007.

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

The staff has completed actions to address this recommendation. On April 2, 2007, the new Idaho National Laboratory (INL) software quality assurance program was implemented. On April 5, 2007, the staff provided OIG with confirmation of this action and with INL Report PDD-13610, Revision 2, "Software Quality Assurance Program," effective date April 2, 2007, and INL Report LWP-13620, Revision 3, "Software Quality Assurance," effective date April 2, 2007. The INL SAPHIRE development project will now make use of this new software quality assurance program. Thus, a fully documented process to conduct and maintain configuration control of PRA software (i.e., SAPHIRE, GEM) has been developed and implemented.

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

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. INL supported the implementation of four recommendations from Idaho National Engineering and Environmental Laboratory Report CCN-42566, "Submittal of Final Report under Job Code Number (JCN) Y6394, Task 8," dated May 30, 2003, for the SAPHIRE project verification and validation. These recommendations 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.

INL will implement these recommendations as requested by the NRC in the SAPHIRE version 8 statement of work. The general release date for SAPHIRE version 8 is anticipated in CY 2009. OIG considers this issue resolved, and the issue will be closed with the release of SAPHIRE version 8.

Technical Adequacy of SPAR Models

The staff implemented an updated SPAR model quality assurance plan covering the Revision 3 SPAR models. The staff has processes in place to verify, validate, and benchmark these models according to the guidelines and standard established by the SPAR Model Development 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 in place processes 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. As discussed in the previous section, the staff discussed with the OIG the issue of development and implementation of a formal, written process for maintaining SPAR models that are sufficiently representative of the as-built, as-operated plant to support model uses, and the OIG has agreed that this issue is resolved.

The staff has also discussed the potential application of Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," to the SPAR models. The staff determined that it was not cost-effective or necessary to perform the Regulatory Guide 1.200 evaluation at this time. The staff believes that, based on the processes discussed in the previous paragraph, the SPAR models are of sufficient quality to support their intended applications.

Cooperative Research for PRA

RES has executed an addendum to the memorandum of understanding with the Electric Power Research Institute 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 results.

The objective of this effort is to work with the broader PRA community to resolve PRA issues and develop PRA methods, tools, data, and technical information useful to both the NRC and industry. The agency has established working groups that include support from NRR, the 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

# Results, Trends, and Insights from the Accident Sequence Precursor Program

This enclosure discusses the results of accident sequence precursor (ASP) analyses conducted by the U.S. Nuclear Regulatory Commission (NRC) as they relate to events that occurred during fiscal years (FY) 2006–2007. Based on those results, this document also discusses the NRC's analysis of historical ASP trends and the evaluation of the related insights. The four tables and eight figures that augment this discussion appear at the end of this enclosure.

## 1.0 ASP Event Analyses

Table 1 summarizes the status of the NRC's ASP analyses as of September 30, 2007. Specifically, the table identifies ASP analyses that the NRC staff has completed for events that occurred during FY 2006–2007. (Note that, as of September 30, 2007, the staff had not yet screened all of the FY 2007 events.) The following subsections summarize the results of these analyses, which are further detailed in the associated Tables 1–4.

***FY 2006 Analyses.*** The ASP analyses for FY 2006 identified 14 precursors. Of the 14 precursors, 13 occurred while the plants were at power. The staff used significance determination process (SDP) analyses to identify 11 of the 14 precursors.

Table 2 presents the results of the staff's ASP analyses for FY 2006 precursors that involved initiating events, while Table 3 presents the analysis results for precursors that involved degraded conditions.

***FY 2007 Analyses.*** The staff has completed all screening and reviews for potential *significant* precursors (i.e., conditional core damage probability (CCDP) or increase in core damage probability (ΔCDP) greater than or equal to $1\times10^{-3}$) through September 30, 2007. In particular, the staff reviewed a combination of licensee event reports (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 FY2007.

The staff is still screening and reviewing LERs concerning other potential precursor events that occurred during FY 2007.[1] The staff plans to complete all FY 2007 analyses by September 2008.

## 2.0 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 1). 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) significantly increased the number of precursors identified compared to those identified in previous years. The data period for trending analyses ends in FY 2006 (the last full year of completed ASP analyses)

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

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 2007. The results for FY 2007 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.

### 2.1 Occurrence Rate of All Precursors

The NRC's Industry Trends Program (ITP) provides the basis for addressing the agency's performance goal measure on the number of "statistically significant adverse industry trends in safety performance" (one measure associated with the safety goal established in the NRC's Strategic Plan). Precursors identified by the ASP Program are 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 2001–2006. A review of the data for that period reveals the following insights:

- The mean occurrence rate of all precursors does not exhibit a trend that is statistically significant for the period from FY 2001–2006, as shown in Figure 1.
- The analysis detected a statistically significant decreasing trend for precursors with a CCDP or ΔCDP greater than or equal to $1\times10^{-4}$ during this same period (see Figure 2).

### 2.2 *Significant* Precursors

The ASP Program provides the basis for the FY 2006 performance goal measure of "zero events per year identified as a *significant* precursor of a nuclear accident" (one measure associated with the safety goal established in the 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 $1\times10^{-3}$) of leading to a reactor accident (see Reference 2).

***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 2001–2007.
- The staff identified no *significant* precursors in FY 2007.
- The staff has identified only one *significant* precursor since FY 2001 (Davis-Besse, FY 2002). Reference 3 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 4 years. The events in this group involve differing failure modes, causes, and systems.

## 3.0 Insights and Other Trends

The following sections provide additional ASP trends and insights from the period FY 2001–2006.

### 3.1 Initiating Events vs. Degraded Conditions

A precursor can be the result of either (1) an operational event involving an initiating event such as a loss of offsite power (LOOP) or (2) a degraded condition found during a test, inspection, or engineering evaluation. A degraded condition involves a reduction in safety system reliability or function for a specific duration (although no reactor trip initiator actually occurred during this time that challenged the degraded condition).

A review of the data for FY 2001–2006 yields insights described below.

***Initiating Events***

- Over the past 6 years, precursors involving degraded conditions outnumbered initiating events (70 percent compared to

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2 The staff has completed all screening and reviews through September 30, 2007.

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 2001–2006, as shown in Figure 3.
- Of the precursors involving initiating events during FY 2001–2006, 68 percent were LOOP events.

***Degraded Conditions***

- The mean occurrence rate of precursors involving degraded conditions exhibits a statistically significant decreasing trend during the FY 2001–2006 period, as shown in Figure 4.
- From FY 2001–2006, 45 percent of precursors involving degraded conditions had a condition start date before FY 2001.

## 3.2 Precursors Caused by Degraded Conditions

Most precursors involving degraded conditions result from equipment unavailabilities. Such events typically occur for extended periods without a reactor trip, or in combination with a reactor trip in which a risk-important component is unable to perform its safety function as a result of a degraded condition.

A review of the data for FY 2001–2006 yields insights described below concerning the unavailability of safety-related equipment.[3]

***Equipment Unavailabilities at Boiling-Water Reactors***

- Of the 15 precursors involving the unavailability of safety-related equipment that occurred at boiling-water reactors (BWRs) during FY 2001–2006, most were caused by failures in the emergency power system (60 percent), residual heat removal system (20 percent), or high-pressure coolant injection system (20 percent).

***Emergency Core Cooling Systems in Pressurized-Water Reactors***

- The unavailability of safety-related high- and/or low-pressure injection trains contributed to 58 percent of all identified precursors that occurred at pressurized-water reactors (PWRs) during FY 2001–2006. Failures in either the emergency core cooling system (ECCS) (11 percent) or emergency power sources (22 percent) caused most of these unavailabilities, or they resulted from design-basis issues involving other structures or systems that impact either the ECCS or one of its support systems (58 percent).
- A condition that affected sump recirculation during postulated loss-of-coolant accidents of varying break sizes caused 16 of the precursors.

***Auxiliary/Emergency Feedwater Systems in Pressurized-Water Reactors***

- The unavailability of one or more trains of the auxiliary and emergency feedwater (AFW/EFW) systems contributed to 41 percent of all precursors that occurred at PWRs. Most of these unavailabilities resulted from failures in the AFW/EFW systems (13 percent) or emergency power sources (38 percent), or they resulted from design-basis issues involving other structures or systems that impact either the AFW/EFW systems or one of their support systems (50 percent).
- The four precursors that involved a failure in an AFW/EFW train yield the following insights:
  - One of the train failures occurred following a reactor trip.
  - All four of the precursors involved the unavailability of the turbine-driven AFW/EFW pump train.

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

*Emergency Power Sources in Pressurized-Water Reactors*

- The unavailability of emergency power sources, such as emergency diesel generators (EDGs) and hydroelectric generators (at Oconee), contributed to 29 percent of all precursors that occurred at PWRs.[4] Most of these unavailabilities resulted from random hardware failures in the emergency power system (35 percent).
- The other unavailabilities were attributable to design-basis issues (48 percent) and losses of service water (17 percent).
- In all the analyzed LOOP events at PWRs, the turbine-driven AFW/EFW pumps were operable.

Section 3.3 discusses insights related to precursors that involved a LOOP with simultaneous EDG unavailability.

### 3.3 Precursors Involving Loss of Offsite Power Initiating Events

Only one LOOP event (resulting in two precursors) occurred in FY 2006. The dual-unit LOOP event occurred at Catawba.

***Results.*** A review of the data for FY 2001–2006 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 2001–2006, as shown in Figure 4.
- Of the LOOP events that occurred during the FY 2001–2006 period, 52 percent resulted from a degraded electrical grid.
- A simultaneous unavailability of an emergency power system train was involved in 2 of the 21 LOOP precursor events during FY 2001–2006.

### 3.4 Precursors at Boiling-Water Reactors versus Pressurized-Water Reactors

A review of the data for FY 2001–2006 reveals the results for BWRs and PWRs described below.

***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 2001–2006, as shown in Figure 6.
- An average of five precursors per year occurred at BWRs during FY 2001–2006.
- LOOP events contributed to 69 percent of precursors involving initiating events at BWRs.

***PWRs***

- The mean occurrence rate of precursors that occurred at PWRs does not exhibit a trend that is statistically significant for FY 2001–2006, as shown in Figure 7.
- An average of 12 precursors per year occurred at PWRs during FY 2001–2006.
- LOOP events contribute to 67 percent of precursors involving initiating events at PWRs.

### 3.5 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 the 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

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[4] Not all EDG unavailabilities are precursors. The ASP Program screens out an EDG unavailability for a period of less than one surveillance test cycle (1 month), assuming no other complications. In addition, the risk contributions of EDG unavailabilities vary from plant to plant and may result in a ΔCDP less than the threshold of a precursor ($1 \times 10^{-6}$).

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 $5\times10^{-6}$. 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 $5\times10^{-6}$ 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 2001–2006. A review of the ASP indices leads to the following insights:

- Based on order of magnitude, the average integrated ASP index for the period from FY 2001–2006 is consistent with the CDF estimates from the SPAR models and the licensees' PRAs.
- Precursors over the 6-year period (FY 2001–2006) made the following contributions to the average integrated CDF:
  - The one *significant* precursor (i.e., CCDP or ΔCDP greater than or equal to $1\times10^{-3}$) contributed to 45 percent of the average integrated CDF from precursors over the 6-year period. The *significant* precursor (Davis-Besse, FY 2002) existed for a 1-year period.
  - Two precursors contribute 24 percent of the average integrated CDF from precursors over the 6-year period. The two precursors stem from long-term degraded conditions at Point Beach Units 1 and 2 (discovered in 2001) that involved potential common-mode failure of all AFW pumps. The associated ΔCDPs of the degraded conditions at Point Beach were high ($7\times10^{-4}$), and the degraded conditions had existed since plant construction.
  - The remaining 31 percent of the average integrated CDF from precursors over the 6-year period resulted from contributions from 101 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 must also 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 since the discovery of precursors involving longer term degraded conditions in future years may change the cumulative risk from the previous year(s). Because of these and other limitations, the staff has primarily used the rate of CCDPs and ΔCDPs as a trending indication.

### 3.6 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 2001–2006 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 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.

## 4.0 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 $1 \times 10^{-3}$) in FY 2006 or FY 2007. The ASP Program provides the basis for the FY 2005 performance goal measure of "zero events per year identified as a *significant* precursor of a nuclear accident." The NRC's Performance and Accountability Report for FY 2007 and the NRC Performance Budget for FY 2008 will report these results.
- ***Occurrence Rate of All Precursors.*** The mean occurrence rate of all precursors does not exhibit a trend that is statistically significant for the period from FY 2001–2006.

  During the same period, the analysis detected a statistically significant decreasing trend for precursors with a CCDP or ΔCDP greater than or equal to $10^{-4}$ and precursors involving degraded conditions.

## 5.0 References


1. NUREG/CR-5750, "Rates of Initiating Events at U.S. Nuclear Power Plants: 1987–1995," U.S. Nuclear Regulatory Commission, Washington, DC, February 1999.
2. NUREG-1100, Vol. 21, "Performance Budget, Fiscal Year 2006," U.S. Nuclear Regulatory Commission, Washington, DC, February 2005.
3. 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 (as of September 30, 2007)**

| Status | FY 2006 | FY 2007[a] |
|---|---|---|
| Analyzed events that were determined not to be precursors | 95 | 32 |
| Events to be further analyzed | — | 18 |
| ASP precursor analyses | 3 | — |
| SDP (or MD 8.3) results used for ASP program input | 11 | 4 |
| Total precursors identified | 14 | 4 |

a. As of September 30, 2007, the staff has not yet screened all of the FY 2007 events and unavailabilities.

**Table 2. FY 2006 Precursors Involving Initiating Events (as of September 30, 2007)**

| Event Date | Plant | Description | CCDP |
|---|---|---|---|
| 2/23/06 | Millstone 2 | Reactor trip caused by loss of instrument air. ***LER 336/06-002*** | $8 \times 10^{-6}$ |
| 3/8/06 | Turkey Point 3 | Loss of RHR while in Mode 5 because of electrical complications. ***EA-06-200*** | White |
| 5/20/06 | Catawba 1 | Dual Unit LOOP. ***LER 413/06-011*** | $9 \times 10^{-5}$ |
| 5/20/06 | Catawba 2 | Dual Unit LOOP. ***LER 413/06-011*** | $6 \times 10^{-5}$ |

**Table 3. FY 2006 Precursors Involving Degraded Conditions (as of September 30, 2007)**

| Event Date[a] | Condition Duration[b] | Plant | Description | ΔCDP/ SDP Color |
|---|---|---|---|---|
| 11/7/05 | 2 years | Turkey Point 3 | AFW pump inoperable for greater time than allowed by technical specifications. ***EA-06-027*** | White |
| 12/1/05 | 147 days | Quad Cities | ERVs were inoperable during extended power uprate conditions because of inadequate power uprate evaluation. ***EA-06-112*** | White |
| 1/20/06 | since plant startup | Clinton | Potential air entrapment of HPCS because of incorrect suction source switchover setpoint. ***EA-06-291*** | White |
| 3/24/06 | 9 years | Calvert Cliffs 1 | Degraded EDG caused by inadequate feeder breaker. ***LER 317/06-001*** | White |
| 4/28/06 | 2 years | Oconee 1 | Failure to maintain design control for an SSF flooding boundary. ***EA-06-199*** | White[c] |
| 4/28/06 | 2 years | Oconee 2 | Failure to maintain design control for an SSF flooding boundary. ***EA-06-199*** | White[c] |
| 4/28/06 | 2 years | Oconee 3 | Failure to maintain design control for an SSF flooding boundary. ***EA-06-199*** | White[c] |
| 5/1/06 | 1 year | Oconee 3 | Potentially degraded containment sump recirculation because of debris. ***EA-06-295*** | White |
| 7/25/06 | 58 days | Palo Verde 3 | Inoperable EDG caused by inadequate maintenance procedures and corrective actions. ***EA-06-296*** | White |
| 8/17/06 | 51 days | Kewaunee | Degraded EDG caused by fuel oil leak. ***EA-07-058*** | Yellow |

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.
c. Final SDP color may or may not change to GREEN pending the outcome of the licensee’s appeal.

**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 | Year | Event Description |
|---|---|---|
| Point Beach 1 | 2006 | Calculation errors could lead to degraded long-term ECCS cooling. ***LER 266/05-006*** |
| Clinton | 2006 | Potential air entrapment of HPCS because of incorrect suction source switchover setpoint. ***EA-06-291*** |
| Oconee 1, 2, & 3 | 2006 | Failure to maintain design control for an SSF 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<br>Crystal River 3 | 2005 | Single-failure vulnerability of 4160 V ESF bus protective relay schemes caused by common power metering circuits. ***LER 302/05-001, LER 373/05-001*** |
| Watts Bar | 2005 | Component cooling backup line from essential raw cooling water was unavailable because silt blockage. ***IR 390/04-05*** |
| Watts Bar | 2005 | Low-temperature, overpressure valve actuations while shut down. ***IR 390/05-03*** |
| 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, RCP seal cooling, loss of RCS 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*** |
| Crystal River 3<br>Three Mile Island 1<br>Surry 1<br>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 339/01-003, LER 339/02-001*** |
| Columbia | 2002 | Common-cause failure of breakers used in four safety-related systems. ***IR 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 HPI pumps. ***LER 346/02-002*** |
| Callaway | 2002 | Potential common-mode failure of all AFW pumps because of foreign material in the CST caused by degradation of the floating bladder. ***LER 483/01-002*** |
| Point Beach 1 & 2 | 2002 | Potential common-mode failure of all auxiliary feedwater (EFW) pumps because of a design deficiency in the EFW 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, nonrecoverable failure of the EFW pumps. ***LER 266/01-005*** |
| Shearon Harris | 2002 | Potential failure of RHR pump A and containment spray pump A because of debris in the pumps' suction lines. ***LER 400/01-003*** |
| Oconee 1, 2, & 3<br>Arkansas 1<br>Palisades | 2001 | RPV head leakage because of cracking of CRDM nozzle(s). ***LER 269/00-006, LER 269/02-003, LER 269/03-002, LER 270/01-002, LER 270/02-002, LER 287/01-001, LER 287/01-003, LER 287/03-001, LER 313/01-002, LER 313/02-003, LER 255/01-002, LER 255/01-004*** |
| Kewaunee | 2001 | 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. ***IR 305/02-06*** |

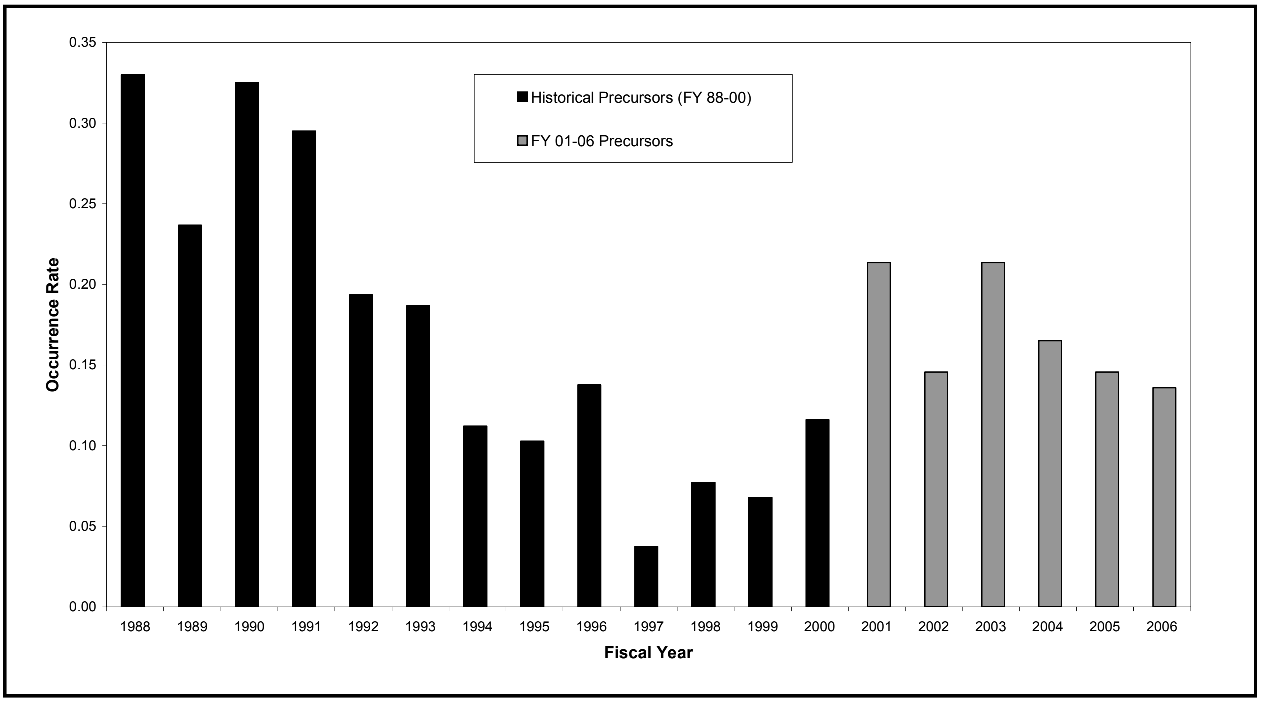


**Figure 1. Total precursors—occurrence rate, by fiscal year.** Data for FY 1988–2000 are shown for historical perspective. No trend line is shown because no statistically significant trend (p-value = 0.20) is detected for the FY 2000–2006 period.

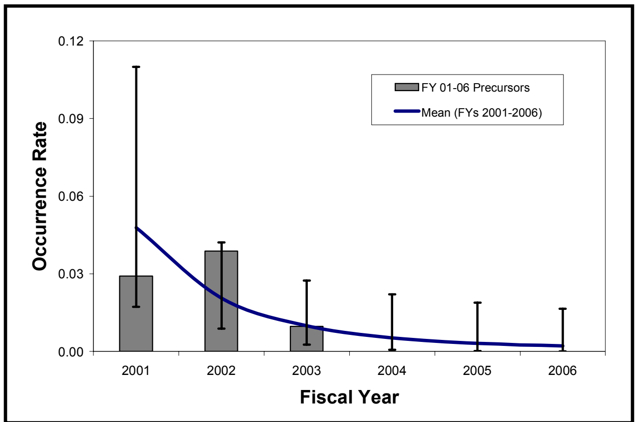


**Figure 2. Precursors with a CCDP or ΔCDP ≥$10^{-4}$—occurrence rate by fiscal year.** A statistically significant decreasing trend (p-value = 0.002) is detected for the FY 2000–2006 period.

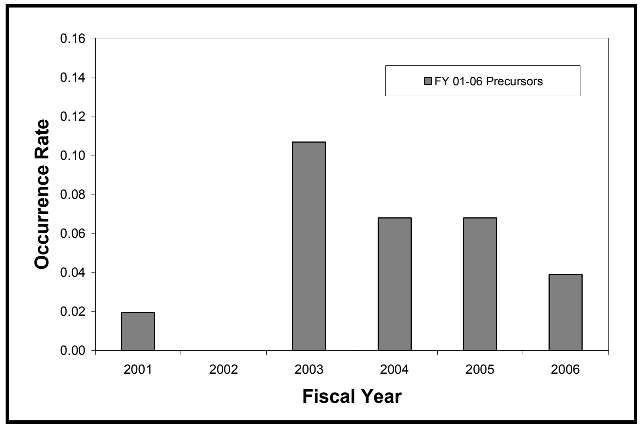


**Figure 3. Precursors involving initiating events—occurrence rate by fiscal year.** No trend line is shown because no statistically significant trend (p-value = 0.15) is detected for the FY 2000–2006 period.

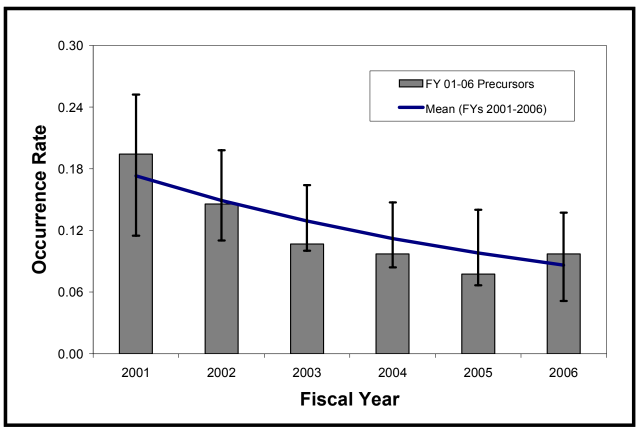


**Figure 4. Precursors involving degraded conditions—occurrence rate by fiscal year.** A statistically significant decreasing trend (p-value = 0.01) is detected for the FY 2000–2006 period.

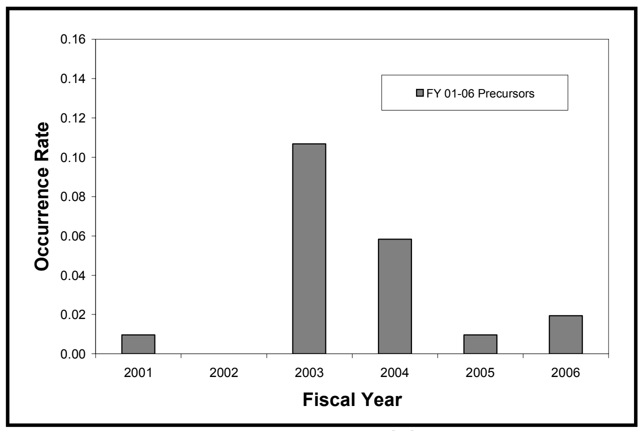


**Figure 5. Precursors involving LOOP events—occurrence rate by fiscal year.** No trend line is shown because no statistically significant trend (p-value = 0.85) is detected for the FY 2000–2006 period.

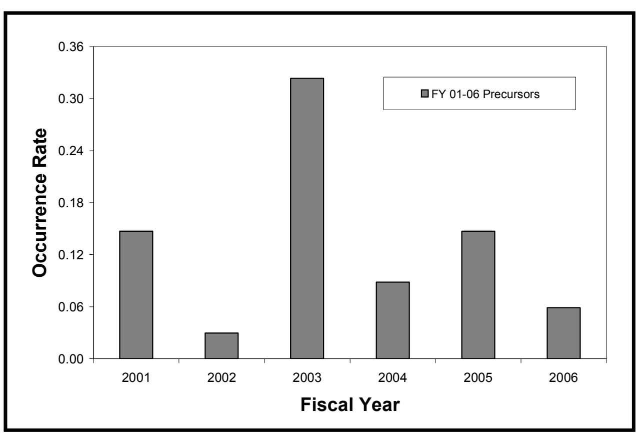


**Figure 6. Precursors involving BWRs—occurrence rate by fiscal year.** No trend line is shown because no statistically significant trend (p-value = 0.54) is detected for the FY 2000–2006 period.

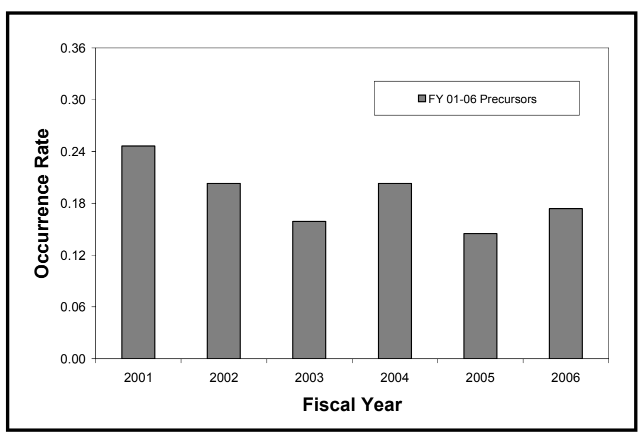


**Figure 7. Precursors involving PWRs—occurrence rate by fiscal year.** No trend line is shown because no statistically significant trend (p-value = 0.26) is detected for the FY 2000–2006 period.

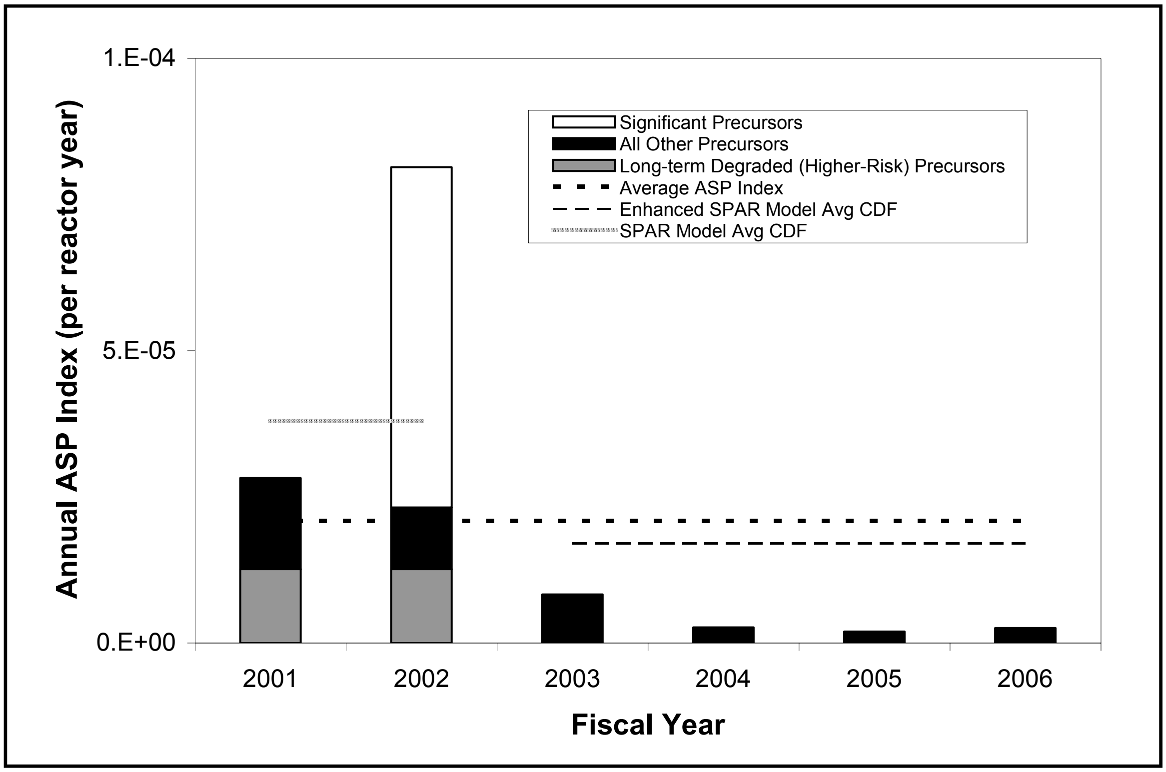


**Figure 8. Integrated ASP index—risk contribution from precursors per fiscal year.** The risk contribution from precursors involving degraded conditions is included in all fiscal years when the degraded condition existed. The risk contribution from precursors involving initiating events is included in the fiscal year in which the event occurred.