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 1×10^{-6} to be a precursor. The ASP Program defines a *significant* precursor as an event with a CCDP or ΔCDP greater than or equal to 1×10^{-3}.

<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 1×10^{-3})
- no more than one significant adverse trend in industry safety performance (determination principally made from the Industry Trends Program (ITP) but supported by ASP results)

Program Scope

The ASP Program is one of three agency programs that assess the risk significance of issues and events. (The other two programs are the significance determination process (SDP) and the event response evaluation process as defined in Management Directive (MD) 8.3, "NRC Incident Investigation Program," 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 1×10^{-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 1×10^{-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

Audit by the Office of Inspector General

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