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

1.0 Accident Sequence Precursor Program Background

The Nuclear Regulatory Commission (NRC) established the Accident Sequence Precursor (ASP Program in 1979 in response to the "Risk Assessment Review Group Report" (NUREG/CR-0400, dated September 1978). The ASP Program systematically evaluates U.S. nuclear power plant operating experience to identify, document, and rank the operating events that were most likely to have led to inadequate core cooling and severe core damage (precursors), accounting for the likelihood of additional failures.

To identify potential precursors, NRC staff reviews plant events from licensee event reports (LERs), inspection reports, and special requests from NRC staff. The staff then analyzes any identified potential precursors by calculating a probability of an event leading to a core damage state. A plant event can be one of two types, either (1) an occurrence of an initiating event, such as a reactor trip or a loss of offsite power (LOOP), with any subsequent equipment unavailability or degradation, or (2) a degraded plant condition depicted by unavailability or degradation of equipment without the occurrence of an initiating event.

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

For the second type, the staff calculates an increase in core damage probability (ΔCDP). This metric represents the increase in the probability of reaching a core damage state for the period that a piece of equipment or a combination of equipment is deemed unavailable or degraded from a nominal core damage probability for the same period for which the nominal failure or unavailability probability is assumed for the subject equipment.

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

Program objectives. The ASP Program has the following objectives:

- provide a comprehensive, risk-informed view of nuclear power plant operating experience and provide 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, Vol. 22, "Performance Budget: Fiscal Year 2007," dated 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 Reactor Oversight Program (ROP) but supported by ASP results)

Program scope. The ASP Program is one of three agency programs that assess the risk significance of issues and events. (The other two programs are the significance determination process (SDP) and the event response evaluation process, as defined in Management Directive (MD) 8.3, "NRC Incident Investigation Program.") Compared to the other two programs, the ASP Program assesses 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) 2004 and FY 2005. The analyses of FY 2006 events are in progress.

Control rod drive mechanism (CRDM) cracking events. The staff completed an analysis for the conditions involving primary water stress-corrosion cracking of CRDM housings initially discovered at 11 plants in FY 2001–2003. The staff is currently documenting and reviewing the analyses. The Office of Nuclear Regulatory Research (RES) has coordinated with the Office of Nuclear Reactor Regulation (NRR) on input for several of these analyses. To complete the remainder of the analyses, the staff decided to simplify the inputs for initiating event frequencies and potential sump-clogging probabilities. This simplification is justified since the staff had determined that more detailed analysis did not result in additional insights. This simplification did not affect ASP trends and results, and the staff has included these events in the total count and trending of all precursors (i.e., CCDP or ΔCDP $\geq 1\times10^{-6}$).

ASP Program status. The staff plans to complete its preliminary assessments of all FY 2006 events by April 2007 and complete all FY 2006 analyses by September 2007. 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.

Investigation of trends and engineering insights. From its analysis of ASP data, the staff has developed and investigated trends to better understand their causes. Enclosure 2 provides the details.

ASP streamlining. In June 2006, the staff implemented changes to streamline the ASP process and thus improve ASP timeliness and efficiency. Although the objectives of the ASP, SDP, and MD 8.3 are different, the risk models and technical methods used are generally

similar. One of the objectives of ASP streamlining is to gain efficiencies by using results from the SDP and MD 8.3 evaluations, where applicable, in the ASP Program. Another major objective is to achieve better coordination among the ASP, SDP, and MD 8.3 Programs. Better coordination will increase the timeliness of all three programs. The following summarizes the new process:

Selection of precursors with an SDP or documented MD 8.3 evaluation. For degraded conditions or significant operational occurrences for which there is an SDP or documented MD 8.3 quantitative risk evaluation, the ASP Program will utilize the results of these evaluations, where applicable, without performing a separate ASP analysis. As in the past, NRR and the regions will be performing the SDP and MD 8.3 evaluations using the respective program's process and guidelines. It is not the intent of this ASP Program change to propose changes to the SDP or MD 8.3 processes; rather, the ASP Program will use documented results from these processes where appropriate and applicable. As part of the NRR user need request on the Risk Assessment Standardization Project (RASP), RES will continue to provide technical assistance to NRR or the regional senior reactor analysts (SRAs), when requested, in utilizing or modifying the standardized plant analysis risk (SPAR) models as part of SDP Phase 3 or MD 8.3 analyses.

Selection of precursors with no SDP or documented MD 8.3 evaluation. The ASP Program will continue to perform analyses for events for which there is no SDP or MD 8.3 evaluation. Examples of these types of events include most initiating events and plant conditions where there are no performance deficiencies. In addition, because of differences in the objectives of the ASP and SDP Programs, in cases where there are concurrent multiple degraded conditions, the ASP process will analyze these conditions together. (The SDP Program analyzes concurrent multiple degraded conditions that involve different performance deficiencies individually.) In performing these ASP analyses, RES will continue to interact with NRR and the SRAs in obtaining plant and event information/data and to discuss results on an ongoing basis.

Potentially significant precursors. For all events (including those being evaluated by the SDP or MD 8.3 processes) that, based on preliminary evaluations, could be significant precursors (defined as events with CCDPs or ΔCDPs greater than or equal to 1×10^{-3}), the ASP Program will perform an expedited analysis to support the reporting requirements in the annual NRC Performance and Accountability Report to Congress and to support the proposed new abnormal occurrence criteria described in SECY-05-0137. In performing these ASP analyses, RES will interact closely with NRR and the regions to obtain plant and event information/data and to discuss results on an ongoing basis.

New peer review process. As part of the new ASP process, the staff will revise the peer review process to make it more efficient. For lower risk events, if the ASP analysis results in a CCDP or ΔCDP of less than 1×10^{-4}, RES will no longer request formal NRR, regional office, or licensee review. RES will issue a summary of the analysis results by memorandum to NRR, the regional offices, and the licensee for information. If NRR, the regional offices, or the licensee chooses to comment on these analyses, RES will continue to address these comments and revise the ASP analysis if necessary. For higher risk events (i.e., for ASP analysis results greater than 1×10^{-4}), RES will continue to request formal review comments by NRR, the regional offices, and the licensee. The staff will issue these ASP analyses as final after resolution of peer review comments. This revised review process will reduce administrative and review burdens to NRC staff and licensees.

3.0 SPAR Model Development Program Background

The objective of the 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 LOOP/station blackout (LOOP/SBO) module, 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 initial set of 72 Revision 3 SPAR models, representing all 103 operating units, was completed and benchmarked against licensee PRAs during the onsite quality assurance reviews of these models. On the whole, the results of the benchmarking indicate that the difference observed between the SPAR models and the licensee plant PRAs is not very significant from an overall risk standpoint.

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 RES, NRR, and the NRC's regional offices. In August 2000, the 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 Recent Achievements

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 Reactor Oversight Program (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, external initiating events, and LERFs.

One recent example of the use of SPAR to support agency work is the assessment of SBO risk. Enhanced SPAR models were applied to this assessment. In FY 2006, the NRC issued NUREG/CR-6890, "Reevaluation of Station Blackout Risk at Nuclear Power Plants." Volume 1 of the report contains updates of LOOP initiating event frequencies and nonrecovery probabilities. Volume 2 presents SBO risk estimates in terms of core damage frequency (CDF) for the nuclear industry and the fleet of nuclear power plants. Volume 3 contains the resolution of comments. The report concludes that LOOP frequencies have decreased, but duration times have increased. The study also shows that SBO CDF estimates have decreased. The baseline results reflect improving emergency diesel generator performance, improving plant-specific SBO coping capabilities (e.g., turbine-driven pump performance), increasing duration of LOOP events, and lower overall loss of offsite power frequency observed during the 1997–2003 period.

Another example of the use of SPAR is the MSPI project. The staff used the SPAR models as part of its review of the technical adequacy of the licensee PRA models for MSPI implementation in FY 2006. The staff reviewed design features, operations features, or modeling methods, as appropriate and made cross-comparisons with SPAR model results. The staff noted differences or outliers and discussed their basis with the licensees. The staff continued to work with licensees until it had resolved all MSPI outlier concerns. The industry implemented over a dozen PRA model changes as a result of this comprehensive review effort. In summary, the use of SPAR models proved to be invaluable in resolving PRA adequacy concerns for implementation of MSPI. Enclosure 3 discusses this in more detail.

The staff is currently using SPAR models to support the development of the state-of-the-art reactor consequence analysis of severe accidents at nuclear power plants. Based on insights resulting from this activity, the staff plans to update the SPAR models, as appropriate, based on current plant capabilities and safety enhancements. Initially, the plants to be evaluated will be the six lead (pilot) plants in the state-of-the-art reactor consequence analysis project. In addition, the staff will update the SPAR models, as appropriate and on a plant-by-plant basis, to include plant safety enhancements resulting from Phases 1, 2 and 3 Section B.5.b assessments as the engineering and risk information on the pertinent systems become available to the staff as part of normal NRC regulatory activities.

5.0 SPAR Model Development Status

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-05-0192).

SPAR models for analysis of internal initiating events during full-power operation

- The staff developed enhanced Revision 3 SPAR models in response to an NRR user need. 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 39 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 (a) during the onsite quality assurance (QA) reviews of the Revision 3 SPAR models, (b) during the MSPI pilot program reviews, and (c) based on feedback from model users.

SPAR models for analysis of internal initiating events during LP/SD operation

- This effort is part of the RASP in support of ASP and SDP Phase 3 analyses.

- Before 2006, the staff had completed initial development of 11 LP/SD SPAR models. It completed no additional models in FY 2006 because of a potential conflict of interest with the NRC contractor at Idaho National Laboratory (INL). The staff has resolved this issue with INL and is now preparing additional LP/SD models in anticipation of onsite quality assurance (QA) reviews.

SPAR models for the calculation of LERF

- This effort is part of the RASP in support of ASP and SDP Phase 3 analyses. The staff completed the LERF SPAR model for Grand Gulf (the lead plant in the fourth class), which is a boiling-water reactor (BWR) with a Mark III containment. The staff subsequently sent the model to the licensee in the course of preparing for the onsite QA review of the model against the Level 2/LERF model.

- The staff also completed models for the lead plant (LaSalle) in the fifth plant class (BWRs with Mark II containments) and the sixth plant class (pressurized-water reactors (PWRs) with subatmospheric containments) in FY 2006.

SPAR models for the analysis of external events

- The staff is performing this effort, which is part of the RASP in support of ASP and SDP Phase 3 analyses, in conjunction with NRR's SDP external events Phase 2 worksheet benchmarking program.

- Nine preliminary SPAR models that contain internal and external events are complete and are available for trial use and evaluation by the staff.

6.0 Additional Achievements

Validation of SPAR models. Validation of the SPAR models is an ongoing effort. The staff compared the SPAR models to the plant PRA models during SDP Phase 2 Notebook plant visits and MSPI reviews and considered feedback from SDP and ASP analysts. The licensees have also provided feedback, which the staff has incorporated as appropriate. Metrics are used to quantify the degree of agreement between the SPAR models and licensee PRAs. On the whole, this benchmarking has indicated that the CDFs from the SPAR models are within a factor of 2, on average, when compared to the estimates from the licensee PRA models. This is within the generally accepted uncertainty for internal event PRAs. Most of the differences are well understood and result from the use of plant-specific versus industry-averaged performance data. In some cases, a few key modeling assumptions account for relatively large differences between licensee PRA and SPAR model results. The reports for each SPAR model describe

the benchmarking comparisons, as well as the significant modeling differences between the SPAR and licensee PRA models.

Advisory Committee on Reactor Safeguards Review. The Advisory Committee on Reactor Safeguards (ACRS) selected the SPAR Model Development Program as one of three projects to review during 2005 for "research quality." The ACRS found the SPAR Model Development Program and its application as part of NUREG/CR-6890, "Reevaluation of Station Blackout Risk at Nuclear Power Plants," to be "more than satisfactory" and found that the program and NUREG/CR results meet the research objectives. The ACRS also noted the value of SPAR models as an "independent capability to evaluate risk issues across the population of operating plants." The ACRS report entitled, "ACRS Assessment of the Quality of Selected NRC Research Projects," dated October 2005, documents the results of their review. This document is publically available and can be accessed from the NRC's Agencywide Documents Access and Management System (ADAMS Accession No. ML053110211).

Methods guidelines. The staff completed initial guidelines for performing risk assessments for the internal fire and flood initiators and external events during power operations in September 2006. The deliverable was in the form of a practical, "how to" handbook of methods, best practices, examples, tips, and precautions for applying the new SPAR models for external events that are under development. The staff issued this handbook for trial use. The staff and the contractor for ASP Program support have been using the trial-basis guidelines for internal events during power operations for over 1 year. The handbook has also proven useful to new analysts who recently started work on the ASP and reactor oversight process programs and will reduce the time and resources needed to train future new analysts. The staff began working on guidelines to address LP/SD operations and LERF. The staff developed draft guidance for the calculation of LERF, applied this guidance in an analysis of a recent LOOP event, and is currently evaluating the results of this pilot application. During FY 2007, the staff will issue a revision of the handbook that incorporates comments from users and expands discussion, guidance, and examples of internal and external events. Plans are to integrate all guidance into one handbook.

Efficiency improvements. Enhancements of the SPAR models, improvements to the Systems Analysis for Hands-on Integrated Reliability Evaluation (SAPHIRE) code, and the implementation of guidelines for agency risk applications all contribute to increased staff efficiency. SPAR models that accurately reflect plant design, operation, and performance result in improved turnaround time for SDP and ASP analyses. When the SPAR models substantially agree with the licensee's own PRA models, less time is required to resolve significant differences between the two models. Improvements to the SAPHIRE code allow efficient development and use of the SPAR models. A SAPHIRE version is under development which streamlines development of large, complex models, such as external events models and can solve integrated internal and external events SPAR models. In addition, improved guidelines for the application of SPAR models to operational events result in reduced training needs and greater standardization.

Finally, the staff is coordinating its development of SPAR fire models with the regulatory efforts under National Fire Protection Association (NFPA) 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants." Significant synergies and resource savings should result from early identification of fire PRA reporting requirements once licensees complete their fire PRA models and NFPA 805 submittals.