Status of the Standardized Plant Analysis Risk Models

1.0 Background

The objective of the U.S. Nuclear Regulatory Commission's (NRC's) Standardized Plant Analysis Risk (SPAR) Model Program is to develop standardized risk analysis models and tools to support various regulatory activities, including the Accident Sequence Precursor (ASP) Program and the Significance Determination Process (SDP). The SPAR models have evolved from two sets of simplified event trees initially used to perform precursor analyses in the early 1980s. Today's SPAR models for internal events are far more comprehensive than their predecessors. For example, the revised SPAR models include improved loss of offsite power (LOOP) and station blackout models; an improved reactor coolant pump seal failure model; new support system initiating event models; and updated estimates of accident initiator frequencies and equipment reliability based on recent operating experience data.

The SPAR models consist of a standardized, set of plant-specific risk models that use the event-tree and fault-tree linking methodology. Although the SPAR models are plant-specific models, they rely on a set of standardized modeling conventions (e.g., standardized naming conventions, standard modeling approaches, and logic structure). They employ a standard approach for event-tree development, as well as a standard approach for initiating event frequencies, equipment performance parameters, and human performance data. These input data can be modified to be more plant- and event-specific, when needed. SPAR standardization is needed to allow agency risk analysts to efficiently use SPAR models for a wide variety of nuclear power plants (NPPs) without having to relearn modeling conventions and basic assumptions. Although the system fault trees contained in the SPAR models generally are not as detailed as those in licensee probabilistic risk assessments (PRAs), in some cases SPAR models may contain more sophisticated modeling, such as for common-cause failures, support systems, and losses of offsite power. The staff maintains 75 SPAR models representing all 99 operating commercial NPPs. The SPAR models for NPPs that have recently permanently ceased operation (Kewaunee, Crystal River, San Onofre, and Vermont Yankee) are no longer being updated but remain available for staff use. All SPAR models are developed under a comprehensive quality assurance (QA) program and have been benchmarked against licensee PRAs through either onsite QA reviews or other information provided by the licensee.

The staff initiated the Risk Assessment Standardization Project (RASP) in 2004. A primary focus of RASP was to standardize risk analyses performed in SDP, in ASP, and under Management Directive (MD) 8.3, "NRC Incident Investigation Program." Under this project, the staff initiated the following activities:

- Enhance SPAR models to be more plant-specific and improve the Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) code 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 hazards (e.g., seismic events and tornadoes); and internal events during low-power and shutdown (LPSD) operations.
- Provide on-call technical support for staff involved with licensing and inspection issues.

This effort resulted in the development of the Risk Assessment of Operational Events Handbook (commonly referred to as the RASP Handbook) and better alignment between the SDP and ASP Program event assessment processes.

2.0 SPAR Model Program Status

The SPAR Model Program continues to play an integral role in the ASP analysis of operating events. Many other agency activities, such as the SDP analyses and MD 8.3 evaluations, also involve the use of SPAR models. All SPAR models include logic modeling covering internal events at power through core damage (i.e., Level-1 PRA model). The NRC is developing new SPAR modules for assessing plant risk for internal fires, external hazards (e.g., high wind and seismic events), and for assessing post-core damage severe accident progression (i.e., Level-2 PRA modeling).

The staff has completed the following activities in model and method development since the previous status report (SECY-14-0107, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models," dated October 6, 2014), as described below.

Technical Adequacy of SPAR Models. The staff implemented a QA plan covering the SPAR models in 2006. It updated the SPAR QA plan in fiscal year (FY) 2013. The main objective of this plan is to ensure that the SPAR models continue to represent the as-built, as-operated NPPs and continue to be of sufficient quality for performing event assessments of operational events in support of the staff's risk-informed activities. In addition to model development, the QA plan provides mechanisms for internal and external peer review, validation and verification, and configuration control of the SPAR models. The staff has processes in place to verify, validate, and benchmark these models according to the guidelines and standards established by the SPAR Model Program. As part of this process, the staff performs reviews of the SPAR models and results against the licensee PRA models, when applicable. The QA plan also provides a feedback process from the model users for error reporting, tracking, and resolution. The staff also has processes in place for the proper use of these models in agency programs such as the ASP Program, the SDP, and the MD 8.3 process. These processes are documented in the RASP Handbook, which serves as a desktop guidance document for agency risk analysts.

In 2010 the staff (with the cooperation of industry experts) performed a peer review of SPAR models for a representative boiling-water reactor (BWR) and a representative pressurized-water reactor (PWR) in accordance with American Society of Mechanical Engineers/American Nuclear Society RA-S-2008, "Standard for Level-1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," and Regulatory Guide (RG) 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities" ADAMS Accession No. ML090410014.

The peer review teams noted a number of strengths for the SPAR models, including:

- The SPAR model structure is robust and well developed.
- The SPAR model fault trees are streamlined with an appropriate level of detail for its intended uses.

- The SPAR model structure and the SAPHIRE software are “state of the technology.”
- The SPAR models are an efficient method to develop qualitative and quantitative insights for risk-informed applications, SDP evaluations, inspections, event assessments, and model evaluations.

The peer review teams also noted a number of enhancements that could be made to the SPAR models. The staff reviewed and prioritized the peer review comments in order to identify potential improvements to the SPAR models. Enhancements that improved the usability, capabilities, and technical adequacy of the models in a cost effective manner were given high priority and the staff initiated projects to address these comments. Specific enhancements that have been completed include structuring the SPAR model documentation to more closely align with the structure of the PRA standard, incorporation of improved LOOP modeling, development of new support system initiating event models, and expanding the SAPHIRE Web site to better log and track model change requests. All high priority BWR and PWR SPAR peer review enhancements were completed by August 2015.

It should be noted that the SPAR models are generally used to categorize and prioritize operational events and conditions, including licensee non-compliance issues with existing regulations. Licensee PRA models developed to support licensing basis changes must meet the technical adequacy requirements of RG 1.200. Although the SPAR models are not maintained under a RG 1.200 program, the SPAR QA program and other process controls (such as internal and external reviews) help to ensure that SPAR-based analyses appropriately reflect the as-built, as-operated NPP.

Routine SPAR Model Updates. Existing SPAR models for operating plants need to be updated regularly as a result of any significant plant changes that may affect the risk profile of the plant. In general, the staff goal is to perform significant updates to approximately 10 to 12 SPAR models per year. As SPAR models are updated, their documentation (i.e., the model report and the plant risk information eBook summary reports) is also updated to represent the latest PRA information included in each SPAR model. Comparisons between the SPAR model baseline results and licensee model results (when voluntarily submitted by the licensee) are also performed. These comparisons include baseline core damage frequency, conditional core damage probability for each initiator type, top cut sets, and importance measures. These comparisons help ensure that SPAR models and associated risk assessments that support the SDP process are of high quality and reflect the as-built, as-operated plants. In FY 2015, the staff performed significant updates to six SPAR models to reflect changes, such as the addition of logic for new station blackout generators, battery charging generators, and broad expansion of electrical power modeling detail. Although the level of effort in FY 2015 was less than the staff goal due to resource limitations, the effort is expected to be increased again in FY 2016 to complete approximately 10 model updates per year.

In FY 2015, the staff also modified all SPAR models to take advantage of new SAPHIRE features and to improve the usability of the models. Among these new SAPHIRE features is the ability to eliminate most event tree linkage rules. SAPHIRE now automatically merges multiple overlapping rules, thus precluding the need to manually generate multiple explicit rule sets.

Automatic generation and application of convolution correction factors is another SAPHIRE enhancement that eliminates multiple manual actions each time a model is updated.

Approximately 30 SPAR models were also updated to support specific SDP or ASP activities. These more limited SPAR model updates are performed when requested by agency risk analysts. These updates are normally required to better model specific features of an operational event that are not normally captured in a base PRA or to reflect an enhanced understanding of the as-built, as-operated plant as a result of event followup activities.

During FY 2015, the staff continued to perform a comprehensive data update to all 75 SPAR models to reflect recent operating experience and implement other enhancements to improve the usability and functionality of the models. In addition to updating SPAR model parameters, this activity will improve model documentation; integrate hazard categories (i.e., internal events, external hazards, Level-2, and LPSD models) into a single report for each SPAR model report; and resolve issues associated with the SPAR logic modeling framework. Other data updates include modification of common cause events to more closely follow the guidance in the RASP Handbook. A plant-specific model convergence analysis (to assess the appropriate truncation level to run the model) and documentation of the results is also included in this task.

SPAR Models for the Analysis of All Hazards (External Events). Development of SPAR All-Hazard (SPAR-AHZ) models, which contain accident scenarios from all hazard categories (including seismic, high wind, and internal fire) applicable to a given site, has continued during FY 2015, although at a lower intensity than the previous year. The lower intensity was due to budgetary constraints and the balancing of limited staff resources to work on other projects, such as the Commission- directed site Level-3 PRA project for the Vogtle site. Currently, 22 of the 75 SPAR models, representing 28 NPPs, include internal fire and external hazard groups. Eighteen of the SPAR-AHZ models are based on assessments conducted for Supplement 5, “Individual Plant Examination of External Events for Severe Accident Vulnerabilities,” to Generic Letter 88 20, “Individual Plant Examination for Severe Accident Vulnerabilities 10 CFR 50.54(f),” and other readily available information. In FY 2015, one new SPAR-AHZ model, which includes internal fire models extracted from the National Fire Protection Association (NFPA) Standard 805- compliant fire model for the Vogtle plant, has been constructed and placed in the SPAR model library for use by NRC risk analysts. SPAR-AHZ models for the Shearon Harris, D.C. Cook, and V.C. Summer NPPs had been previously completed. Because the licensee-developed NFPA 805-compliant fire PRA models contain thousands of quantified fire sequences, a significant focus of the SPAR-AHZ effort was combining similar sequences to enhance model usability while retaining the resolution contained in the licensee models.

Recently, a new SPAR-AHZ model for the Point Beach site was developed, and the SPAR-AHZ model for the Sequoyah site underwent a major upgrade. The staff is currently working on a major update to the Peach Bottom SPAR-AHZ model. Development of the Peach Bottom SPAR-AHZ model includes licensee site visits to gather information and discuss modeling assumptions and results. Currently, the Office of Nuclear Regulatory Research (RES) and the Office of Nuclear Reactor Regulation (NRR) are working together to identify ways to improve the efficiency and therefore increase the pace of SPAR-AHZ model development, given expected resource constraints in FY 2016 and beyond.

New Reactor SPAR Models. Before new plant operation, the staff may perform risk assessments to inform potential risk-informed applications for combined licenses, focus construction inspection scope, or assess the significance of construction inspection findings. Once the plants begin operation, independent assessments using SPAR models will be used by the staff for the evaluation of operational findings and events similar to the assessments performed for current operating reactors.

There are currently five new reactor internal hazard SPAR models. These include one model for the AP1000, two Advanced Boiling-Water Reactor (ABWR) models (one for the Toshiba design and one for the General Electric-Hitachi design), one model for the U.S. Advanced Pressurized-Water Reactor (US-APWR), and one model for the U.S Evolutionary Power Reactor (U.S. EPR). In addition to these internal events models, there is a seismic model for the AP1000 and a LPSD model for the Toshiba ABWR. Since FY 2013, the staff has been extending the capabilities for the AP1000 reactor design SPAR model. The AP1000 SPAR-AHZ model includes an internal flooding model (completed in FY 2013) and an internal fire model (completed in FY 2014). The staff is in the process of completing a LPSD model and developing a new severe accident model (Level-2 PRA model) for the AP1000 reactor design.

The staff plans to continue developing new reactor SPAR models, including AHZ and LPSD models, as needed, to support licensing and oversight activities.

MELCOR Thermal Hydraulic Analysis for SPAR Model Success Criteria. The staff continues to perform MELCOR analyses to investigate success criteria associated with specific Level-1 PRA sequences. In some cases, these analyses confirm the existing technical basis, and in other cases they support modifications that can be made to increase the realism of the agency's SPAR models. The latest round of activity is documented in two reports: (1) soon to be published NUREG-2187, "Confirmatory Thermal-Hydraulic Analysis to Support Specific Success Criteria in the Standardized Plant Analysis Risk Models—Byron," and (2) NUREG/CR-7177, "Compendium of Analyses to Investigate Select Level-1 Probabilistic Risk Assessment End-State Definition and Success Criteria Modeling Issues," published in May 2014 (ADAMS Accession No. ML14148A126). The results of these studies will be used to confirm specific success criteria for a suite of four-loop Westinghouse plants, which are similar to Byron, with appropriate consideration of the design and operational differences of these plants. They also will be used to support application-specific consultation on the use of the SPAR models.

This effort directly supports the agency's goal of using state-of-the-art tools that promote effectiveness and realism. The NRC is communicating the project plans and results to internal and external stakeholders through mechanisms such as the Regulatory Information Conference and the industry's Modular Accident Analysis Program Users' Group.

3.0 Additional Activities

SAPHIRE Maintenance and Improvements. In FY 2015, new features and capabilities were implemented in SAPHIRE to better support NRC regulatory activities. The new features include:

- SAPHIRE offers multiple methods for solving PRA models. Models can be assessed by solving individual accident sequences or by grouping sequences by common end states. A new capability in SAPHIRE allows users to trace the contribution of individual accident sequences regardless of the solving method that is used.
- Improvements to the reporting capabilities for external hazard model results.
- Improved tools for modelers to update and maintain the SPAR models.

All of these improvements to SAPHIRE have been performed in accordance with the SAPHIRE software QA program. A set of software QA documents has been developed for SAPHIRE. These documents cover topics such as the software development plan, configuration management, requirements tracking, and testing and acceptance. The NRC project manager performs an annual audit of the SAPHIRE software QA program. The most recent audit was completed on January 15, 2015, and no significant issues were identified. The NRC project manager confirmed that the maintenance and implementation of the SAPHIRE software QA program is consistent with the guidance contained in NUREG/BR-0167, "Software Quality Assurance Program and Guidelines," dated February 1993 (ADAMS Accession No. ML15043A791).

The SAPHIRE developers continue to explore advanced features and enhancements that may be implemented in future SAPHIRE revisions. The SAPHIRE team has developed a demonstration version of a Web-based SAPHIRE application. A Web-based SAPHIRE application is envisioned to have several advantages that are not available with a desktop application, such as improved configuration management of models and analyses, enhanced collaboration capabilities, and remote access to high-performance computing resources. After successfully demonstrating a limited capability prototype version of a Web-based application capable of supporting SAPHIRE, the SAPHIRE team developed an implementation plan to describe how a fully functional Web-based version could be completed and made available to users as a replacement to the current personal computer version of SAPHIRE. Research activities on the Web-based version also identified other potential algorithmic enhancements that could be implemented in the current version of SAPHIRE. The team continues to enhance the quantification and analysis capabilities to remain consistent with industry-wide accepted PRA practices and tools. In addition to this work, the SAPHIRE team continues to remain cognizant of academic and international research activities on advanced PRA quantification techniques.

Cooperative Research for PRA. The staff has executed an addendum to the memorandum of understanding with the Electric Power Research Institute (EPRI) to conduct cooperative nuclear safety research for PRA. Several of the initiatives included in the addendum are intended to help resolve technical issues that account for the key differences between NRC SPAR models and licensee PRA models.

During FY 2015, significant efforts have been made in implementing PRA methods for support system initiating event (SSIE) analysis and treatment of LOOP in PRAs. The SSIE PRA modeling approach was developed in collaboration with EPRI and is documented in EPRI Report 1016741, "Support System Initiating Events," published December 19, 2008. These methods are being implemented in the SPAR models as one of the activities associated with addressing the peer review comments. To date, all SPAR models have been enhanced

with the improved SSIE modeling methodology. Various LOOP methodology enhancements have been added to all models, with the remaining enhancements expected to be completed in conjunction with routine SPAR model updates. The staff plans to continue these cooperative efforts with EPRI and other stakeholders to address the remaining issues over the next several years.

On July 14–15, 2015, RES, in collaboration with Idaho National Laboratory staff, held a two-day public workshop on the agency's SPAR model program. Workshop discussions included the objectives of the SPAR model program; data collection and analysis; human reliability analysis; loss of offsite power modeling; and SPAR model maintenance and QA. The workshop participants included representatives from NPPs, industry contractors, international partners, and public interest groups. In addition, NRC staff from NRR, Office of New Reactors, and the Regions attended. A meeting summary of the workshop can be found in ADAMS at Accession No. ML15198A191.

4.0 Conclusion

SPAR models are one of the primary risk tools for the agency and support a wide variety of regulatory uses. The staff maintains and updates the suite of SPAR models to help ensure that agency-performed risk assessments represent the as-built, as-operated reactor plants. Recent activities have focused on the development of external hazard models, updates to model parameter estimates to reflect recent plant operating experience, and increased public outreach to promulgate information about the SPAR model program.