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 for staff analysts to support various regulatory activities, including the Accident Sequence Precursor (ASP) Program and Phase 3 of the Significance Determination Process (SDP). The SPAR models have evolved from two sets of simplified event trees initially used to perform precursor analyses in the early 1980s. Today's 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 modules; 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, plant-specific set of 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) to allow agency risk analysts to proficiently assess the risk significance of findings and operational events. They employ a standard approach for event-tree development, as well as a standard approach for input data for initiating event frequencies, equipment performance, and human performance. These input data can be modified to be more plant- and event-specific, when needed. SPAR standardization is needed to allow agency risk analysts to efficiently use SPAR models for a wide variety of nuclear plants 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 for common-cause failure, support systems, and loss of offsite power. To date, the staff has completed 79 SPAR models representing all 104 commercial nuclear power units. All SPAR models are developed under a comprehensive quality assurance program and have been benchmarked against licensee PRAs through either onsite quality assurance 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 Phase 3, 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 operational 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, involve the use of SPAR models. The NRC is developing new SPAR modules in response to staff needs for assessing plant risk for external hazards and for assessing accident progression to the plant damage state level.

The staff has completed the following activities in model and method development since the previous status report (SECY-13-0107, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models," dated October 4, 2013), as described below.

Technical Adequacy of SPAR Models

The staff implemented a Quality Assurance (QA) Plan covering the SPAR models in 2006. The SPAR QA plan was updated 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 nuclear plants 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 in conjunction with 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 addition, 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 (ASME)/American Nuclear Society (ANS) RA-S-2008, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," and Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities."

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 computer software are "state of the technology."

- The SPAR model is 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 has reviewed the peer review comments and has initiated projects to address these comments, where appropriate. Activities in progress to address these peer review items include structuring the SPAR model documentation to more closely align with the structure of the PRA standard, incorporation of improved LOOP modeling, and addressing the high priority items for the BWR models. The pace of these activities was significantly reduced during FY 2013 because of sequestration-related budget cuts. With funding restored in FY 2014, the staff continued the resolution of peer review items, including documentation enhancements and model upgrades. The staff plans to complete the PWR peer review enhancements in August 2015, on schedule. The BWR peer review enhancements have been delayed, with an expected completion date of 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, while licensee PRA models developed to support licensing basis changes must meet the technical adequacy requirements of Regulatory Guide 1.200.

Routine SPAR Model Updates

Existing SPAR models need to be updated regularly as a result of any significant plant changes that may affect the risk profile of the plant. As the SPAR model is updated, its 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 the 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 comparisons of baseline CDF, 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. Although the level of effort was reduced to 6 updates per year because of budget constraints in FY 2013, the effort was increased again in FY 2014 to complete approximately 10 model updates per year.

In addition to these routine SPAR model updates, more limited SPAR models updates are performed to support specific operational event assessment activities 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 follow-up activities. In FY 2014 the staff updated 47 SPAR additional models to support specific SDP or ASP activities. These updates included 75 specific SPAR model modifications, 19 of which were considered significant upgrades to the SPAR models. As a result of these activities, well over half of the existing SPAR models were updated in FY 2014.

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 applicable to a given site, has continued during FY 2014, although at a

lower intensity because of budgetary constraints and balancing limited staff resources to work on other projects, such as the Level 3 PRA project for the Vogtle site. In FY 2014, 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. The NRC is currently working on the V.C. Summer and Peach Bottom SPAR-AHZ models. Development of these models includes licensee site visits to gather information and discuss modeling assumptions and results. Because the licensee-developed NFPA 805-compliant fire PRA models contain thousands of quantified sequences, a significant focus of the SPAR-AHZ effort was combining similar sequences to enhance model usability while maintaining the ability to retain the resolution contained in the licensee models. Currently, the NRC Office of Nuclear Regulatory Research (RES) and the NRC Office of Nuclear Reactor Regulation (NRR) are working together to identify ways to increase the pace of SPAR-AHZ model development, given expected resource constraints in FY 2015 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 (COLs), 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 six 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 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 low power and shutdown model for the Toshiba ABWR. Since FY 2013, the staff has been developing a SPAR-AHZ model for the AP1000 reactor design. This AHZ model includes an internal flooding model (completed in FY 2013) and an internal fire model (completed in FY 2014). The staff is currently developing a low power and shutdown model for the AP1000 reactor design.

The staff plans to continue developing new reactor SPAR models, including external hazards and low power and shutdown 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) an upcoming NUREG report entitled "Confirmatory Thermal-Hydraulic Analysis to Support Specific Success Criteria in the Standardized Plant Analysis Risk Models—Byron," and (2) NUREG/CR-7177, entitled "Compendium of Analyses to Investigate Select Level 1 Probabilistic Risk Assessment End-State Definition and Success Criteria Modeling Issues," published in May 2014. 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 2014, new features and capabilities have been implemented in SAPHIRE to better support NRC regulatory activities. The new features include:

- A method to automatically adjust the model truncation level and produce a summary report of the convergence results.
- A cut set editor that allows users to efficiently review cut set results, quickly apply changes and sensitivity cases, and recalculate the results.
- The ability to use an external solving engine[1], which allows for comparisons of results using different solving methods.
- Level 2 PRA model quantification features (e.g., the ability to utilize decomposition event trees) and improved integration of Level 1 and Level 2 modeling.

Many of these advanced features were created to support specific NRC projects, and the features were advanced through different developmental versions of the software. In accordance with SAPHIRE configuration management practices, these developmental versions had restricted use and limited availability to users. At this time, all of the above stated features have been merged into a single SAPHIRE version, which is now available to the entire SAPHIRE user community.

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 quality assurance program. The most recent audit was completed on January 16, 2014, and no significant issues were identified. The NRC Project Manager confirmed that the maintenance and implementation of the SAPHIRE software quality assurance program is consistent with the guidance contained in NUREG/BR-0167, "Software Quality Assurance Program and Guidelines."

The SAPHIRE developers continue to explore advanced features and enhancements that may be implemented in future SAPHIRE revisions. The SAPHIRE team is planning to demonstrate the feasibility of developing a web-based version of SAPHIRE. 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

[1] SAPHIRE now has the ability to use the FTREX solving engine that is typically used with the Computer Aided Fault Tree Analysis (CAFTA) system. CAFTA was developed by the Electric Power Research Institute (EPRI) and is used by the majority of utilities in the United States.

collaboration capabilities, and remote access to high-performance computing resources. The work to establish the feasibility of a web-based SAPHIRE version began in FY 2014 and is expected to be completed in calendar year (CY) 2015. In addition, the SAPHIRE team continues to research advanced PRA quantification techniques that can improve accuracy and solving speeds. The team has evaluated quantification approaches using Binary Decision Diagram based methods and has remained cognizant of ongoing academic research with Boolean satisfiability or "SAT" methods.

Cooperative Research for PRA

The staff has executed an addendum to the memorandum of understanding (MOU) 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 2014, significant efforts have been made in implementing PRA methodologies for support system initiating event (SSIE) analysis and treatment of LOOP in PRAs. These methodologies are being implemented in the SPAR models as one of the activities associated with addressing the peer review comments. To date, 40 models have been enhanced with the improved SSIE modeling methodology and 66 models have been enhanced with the improved LOOP methodology. The staff plans to continue these cooperative efforts with EPRI and other stakeholders to address the remaining issues over the next several years.

Integrated Modeling

The Office of Nuclear Regulatory Research continues to enhance SAPHIRE and the SPAR models to support development of integrated models. To this end, RES recently completed an integrated model for Peach Bottom Unit 2 containing state-of-the-practice SPAR models for Level 1 internal events at power and during shutdown, other hazards, and Level 2 events. This effort included the incorporation of other ongoing modeling initiatives (e.g., modeling of SSIEs), use of modeling features new to SAPHIRE8 (e.g., decomposition event trees), and further validation of the Level 2 PRA model. This work directly benefits the RES Vogtle site Level 3 PRA project (SRM -SECY-11-0089) by guiding the approach to Level 2 and integrated hazard modeling.