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 use in many 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 a new, improved loss of offsite power (LOOP) and station blackout 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 SPAR models consist of a standardized, plant-specific set of risk models that use the event-tree and fault-tree linking methodology. 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. The system fault trees contained in the SPAR models generally are not as detailed as those contained in licensee probabilistic risk assessments (PRAs). To date, the staff has completed 79 SPAR models representing all 104 commercial operating units and benchmarked them against licensee PRAs during the onsite quality assurance reviews of these models.

The 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 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 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); and internal events during low-power and shutdown (LPSD) operations.

- Provide on-call technical support for staff involved with licensing and inspection issues.

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 models in response to staff needs for assessing plant risk during shutdown operations and external events 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-11-0138, "Status of the Accident Sequence Precursor Program

and the Standardized Plant Analysis Risk Models," dated September 30, 2011) as described below.

Technical Adequacy of SPAR Models

The staff implemented a SPAR Model Quality Assurance Plan covering the SPAR models in 2006, which was recently updated. The main objective of this plan is to ensure the SPAR models continue to be of sufficient quality for performing event assessments of operational events in support of the staff's risk-informed activities. 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. 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.

In addition, the staff (with the cooperation of industry experts) performed a peer review of a representative boiling-water reactor (BWR) SPAR model and pressurized-water (PWR) reactor SPAR model in accordance with American Society of Mechanical Engineers (ASME) RA-S-2008, "Standard for 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 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 loss of offsite power modeling, and addressing the high priority items for the BWR models. These activities have been delayed approximately 1 year because of higher priority Reactor Oversight Process support and activities related to the Fukushima Dai ichi event in Japan. The staff is planning to complete this effort in 2014.

SPAR Models for the Analysis of All Hazards (External Events)

A SPAR all-hazards model was completed for Shearon Harris Nuclear Power Plant that is available in the SPAR models library for use by NRC risk analysts. Currently, 18 SPAR models have all-hazard scenarios (previously labeled as "external event" scenarios), as well as "internal event" scenarios. The Shearon Harris all-hazards model also incorporated internal fire scenarios from the National Fire Protection Association (NFPA) 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants," pilot application. Based on a request from the Office of Nuclear Reactor Regulations to the Office of Nuclear Regulatory Research (RES), the NRC is conducting further work to add more models and update current models. The existing all-hazards SPAR models allow NRC risk analysts to estimate the overall risk from a range of initiating events, including (i) fire risk based on up-to-date NFPA-805 considerations, and (ii) extremely low frequency but high consequence scenarios, such as non-recoverable station blackout scenarios that could arise from seismic events and external floods.

SPAR Models for Analysis of Internal Initiating Events during Shutdown Operation

The staff places a priority on creating methods and guidance for the risk assessment of shutdown events, with emphasis on SDP Phase 3 analyses. For this purpose, eight SPAR models that contain selected shutdown event scenarios, as well as internal event scenarios, have been developed. A handbook for analysts, a model maker's guideline for the construction

of other models and scenarios, an event tree template library, and a human-error probability library all support these models. Currently, the NRC has no plans to make further SPAR shutdown models. Available models, together with the supporting documents, can be used to support SDP Phase 3 evaluations of LPSD events and degraded conditions for other plants, by generating further models from the existing templates.

New Reactor SPAR Models

Before new plant operation, the staff may need to perform risk assessments to confirm PRA results provided in licensing submittals or to evaluate risk-informed applications. Once the plants begin operation, the results from licensee PRAs or independent assessments using SPAR models may be used by the staff for the evaluation of operational findings and events similar to the assessments performed for current operating reactors.

The staff has developed two design-specific internal events SPAR models for the Advanced Boiling Water Reactor (ABWR)—one for the ABWR/Toshiba reactor design and one for the ABWR/General Electric design. As part of the SPAR model development, the staff also completed the requisite supporting documentation. Although the SPAR model for the ABWR/Toshiba reactor design has been completed, the staff is currently working on a modification to incorporate a LPSD model. Work on this matter is progressing, and the model will soon be posted for internal review and comments.

The staff also has developed a design-specific internal events SPAR model for the U.S. Advanced PWR. The staff has initiated work on developing a design-specific internal events SPAR Model for the U.S. Evolutionary Power Reactor (EPR). The SPAR model fault tree and event tree development for the U.S EPR is in progress.

Although the staff completed the AP1000 SPAR model in February 2010, a modification was made to the SPAR model to include an external events seismic model. This modification has been completed and submitted to the Office of New Reactors for review, and comments are being resolved.

The staff plans to continue to develop new reactor SPAR models, including external events and shutdown models, as needed, to support licensing and oversight activities. Because design standardization is a key aspect of the new plants, it should only be necessary to develop one internal events SPAR model for each of the new designs.

MELCOR Thermal Hydraulic Analysis for SPAR Model Success Criteria

The staff has performed MELCOR analyses, using input decks developed under the State-of-the-Art Reactor Consequence Analysis Project, 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 results of these analyses, which are documented in NUREG-1953, "Confirmatory Thermal-Hydraulic Analysis to Support Specific Success Criteria in the Standardized Plant Analysis Risk Models—Surry and Peach Bottom," have been incorporated in the technical bases supporting the Surry and Peach Bottom SPAR models. The results have been extended to include an additional 19 BWR SPAR models and eight PWR SPAR models. RES is currently performing similar analyses for the Byron plant, and plans to use these results 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.

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.

SPAR Models Plant Risk Information e-Books

The staff completed the development of new Plant Risk Information e-Books (PRIBs) for all 79 SPAR models. The PRIB reports identify risk significant systems, structures, and components and provide summary risk information for each operating nuclear power plant. These reports will support the transition of the SDP from the use of Phase 2 notebooks to the Systems Analysis Program for Hands-On Integrated Reliability Evaluations (SAPHIRE) computer code platform.

3.0 Additional Activities

SAPHIRE Maintenance and Improvements

In fiscal year (FY) 2012, new features and capabilities have been implemented in SAPHIRE to better support NRC regulatory activities. SAPHIRE includes a new common-cause failure (CCF) probability calculation module. The module provides greater transparency of the CCF terms and calculation details to the users. SAPHIRE also has been modified to automatically adjust the applicable CCF probabilities when performing event and condition assessments. This is an improvement on previous versions of SAPHIRE, which required the user to make manual adjustments to achieve the correct CCF calculations. SAPHIRE also includes a new module for analyzing convoluted probability distributions. This type of analysis is used for modeling recovery from station blackout conditions (e.g., recovery of any available emergency diesel generator during a specified time window). In addition, the SAPHIRE developers are exploring new quantification techniques that can improve upon the approximation and truncation methods that are commonly used in PRA software. One method that has been explored is the use of binary decision diagrams (BDDs). A new BDD quantification tool is being incorporated into SAPHIRE. The work on this tool is expected to be competed in FY 2012. All of these improvements to SAPHIRE have been performed in accordance with the SAPHIRE software quality assurance program. A set of software quality assurance documents has been developed for SAPHIRE. These documents cover topics such as the software development plan, configuration management, software requirements tracking, and software 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 February 1, 2012.

Another aspect of the ongoing review and improvement of SAPHIRE during FY 2012 was the staff's response to an audit by the Office of the Inspector General (OIG), which is documented in the audit report OIG-11-A-18. The results of the audit found that SAPHIRE met its operational capabilities, but there were additional measures the NRC should take to ensure SAPHIRE is properly managed. Several improvements were made to the management of the SAPHIRE program in response to the recommendations in the audit report. The staff developed formal guidelines for granting access to SAPHIRE and implemented a process to annually review individual users to determine if access to SAPHIRE is still required. In addition, the staff redesigned the SAPHIRE Web site and implemented improved access controls. The new

web site design incorporates user support features, including an automatic password retrieval system to assist active users in maintaining access to the secure site. The OIG found the staff's response to the audit acceptable, and all recommendations were closed on April 12, 2012.

Cooperative Research for PRA

The staff has executed an addendum to the memorandum of understanding (MOU) with 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. The staff also continues to work with the National Aeronautical and Space Administration to address PRA issues of mutual interest. In addition, during FY 2012, the NRC used the cooperative agreement and grant program to establish collaborative PRA research projects with the University of Maryland and Ohio State University. The objective of this effort is to work with the broader PRA community to facilitate resolution of PRA issues and to develop PRA methods, tools, data, and technical information useful to both the NRC and industry.

Initial cooperative efforts under the EPRI MOU have focused on the following:

- Support system initiating event analysis,
- Treatment of LOOP in PRAs,
- Treatment of uncertainty in risk analyses,
- Standard approach for injection following BWR containment failure,
- Standard approach for containment sump recirculation during small and very small loss-of-coolant accidents,
- Human reliability analysis,
- Digital instrumentation and control risk methods,
- Advanced PRA methods, and
- Advanced reactor PRA methods.

Significant efforts have been made in the past year in the areas of support system initiating event analysis, treatment of LOOP in PRAs, and treatment of uncertainty in risk analysis. For example, in the area of support system initiating event (SSIE) analysis, the staff and industry have come to agreement on a common approach to modeling support system initiators and worked together to resolve common cause issues that significantly affect model quantification results. The staff plans to use the SSIE methodology and the improved treatment of LOOP events to further enhance the realism and accuracy of the SPAR models. These methodologies will be implemented in the SPAR models as one of the activities associated with addressing the peer review comments. To date, 37 models have been enhanced with the improved SSIE modeling methodology and 57 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

RES continues to enhance SAPHIRE and the SPAR models to support development of integrated models. To this end, RES is developing an integrated model for Peach Bottom Unit 2 containing state-of-the-practice SPAR models for Level 1 internal events at-power, shutdown,

external hazards, and Level 2. This effort includes the incorporation of other ongoing modeling initiatives (e.g., modeling of SSIEs, use of modeling features new to SAPHIRE (e.g., phases), and further development of the Level 2 PRA model. This work is scheduled for completion at the end of the calendar year and is expected to directly benefit the RES Vogtle site Level 3 PRA project.