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Use of SPAR Models for New Reactors

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Abstract: This paper describes the use of the Standardized Plant Analysis Risk (SPAR) models by the U.S. Nuclear Regulatory Commission staff in risk-informed regulatory activities including reactor oversight. The authors discuss how SPAR models have been used for currently operating plants and how the staff expects to extend this use for evolutionary and passive light-water reactor designs. The staff has been actively exercising the AP1000 SPAR model developed by Idaho National Laboratory (INL) in 2009. Current plans are for INL to complete the development of the Advanced Boiling Water Reactor (ABWR) design model, followed by SPAR models for the Economic Simplified Boiling Water Reactor (ESBWR), United States Evolutionary Power Reactor (U.S. EPR), and United States Advanced Pressurized Water Reactor (US-APWR). Challenges related to the use of the SPAR models, including technical adequacy and configuration control, are discussed.

Keywords: PRA, SPAR models, new reactors

1. INTRODUCTION AND BACKGROUND

1.1. SPAR Models for Currently Operating Plants

The U.S. Nuclear Regulatory Commission (NRC) has increased the use of probabilistic risk assessment (PRA) in regulations and reactor oversight based on the Commission's commitment to risk-informed regulation. The Commission policy statement on the use of PRA [1] states that the use of PRA technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data, in a manner that complements the NRC's deterministic approach and supports the NRC's traditional defense-in-depth philosophy.

To allow NRC staff to assess plant risk at all operating reactors, the NRC developed Standardized Plant Analysis Risk (SPAR) models [2]. Idaho National Laboratory (INL) maintains the SPAR models under the direction and guidance of the Office of Nuclear Regulatory Research (RES). These models evolved from two sets of simplified event trees that were initially used to perform precursor analyses in the early 1980s.

As a result of a significant effort to improve the SPAR models, they are significantly more comprehensive than their predecessors, including internal events during full-power and shutdown operation, multiple external initiating events, and calculation of large early release frequency (LERF). They use an NRC-developed standard set of event trees and standardized input data for initiating event frequencies, equipment performance, and human performance, although these input data may be modified to be more plant- and event-specific when needed. To enable a simplified, consistent approach, the system fault trees contained in the SPAR models are not as detailed as those contained in licensees' PRA models.

Ongoing enhancements to the models include improvements to the software, enhanced plant-specific information, documentation of methods and guidelines for performing risk assessments, and availability of on-call technical support.

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1.2. Current Uses of SPAR Models

Risk analysts in the NRC's regional offices, Office of Nuclear Reactor Regulation (NRR), and RES frequently use the SPAR models in many applications, both to understand and benchmark licensees' results and to evaluate technical issues and events. The SPAR models also support the NRC's reactor oversight process (ROP).

Significance Determination Process

The NRC staff uses the SPAR models to determine the risk significance of inspection findings under the Significance Determination Process (SDP). These evaluations are guided by Inspection Manual Chapter (IMC) 0609 [3] and its attachments. Inspectors and risk analysts perform an initial screening of inspection findings, followed by worksheet-based (Phase 2) and SPAR model (Phase 3) assessments of more significant findings. SPAR models are used to evaluate the change in core damage frequency (ΔCDF), change in core damage probability (ΔCDP), or conditional core damage probability (CCDP) that is associated with each finding. Table 1 shows the significance levels for ΔCDP. Similar analyses are performed for the impact on LERF and conditional large early release probability using thresholds one order of magnitude lower than for the core damage metrics. The NRC staff uses information about the significance of the finding to decide the allocation and characterization of inspection resources, the initiation of an inspection team, or the need for further analysis or action by other agency organizations.

Table 1: Significance Level of Inspection Finding

Risk impact of finding	Level of risk significance
$\Delta CDP \geq 1$ E -4	Red: high
1 E -5 $\leq \Delta CDP <$ 1 E -4	Yellow: substantive
1 E -6 $\leq \Delta CDP <$ 1 E -5	White: low to moderate
$\Delta CDP <$ 1 E -6	Green: very low

Mitigating Systems Performance Index

The mitigating systems performance index (MSPI) is a risk-informed performance index that replaced a previous set of indicators related to safety system unavailability. The MSPI provides a more accurate indication of the risk associated with changes in the availability and unreliability of important safety systems. During the development of the MSPI, NRC staff extensively tested the methodology by comparing MSPI results obtained from licensees' PRA models with those from the SPAR models. NUREG-1816 [4] provides a detailed discussion of this evaluation. To reconcile differences between the plant-specific PRA models and the SPAR models, the staff undertook a major effort to enhance the SPAR models further. Overall, the MSPI results from the pilot plant models agreed quite well with the updated SPAR models.

Accident Sequence Precursor Event Evaluations

The NRC established the accident sequence precursor (ASP) program in 1979 to identify, document, and rank the operating events that are most likely to lead to accident precursors [5]. A precursor event is an event that has a probability of greater than 1 in 1 million of leading to substantial damage to the reactor fuel. Depending on the type of event, the NRC staff uses the SPAR models and event-specific information to estimate either a CCDP or ΔCDP as discussed above for the SDP. The ASP program considers an event with a CCDP or ΔCDP greater than or equal to 1×10^{-6} to be a precursor. A significant precursor is an event with a CCDP or ΔCDP greater than or equal to 1×10^{-3}.

Notices of Enforcement Discretion

The NRC can grant a notice of enforcement discretion (NOED) if compliance with technical specifications or another license condition would involve an unnecessary plant transient; performance of testing, inspection or system realignment that is inappropriate for the specific plant conditions; unnecessary delays in plant startup without a corresponding health and safety benefit; or the potential for an unexpected plant shutdown that could exacerbate degraded grid conditions and adversely impact overall public health and safety. The NOED guidance presented in IMC 9900 [6] describes the PRA results that the licensee is expected to present to justify that the incremental risk increase resulting from the NOED would be within established thresholds. The NRC staff performs an independent analysis using the SPAR model to understand the licensee's results and inform the decision whether to grant a NOED.

Incident Investigations

The NRC staff conducts incident investigations, following the guidance in Management Directive 8.3 to review operational events that pose actual or potential hazards to public health and safety, property, or the environment [7]. The level of response is determined by the risk significance, complexity, and generic implications of the event. As part of this process, the NRC staff uses the SPAR models to estimate the CCDP during the event, reflecting the loss of defense in depth due to the event. Table 2 shows how the CCDP is used as input to the staff's response.

Table 2: NRC Incident Response Options

<table>
<tr><th colspan="5">Estimated Conditional Core Damage Probability (CCDP)</th></tr>
<tr><td>CCDP < 1E-6</td><td>1E-6 – 1E-5</td><td>1E-5 – 1E-4</td><td>1E-4 – 1E-3</td><td>CCDP > 1E-3</td></tr>
<tr><td colspan="2">No additional inspection</td><td colspan="3"></td></tr>
<tr><td></td><td colspan="2">Special Inspection Team</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="2">Augmented Inspection Team</td><td></td></tr>
<tr><td colspan="4"></td><td>Incident Investigation Team</td></tr>
</table>

License Amendment Requests

Licensees frequently request risk-informed changes to their licensing basis, following the processes outlined in Regulatory Guides 1.174 and 1.177 [8, 9]. While evaluating these requests, the NRC staff uses the plant-specific SPAR model to understand the PRA results presented by the licensee and to confirm that the requested change is consistent with the guidelines documented in the Regulatory Guides.

Generic Issue Prioritization

In assessing plant operation, the NRC has identified certain issues involving public health and safety, the common defense and security, or the environment that could affect multiple entities under NRC jurisdiction. The generic issues program [10] was developed to explore and resolve these issues. For generic issues that are screened into the process, the NRC staff develops an action plan that includes a safety and risk assessment, following criteria based on existing agency documents for performing regulatory analyses. The staff uses the SPAR models to develop the risk estimates needed for this process.

2. CURRENT AND EXPECTED USES OF NEW REACTOR SPAR MODELS

The staff has been actively exercising the AP1000 SPAR model developed by INL in 2009. Current plans are for INL to complete the development of the Advanced Boiling Water Reactor (ABWR) design model, followed by SPAR models for the Economic Simplified Boiling Water Reactor (ESBWR), United States Evolutionary Power Reactor (U.S. EPR), and United States Advanced Pressurized Water Reactor (US-APWR). SPAR models for other new light-water reactor (LWR) designs, including modular reactors, will be considered on a case-by-case basis. The availability of NRC resources as well as the number and schedule of potential combined license (COL) applications will factor into the decisions.

The discussion below describes how the staff intends to use the SPAR models in various capacities.

2.1. Licensing Reviews

Risk Insights

During the review of new reactor applications, risk analysts in the Office of New Reactors (NRO) frequently work with staff in other technical disciplines to provide risk insights on design and operational topics. Following submittal of major design certification or COL applications, risk analysts used the applicants' documents to identify important design features, assumptions, equipment, and human actions. After these insights were presented to the technical staff, NRO has observed an increase in communication between the risk staff and other technical reviewers seeking information on the risk significance of issues they discover during their reviews.

Now that design-specific new reactor SPAR models are being developed, the risk staff expects to use these models to provide on-demand risk insights to technical staff. Applicants' documents include a defined amount of information on their PRA model, but a broader range of sensitivity studies, importance information, and qualitative insights can be obtained using the SPAR models. For example, risk analysts could manipulate the SPAR model to understand the potential risk benefits of design alternatives under review by the technical staff.

Internal Training

The design-specific new reactor SPAR models provide a valuable training tool for NRC staff. Before the development of the SPAR models, NRC staff created extremely simple new reactor models as an on-the-job training exercise to gain familiarity with the plant design and PRA structure. Risk analysts used these models to understand the PRA development process, the details of important core-damage sequences, and the relative importance of various systems and initiating events. The staff envisions that internal training will be greatly enhanced by the availability of the new reactor SPAR models, because staff can use these models on demand to answer questions about the plant design, risk profile, and PRA modeling. Use of the new reactor SPAR models may be included in the future as part of the reliability and risk analyst training plan, an outline of developmental study and practical activities designed to enhance the technical abilities of new risk analysts in NRO.

2.2. Construction Inspection Prioritization

The Center for Construction Inspection (CCI) was created in 2006 to consolidate inspection of new reactor construction. CCI is part of the NRC's Region II office in Atlanta, GA and performs inspections to verify that new reactors are constructed in accordance with approved design criteria. A major portion of this effort is the inspection of construction activities related to inspections, tests, analyses, and acceptance criteria (ITAAC). The ITAAC define verification activities that must be performed by licensees during construction to ensure that certain key design parameters are met. Each of the four certified designs (AP600, AP1000, ABWR, and System 80+) has a unique set of ITAAC that were approved by the NRC during the licensing process. Prior to authorizing operation of a facility, the Commission must make a finding that all ITAAC acceptance criteria have been met. To support this finding, CCI will conduct inspections to verify that the ITAAC for that facility have been met. This will be done by inspecting a smart sample of about one third of the ITAAC and expanding the sample if significant construction issues are identified.

Many ITAAC reference large tables or lists of components, and it may not be necessary to inspect every component described by a given ITAAC. CCI has addressed this issue in part by using the AP1000 SPAR model to identify the components with highest risk significance, thereby providing an opportunity to develop a risk-informed inspection sample. This concept is best illustrated with an example, as shown below in Table 3.

Table 3: Example ITAAC for Risk-Informed Sampling

ITAAC 2.2.01.12b		
AP1000 Passive Core Cooling System (PXS)		
Design Commitment	**Inspections, Tests, Analyses**	**Acceptance Criteria**
After loss of motive power, the remotely operated valves identified in Table 2.2.3-1 assume the indicated loss of motive power position.	Testing of the installed valves will be performed under the conditions of loss of motive power.	After loss of motive power, each remotely operated valve identified in Table 2.2.3-1 assumes the indicated loss of motive power position.

Table 2.2.3-1 in the AP1000 Design Control Document (DCD) identifies 24 valves that are addressed by this ITAAC. An inspector may observe testing of all 24, or may opt for a sample. CCI risk staff can use the AP1000 SPAR model to determine which valves are the most risk significant, thereby providing a risk-informed approach. This approach is valuable because the safety significance of valves (or other components described by ITAAC) is not always intuitively obvious. For example, the AP1000 relies on squib valves that must open in certain accident sequences to provide long-term core cooling. SPAR model calculations show that some of these valves have substantially higher risk importance because of their location. This information could be used along with deterministic insights to develop a prioritized, risk informed inspection sample.

2.3. Operation

The staff will continue to use the SPAR models to support the ROP and license amendment reviews once new reactors begin operating. Similar to the process for currently operating reactors, the NRC staff expects that new reactor licensees will request risk-informed changes to their licensing basis. Although the process for staff review of these applications is currently under development, the new reactor SPAR models will provide a convenient, simple, and powerful means of enhancing staff review of the requests. The new reactor SPAR models will be valuable in understanding the PRA results presented by the licensee and confirming that the requested change is consistent with the guidelines for new reactor licensing basis changes.

3. CHALLENGES

3.1. Technical Adequacy

A quality assurance plan was formally established in 2006 for SPAR model development activities. In addition to internal quality-assurance efforts, the staff is working with industry representatives to ensure that the models and risk assessment techniques continue to be improved and updated. The staff and the Electric Power Research Institute executed an addendum to the memorandum of understanding to conduct cooperative research for PRA. Several of the initiatives in this effort are intended to resolve technical issues that account for differences between NRC's SPAR models and the licensees' PRAs. In addition, the staff, with the cooperation of industry experts, performed peer reviews of a typical boiling-water reactor SPAR model and a typical pressurized-water reactor SPAR model in accordance with the PRA consensus standard, ASME RA-S-2002 [11], as endorsed by the NRC in Regulatory Guide 1.200 [12]. While the staff has no current plans to perform peer reviews on the new reactor SPAR models, lessons learned from the peer reviews for the two operating plant models discussed above may be factored into the new reactor models as resources permit.

Level 2 module. After the Level 1 internal events models are developed, the staff will consider whether Level 2 models should be developed.

If such models are developed in the future, one aspect of the decision will be whether to calculate LERF or large release frequency (LRF). New reactor applicants calculated LRF in their design certification PRAs, and the appropriate use of LERF and LRF for new reactors in the future is still under discussion. Although a consistent definition for LRF has not been established, the frequencies of large radiological release from new reactor designs are approximately one to four orders of magnitude lower than the mean of operating plants. LRF during shutdown can also be significant because of assumptions related to containment closure during some phases of refueling. Therefore, as with external events and shutdown, the staff's decision will take into account the risk profile of the design and the planned uses of the model, as well as resource considerations.

3.4. Configuration Control

The SPAR models for new reactors represent generic, site-neutral reactor designs. Some site-specific features such as the ultimate heat sink and offsite power configuration are modeled, but only to a limited extent. Regulations for new reactors specify that the PRA for a COL must use PRA information for the certified design and must be updated to account for site-specific design information and any design changes or departures.

Some new reactor design centers are considering innovative approaches that build upon the commonality of design at multiple reactor sites. One possible approach would be to construct a single PRA model to represent the generic reactor island, with modules for site-specific features that can be switched on or off for plant-specific applications. The staff recognizes the advantages of economy of scale that such an approach offers for new reactor SPAR models in the future as well. For example, in the current situation for operating reactors, 77 models are needed to provide a reasonable representation of 104 operating units. Even some multi-unit sites with seemingly identical designs by the same reactor vendor have enough differences between the units to warrant separate SPAR models. To construct one SPAR model to represent 8 or 10 nuclear power plant units would be a major paradigm shift.

This approach does represent some potential challenges. Maintaining configuration control of the single SPAR model that represents multiple reactor sites would require a close working relationship between the NRC and its contractor, and the organization that ultimately maintains the single PRA model. In addition, while the approach of using a single model for internal events offers many advantages, incorporating external events for multiple sites with greatly varying degrees of hazards would have to be considered carefully.

4. CONCLUSION

The NRC staff, working in collaboration with its contractor INL, is developing SPAR models for the new evolutionary and passive LWR designs. An AP1000 model was developed in 2009 and is being exercised by the staff. The staff has plans for the continued development of SPAR models for all the new reactor designs for which there is a COL application. SPAR models for other new LWR designs, including modular reactors, will be considered on a case-by-case basis.

The staff intends to use these models in much the same way that SPAR models are being used for currently operating reactors. Support of licensing reviews, internal staff training on risk insights, and the ROP are primary examples. In addition, the staff is using the models to support construction inspection prioritization.

Some challenges in the use of the SPAR models are evident. External events and low power/shutdown can be major contributors to CDF and risk for some new reactor designs. Maintaining configuration control of the SPAR models from the reactor design stage, through construction and into operation, could pose some unique challenges, especially if the model were to be *modularized* to represent the PRA for multiple units at multiple sites.

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