EPRI | ELECTRIC POWER RESEARCH INSTITUTE

A Survey of Current Shutdown Risk Evaluation Practices at Nuclear Power Plants

EPRI Configuration Risk Management Forum Research Task

3002003063

A Survey of Current Shutdown Risk Evaluation Practices at Nuclear Power Plants

EPRI Configuration Risk Management Forum Research Task

3002003063

Technical Update, April 2014

EPRI Project Manager

D. Hance

All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product.

YES NO

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THE FOLLOWING ORGANIZATION(S), UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

Enercon Services, Inc.

THE TECHNICAL CONTENTS OF THIS PRODUCT WERE **NOT** PREPARED IN ACCORDANCE WITH THE EPRI QUALITY PROGRAM MANUAL THAT FULFILLS THE REQUIREMENTS OF 10 CFR 50, APPENDIX B. THIS PRODUCT IS **NOT** SUBJECT TO THE REQUIREMENTS OF 10 CFR PART 21.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

Enercon Services, Inc.
3615 Westchester Court
Middletown, MD 21769

Principal Investigator
T. Morgan

This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

A Survey of Current Shutdown Risk Evaluation Practices at Nuclear Power Plants: EPRI Configuration Risk Management Forum Research Task. EPRI, Palo Alto, CA: 2014. 3002003063.

PRODUCT DESCRIPTION

The EPRI Configuration Risk Management Forum (CRMF) conducts research to support nuclear power plants in assessing the risk of maintenance activities and other plant configuration changes as required by the Maintenance Rule and other risk-informed applications. This report provides the results of a survey effort to assess current shutdown risk evaluation practices at nuclear power plants. The report addresses the type of shutdown models that are used in the industry, organizational aspects of shutdown risk evaluation, frequency of model updates, transition mode risk, treatment of high-risk evolutions (HREs) and initiating events, heavy-load lift activities during shutdown, spent fuel pool evaluations, programmatic considerations, and dominant key safety functions (KSFs).

Background

In 2011, the CRMF conducted a survey of industry configuration risk practices for both at-power and shutdown conditions. The survey results indicated that there may be variations in the risk models and the evaluation criteria used for shutdown risk evaluation. To further investigate shutdown risk practices, a follow-up survey was conducted in 2013 to specifically focus on shutdown risk evaluation practices.

Objectives

The objectives of the shutdown risk evaluation practices survey were to characterize current practices and to explore the reasons for the variations observed in shutdown risk results. The issues explored in the survey included the following:

- The type of shutdown models used (for example, qualitative, quantitative, or a blended approach) and the level of detail incorporated into these models
- The utility organization(s) responsible for performing shutdown risk evaluations and the frequency of model updates
- Treatment of transition modes, HREs, and shutdown initiating events
- Treatment of heavy load activities and spent fuel pool risk within the shutdown CRM program
- Programmatic aspects that might apply to outage risk evaluations, and the impact of these aspects on the risk evaluation results
- Single configuration changes that could cause the risk evaluation result to change from green or yellow to red
- Specific KSFs that dominate risk during a typical plant outage
- Consideration of mitigating factors in the risk evaluation

Approach

A survey of shutdown risk assessment issues was conducted. The responses were compiled and analyzed. Following this, the shutdown risk models of two BWRs and three PWRs were examined further to explore issues related to differences in risk evaluation results.

Results

A total of 19 surveys were completed, representing 40 nuclear plant units. Clear majorities indicated that they use qualitative defense-in-depth models, that they have reviewed the model for consistency with the as-built, as-operated plant in the last year, and that the modeling is done at the component level or a combination of train-level and component level. Other insights included the following:

- PWRs, particularly older PWRs, tend to be more likely to spend the majority of an outage in a yellow risk condition than BWRs.
- Programmatic aspects such as administrative requirements were considered by the survey respondents to have a minor impact. However, review of individual shutdown risk models did identify some programmatic aspects that could influence the overall results.
- Decay Heat Removal, Inventory Control, and Support System Availability were the dominant KSFs for most plants. For BWRs, Inventory Control was dominant for plants having outages that were "mostly green," and Support System Availability was dominant for plants having outages that were "mostly yellow."
- The focused review revealed that differences in the aggregation of the KSF risk metrics, risk evaluation methods, outage work practices, and design characteristics can each have an impact on the overall result. These included evaluation of cross-connections between units.

Applications, Value, and Use

This report is written for EPRI members to provide comparative information that will enable them to better assess their shutdown risk evaluation practices and help to define the CRMF research priorities, going forward. Member utilities can review the report and compare their individual results for benchmarking and program improvement. The report also identifies issues that may warrant additional research or guidance.

Keywords

Defense in depth
Low power and shutdown
Qualitative risk assessment
Risk
Risk assessment
Shutdown

EXECUTIVE SUMMARY

The EPRI Configuration Risk Management Forum (CRMF) conducts research to support nuclear power plants in assessing the risk of maintenance activities and other plant configuration changes as required by the Maintenance Rule and other risk-informed applications. In 2011, a survey of industry configuration risk practices was performed [1]. The survey results indicated that there may be variations in the risk models and the evaluation criteria used for shutdown risk evaluation. To further investigate shutdown risk practices, a focused survey was conducted, and additional data was collected from selected plants.

The questions surveyed included the following:

- The type of shutdown models used (for example, qualitative, quantitative, or a blended approach) and the level of detail incorporated into these models
- The utility organization(s) usually responsible for performing shutdown risk evaluations
- The frequency of model updates
- How transition modes risk is evaluated in the configuration risk management (CRM) program
- The types of treatments used to consider the risk impacts of HREs and shutdown initiating events
- The treatment of heavy load activities within the shutdown CRM program
- The treatment of spent fuel pool risk within the CRM evaluations
- The types of "programmatic aspects" and other management rules that might apply to outage risk evaluations and the impacts of these items on the risk evaluation results
- The specific key safety functions (KSFs) that dominate risk during a typical plant outage

A brief addenda survey was also prepared and issued to inquire about the consideration of mitigating factors that might be considered in the risk evaluation, based on a suggestion from a CRMF member utility.

The results of the survey provided additional insights into current risk evaluation practices. It was observed that there are differences between plants concerning dominant KSFs that may account for some of the observed variation in overall results. Plant age and plant type (BWR vs. PWR) also have some influence on the overall risk results.

The survey also showed that shutdown models are frequently reviewed against current plant practices to ensure consistency with the as-built, as-operated plant. The level of detail of these models is typically at the component or train level, or utilizes a combination of component and train modeling. There are variations in how HREs and shutdown initiating events are considered in the models; however, it did not appear that these variations were important contributors to the observed variation in overall risk results.

The survey sought to determine if programmatic aspects, such as administrative requirements, rules and other similar practices, might impact the risk results. The survey responses indicate that these items do not have a significant effect; however, some programmatic influences were noted in a further review of information from several plants (as discussed below).

Respondents were also asked if there were specific conditions in which a single configuration change could cause the risk color evaluation to change from green or yellow to red. The intent of this question was to identify the extent of situations in which an acceptable level of risk can transition directly to an unacceptable risk, or a zero defense-in-depth condition. A significant subset of the respondents indicated that such transitions would be possible under their shutdown CRM modeling approach. In general, these situations often involved issues concerning containment integrity (for example, loss of containment closure capability), support system failures (particularly, electrical and ventilation system unavailability), and residual heat removal (RHR) systems (for example, changes in unavailability of RHR trains under high heat conditions. Further study of these situations may be warranted to ensure that consistent modeling approaches are used throughout the industry.

The shutdown risk models of several plants were examined further, and it was noted that reported differences in outage risk results were influenced by differences in types of qualitative risk models used (for example, point-based defense-in-depth evaluations vs. safety function assessment trees), as well by differences in how the risk results from individual KSFs were aggregated to determine an overall outage "risk color." Different programmatic treatments of the risk impacts of support systems that are shared between units were also observed to influence the risk results. Plant-specific design features and differences in outage practices also affect the results (as would be expected).

The survey and the subsequent focused review of several plants helped to identify some areas for further investigation and possible guidance development that could benefit the industry. The evaluation of shutdown risk is quite mature in the U.S. nuclear industry. The details of the survey results show that these evaluations are detailed, that they consider the key risk contributors, and that the models are frequently reviewed and updated to ensure consistency with the as-built, as-operated plant.

The results of this study have shown that there are many possible reasons for the reported variation in risk results. Each plant's results, looked at individually, appear to be following the evaluation method identified. However, the limited investigation performed here indicates that differences in model development, in risk color aggregation, and in how shared system risk impacts are allocated between units could impact the reported results.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

The EPRI Configuration Risk Management Forum (CRMF) conducts research to support nuclear power plants in assessing the risk of maintenance activities and other plant configuration changes as required by the Maintenance Rule and other Risk-Informed applications. An annual meeting is also held to allow CRM personnel to exchange insights and experience and to learn about current industry and regulatory trends that may affect CRM programs. One of the key tasks performed by the CRMF is a periodic survey of industry practices. The most recent survey was performed in 2011 [1]. A significant fraction of the industry participates in this survey, and the results have been proven useful for benchmarking of individual utility practices against those of their peers. The survey also provides information about current industry trends and often helps to identify areas that may benefit from performing additional data gathering or research or from developing guidelines and improved methodologies.

A key observation from the 2011 industry survey was that there was considerable variability in the fraction of time that plants spent in the various "risk colors" (e.g., "green", "yellow", "orange", etc.) during outages. This was in contrast to the percentage of time spent in each risk color zone for the at-power CRM evaluations, which was quite consistent. To further investigate the reasons for these variations, a follow-up survey was conducted in 2013 to specifically focus on shutdown risk evaluation practices. This report documents the results of the 2013 survey and follow-up reviews. The analysis of the new survey data provided further insights and identified some potential reasons for some of the variation.

Additional data was collected from several plants in a focused review, to examine how differences in the modeling of various Key Safety Functions (KSFs) might explain some of the observed variations.

Section 2 of this report summarizes the background of the issue and the survey that was conducted. Section 3 provides an analysis of the survey responses. Section 4 discusses the review of the KSF modeling at several plants. Section 5 presents overall conclusions based on the obtained data. Section 6 provides references that were used in the development of this report. Appendix A provides the detailed responses provided to the survey questions; this data may be useful for more detailed benchmarking of plant practices.

2
SHUTDOWN RISK EVALUATIONS: CURRENT INDUSTRY METHODS AND ISSUES

The US nuclear power industry has been performing shutdown risk evaluations on a routine basis since the early 1990s. These evaluations are typically qualitative in nature, based on the assessment of the degree of Defense in Depth (DID) provided for each of the Key Safety Functions (KSFs) that are required to protect the health and safety of the public. The EPRI CRMF has conducted surveys of current industry configuration risk management practices every four years (in 2003, 2007 and 2011). While the initial 2003 survey focused primarily on the assessment of risk during power operation, the number of survey questions targeted towards shutdown risk evaluation practices has increased in each successive survey. The 2011 survey [1] asked respondents to describe the methods used to evaluate shutdown risk and indicate what fraction of time the plant spends in each of the various risk color zones (e.g., green, yellow, orange, and red) during each outage.

The 2011 survey results indicated that the fraction of outage time that each plant remained in the various risk color zones varied significantly. Basically, plants could be characterized as falling into the following three categories, in terms of time spent in various risk colors:

- The plant spends the majority of the outage in the "green" risk color zone
- The plant spends the majority of the outage in the "yellow" (or higher) risk color zone
- The plant spends roughly 50% of the time in "green" and the remaining 50% of the time in "yellow" or a higher risk color zone

This variability, by itself, does not necessarily indicate that any specific issues exist; however, the CRMF steering committee recommended that additional study of the causes of the variability be performed to try to determine if the results reflect differences in plant designs and outage practices, or are the result of differences in CRM modeling. Based on the results, the potential need for further industry research or guidance development could be determined.

Additional analyses [2] were performed of both the at-power and shutdown risk evaluations based primarily on the data from the 2011 survey responses. The analyses did confirm that overall methods used to evaluate shutdown risk colors were consistent (based upon the evaluation of how many unique system trains that are available to support each KSF). Additional analyses of the extent of the risk color variability were also performed.

Based on the results obtained [1, 2], it was determined that additional data would need to be collected to better determine the causes for the observed variation. To help identify the types of information that would be helpful to study the plant practices further, several possible hypotheses were defined to explain the observed variation:

- Programmatic aspects, such as administrative requirements or management philosophy might contribute to some plants having higher or lower risk color results than other plants.

- Some Key Safety Functions (KSFs) might be more important for plants that spend most of their outage in "yellow" as compared to limiting KSFs in plants with mostly "green" outages
- Some differences in the observed outage risk color variations during outages might be due to plant type or vintage.

The survey included questions to try to help evaluate the accuracy of these hypotheses. In addition, other shutdown risk evaluation-related questions were asked to collect data that may be useful for benchmarking and future research purposes. The questions surveyed included the following:

- The type of shutdown models used (e.g., qualitative, quantitative, or a blended approach) and the level of detail incorporated into these models
- The utility organization(s) usually responsible for performing shutdown risk evaluations
- The frequency of model updates
- How transition modes risk is evaluated in the CRM program
- The types of treatments used to consider the risk impacts of HREs and shutdown initiating events
- Treatment of heavy load activities within the shutdown CRM program
- Treatment of spent fuel pool risk within the CRM evaluations
- The types of programmatic aspects and other administrative requirements that might apply to outage risk evaluations and the impacts of these items on the risk evaluation results
- The specific Key Safety Functions (KSFs) that dominate risk during a typical plant outage

Shortly after the survey was issued to the industry, a CRMF member utility suggested that several additional questions be asked concerning the consideration of mitigating factors that might be considered in the risk evaluation under certain conditions. An addenda survey was prepared and issued to be completed along with the initial survey.

3
ANALYSIS OF SURVEY RESPONSES

This chapter presents an overall summary and interpretation of the results. Based on the survey results, some additional data was collected and evaluated in a focused review of particular plants, as discussed in Section 4. Appendix A provides a detailed compilation of the survey results for possible use in benchmarking or for further analysis.

A total of 19 surveys were completed, representing a total of 40 power plant units (34 units were located in the US and 6 were located in other countries). The overall level of survey participation was quite high. However, some utilities that provided input to the 2011 survey did not respond to this survey, and vice versa. The addenda survey was responded to by 13 respondents, representing 31 units. In some cases, plants provided a response to the initial survey but not the addenda. A few plants responded to the addenda but not the initial survey.

In summarizing the survey results in terms of percent of plants responding, the results do not always total 100%, due to multiple approaches described by some plants, or plants that did not provide answers for all questions.

Main Survey Results

The first portion of the survey collected basic information about the shutdown risk assessment process and models. The results obtained from this section of the survey were not expected to directly address possible causes for the observed variations in shutdown CRM "risk color" results; however, this information helps to assess overall industry practices concerning the maintenance and use of the shutdown CRM models. This data can also be useful for benchmarking purposes.

As expected, most respondents indicated that they used qualitative DID models for shutdown. However, five units indicated that quantitative shutdown risk models are used. Which group at the plant performs the shutdown risk evaluations varies significantly from plant to plant. In many cases, several groups were noted as having at least some of the responsibility. The most frequent answers provided were "PRA group" and "Operations Personnel".

Respondents were asked to indicate when their shutdown CRM models were last reviewed for consistency with the current plant design and outage practices. Thirty-one of the forty units (78%) indicated such a review was performed with the past year. Seven units (18%) indicated the review was performed within the last 5 years. One unit said it performed such a review with in the last 3 years, and one unit said it had been performed within the last 10 years. So, the responses indicate that the industry is keeping their shutdown CRM models up to date, with almost 98% performing a model review within the past 5 years. In addition, almost 83% of the respondents indicated that their shutdown CRM models had been updated to reflect plant-specific operating experience.

Figure 3-1 summarizes the results of a question concerning the level of detail to which the shutdown CRM models have been developed. As can be seen, about half of the respondents said the level of detail of their models was a combination of system level and component level features.

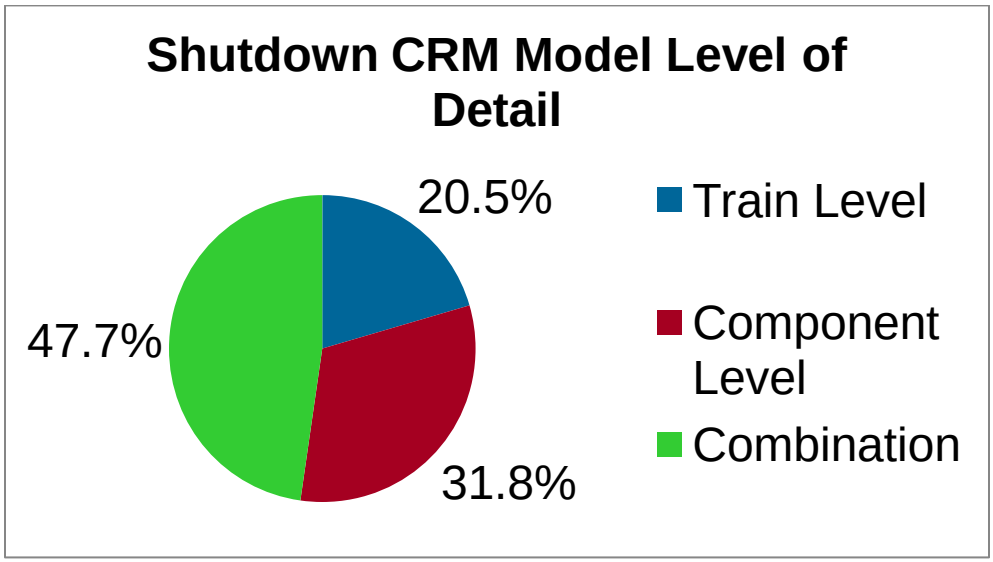

Figure 3-1
Level of Detail of Shutdown CRM Models

The last question in this section of the survey pertained to the types of models used during the transition modes. All plants indicated that transition modes were considered in their CRM program. However, a range of responses were provided concerning how these modes were evaluated. In general, it appears that the at-power quantitative model is used for at least a portion of the transition modes (e.g., from hot standby). Qualitative defense in depth models are often used for the remaining transition modes (e.g., hot and cold shutdown). See Appendix A to review the individual responses.

The next section of the survey explored specific attributes of shutdown CRM Models. This information was also felt to be of value for benchmarking purposes, but the questions asked here were also intended to obtain a better understanding of the scope of the shutdown models and "adjustment factors" that might influence the calculated risk results.

The first question in this section inquired as to how HREs are addressed in the CRM model. This question required a written response. The individual responses are presented in Appendix A. The treatments used vary over a range of possible options including:

- Explicit inclusion within the DID model (i.e., the HRE results in different DID decision logic being utilized to evaluate risk color), usually resulting in an increase of the risk color by one level (e.g., green to yellow, yellow to orange, etc.)
- HRE impact is considered qualitatively separately from the DID model's results. (In this case, the risk color calculated by the DID model might be modified based on the occurrence of the HRE)
- The HRE requires that specific risk management plans be developed and implemented. However, there may not necessarily be a change in the calculated risk color.

The next survey question asked whether potential shutdown initiating events are addressed in the shutdown CRM model. Half of the plants indicated that these events were considered; the initiating events are typically either implemented as HREs or specific initiator logic was added into the shutdown CRM models. The other half of the respondents indicated that they did not address shutdown initiating events in their CRM models.

The next question inquired as the treatment of spent fuel pool systems in the shutdown CRM model. All 40 units responded that their current models address spent fuel pool risk. In general, the responses indicate that specific defense-in-depth trees have been developed to assess fuel pool cooling and, in some cases, inventory control.

Two questions (one for plants using a four-color "risk color" approach and a similar question for plants using a three-color approach) were asked to determine if there were specific conditions in which a single configuration change could cause the risk color evaluation to change from green or yellow to red. The intent of this question is to identify the extent of situations in which an acceptable level of risk can transition directly to an unacceptable risk, or a zero defense-in-depth condition. Twenty-nine of the units indicated that such transitions would be possible under their shutdown CRM modeling approach, while nine indicated that they were not possible with their CRM model. (As none of the respondents used a three-color approach, all responses pertained to the four-color question.)

In general, these situations often involved issues concerning containment integrity (e.g., loss of containment closure capability), support system failures (particularly, electrical and ventilation system unavailability), and residual heat removal systems (e.g., changes in unavailability of RHR trains under high heat conditions). Appendix A lists the specific responses obtained concerning the situations that could cause a multiple-color change in risk level, and should be reviewed to examine the specific situations that were cited.

The next question in the survey asked respondents about the types of "programmatic aspects" associated with the CRM program and the extent that these items impact the risk color determination or the performance of maintenance tasks. These items could include specific plant procedures, guidelines, and management expectations that impose constraints on the risk assessment process and the scheduling of maintenance work. As noted in Section 2, these programmatic aspects might be one of the reasons for risk color variations from plant to plant. Appendix A lists the specific types of "programmatic aspect" items that were noted by the respondents.

One-third of the responding units indicated they did not have any such items that affected their CRM process. For the other two-thirds of the units, the types of programmatic items noted generally fell into one of the two following general categories:

- Limitations on the highest risk color level that can be attained
- Requirements that specific plant configurations (e.g., PWR mid-loop operation, specific electrical system alignments, etc.) be classified as a certain risk color

When asked how much these programmatic aspects affected the CRM evaluation or the scheduling of maintenance activities, almost 75% of the plants with such programmatic aspects said these items had a minor effect. Figure 3-2 summarizes the results.

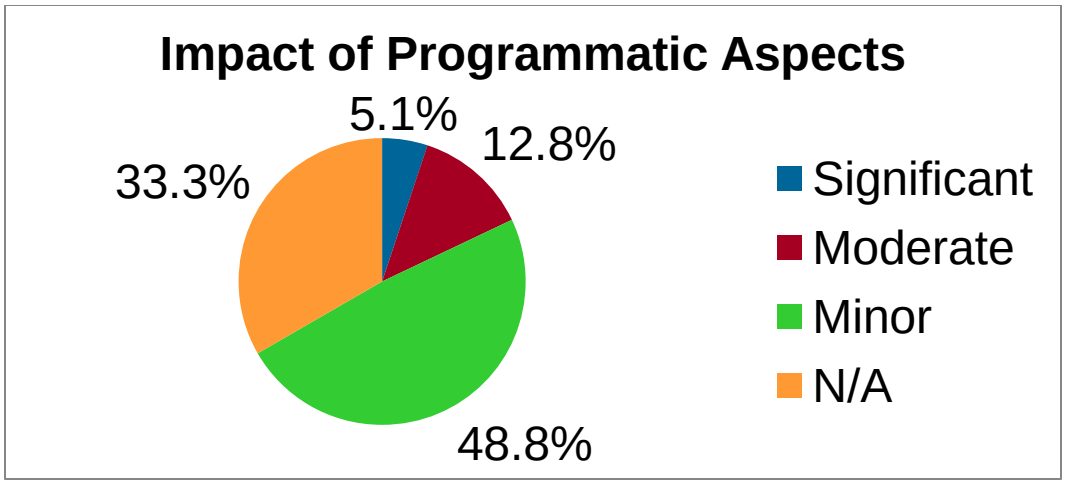

Figure 3-2
Impact of Programmatic Aspects on Shutdown CRM Process

The last question in this section investigated the evaluation of heavy load activities in the shutdown CRM process. Thirty-four (85%) of the responding units indicated that these activities are considered in their CRM process.

A related question asked to what extent the EPRI heavy loads CRM guidance [3] is used to evaluate these activities. Thirty units responded to this question, of which nine (30% said they did not use the guidance, seventeen (56.7%) indicated that their evaluation approach relied partially on the EPRI guidance, and four (13.3%) responded that their approach largely followed the EPRI guidance.

The final section of the survey investigated the key safety functions (KSFs) that were most limiting for each plant's outages. The first question of the survey repeats that used in the original 2011 survey [1] concerning the percentage of time each plant spends in the various risk colors during the outage. This question was re-asked to ensure that the current respondents demonstrated the same variability in the fraction of time spent in risk color as the original survey. Rather than report the specific percentages noted for each respondent, the responses were grouped into three categories. The results are summarized below:

- Outage risk profile is "Green" more than 50% of the time – 17 units (42.5%)
- Outage risk profile is "Yellow" more than 50% of the time – 18 units (45%)
- Outage risk profile is "Green" 50% of the time and "Yellow" or "Orange" 50% of the time – 5 units (12.5%)

These results are consistent with the results of the 2011 survey, so there does not appear to have been any significant change in overall shutdown CRM modeling approach since the 2011 survey.

The last question of the survey asked which KSFs are the most limiting during the outage. Figure 3-3 presents the results for all of the respondents, where the number of respondents is shown on the y-axis. Note that a plant may have indicated that several KSFs are limiting at different points in the outage.

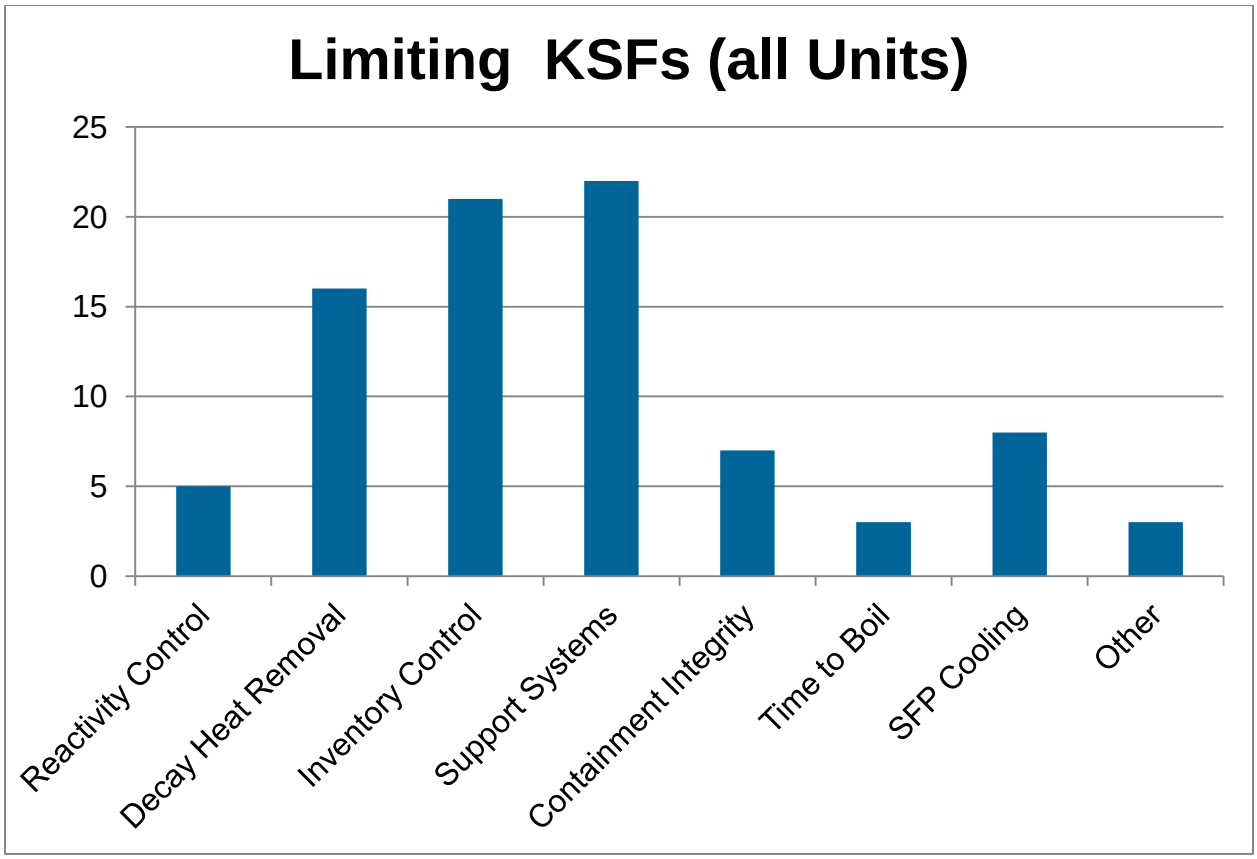

Figure 3-3
Limiting KSFs During Outage (all Units)

The results show that the most limiting safety functions are typically Support Systems Unavailability, Inventory Control and Decay Heat Removal. These three comprise the bulk of the responses.

The data was then subdivided further to consider only those units that had outages that were primarily in the "yellow" risk color region and those units with outages primarily in the "green" risk color region. Figure 3-4 presents the results for the "yellow" outage plants and Figure 3-5 presents the results for the "green" outage plants. As can be seen, plants with "yellow" outages indicated that Support System Unavailability is most often limiting, with Inventory Control and Decay Heat Removal also contributing. Plants with "green" outages have a fairly similar distribution, but Inventory Control is the most likely limiting KSF, with decay Heat Removal and Support Systems Availability ranked second and third most limiting.

The results shown in figures 3-4 and 3-5 don't show any clear differences in limiting KSFs. So, the results were further sub-divided by plant type.

For BWRs, Figures 3-6 and 3-7 show the limiting KSFs for plants with primarily "Yellow" and "Green" outages, respectively. The BWRs with "yellow" outages have Support System Unavailability, Decay Heat Removal, and Spent Fuel Pool Cooling as the most limiting KSFs; Inventory Control is not shown as a limiting function for any unit. On the other hand, the BWRs with "green" outages have Inventory Control, Decay Heat Removal, and Reactivity Control as

limiting KSFs, and Support System Availability is not shown as a limiting function for any unit. All the BWRs show Containment Integrity as an additional limiting KSF.

For PWRs, Figures 3-8 and 3-9 show the limiting KSF results. There is not as much difference in the reported limiting KSFs between plants with "yellow" and "green" outages. Plants with "yellow" outages show Support System Unavailability and Inventory Control as the most limiting KSFs. Plants with "green" outages show Inventory Control, Decay Heat Removal and Support System Unavailability as the limiting KSFs.

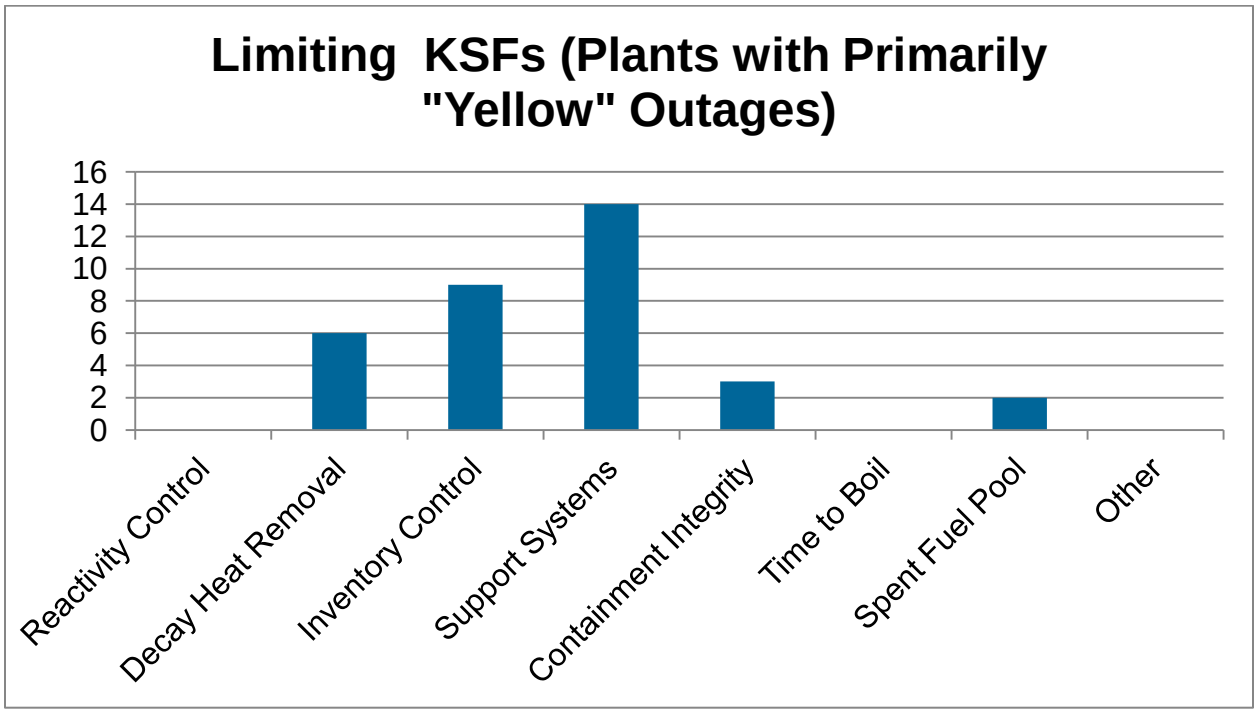

Figure 3-4
Limiting KSFs During Outage (Units with Primarily "Yellow" Risk Outages)

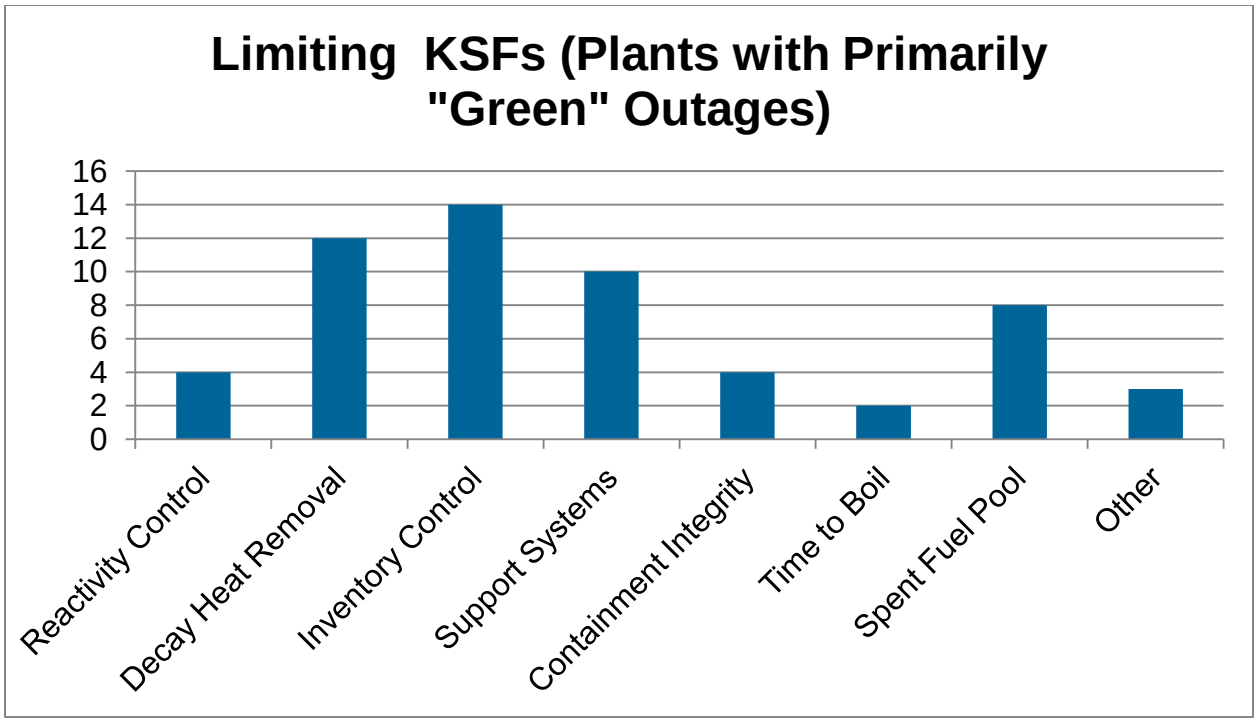

Figure 3-5
Limiting KSFs During Outage (Units with Primarily "Yellow" Risk Outages)

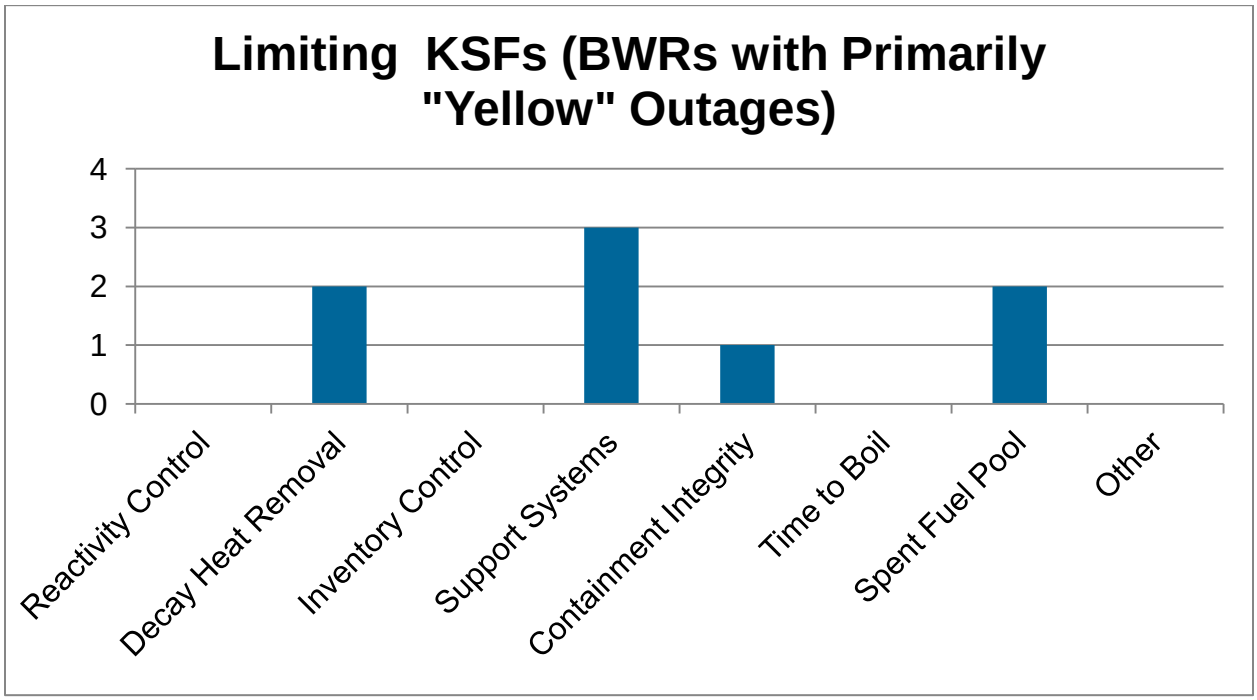

Figure 3-6
Limiting KSFs During Outage (BWRs with Primarily "Yellow" Risk Outages)

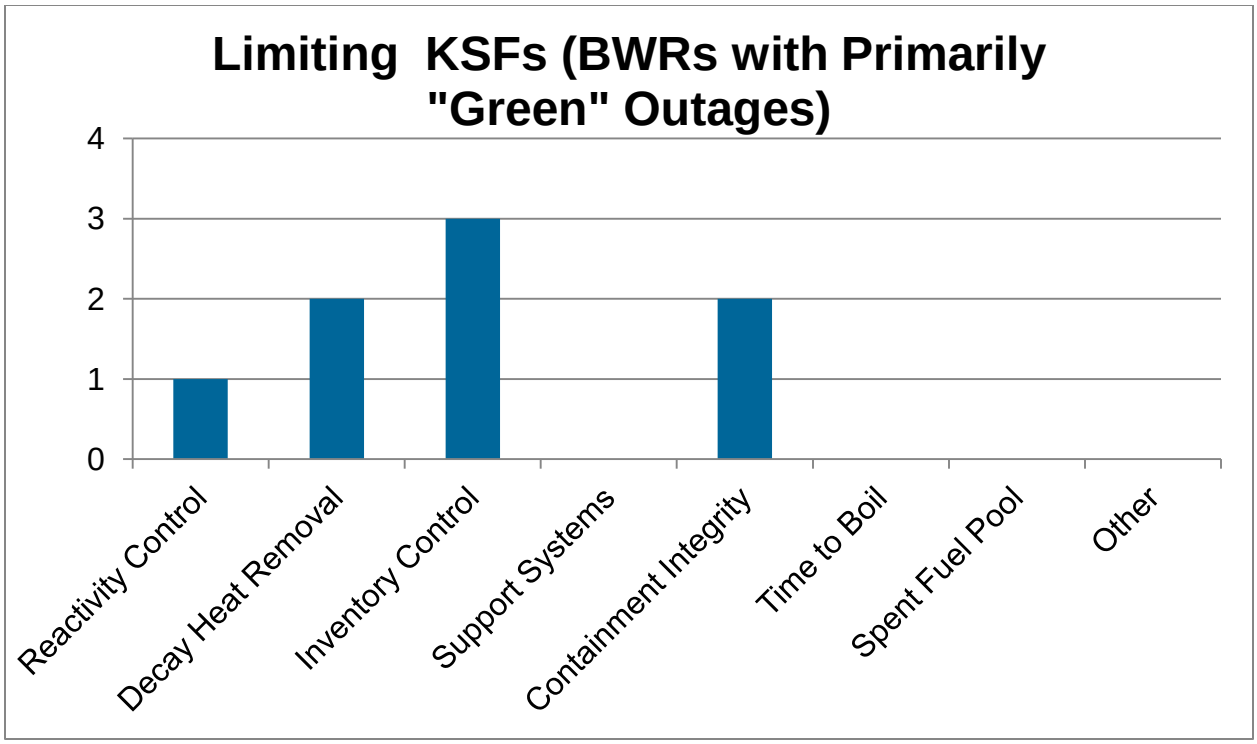

Figure 3-7
Limiting KSFs During Outage (BWRs with Primarily "Green" Risk Outages)

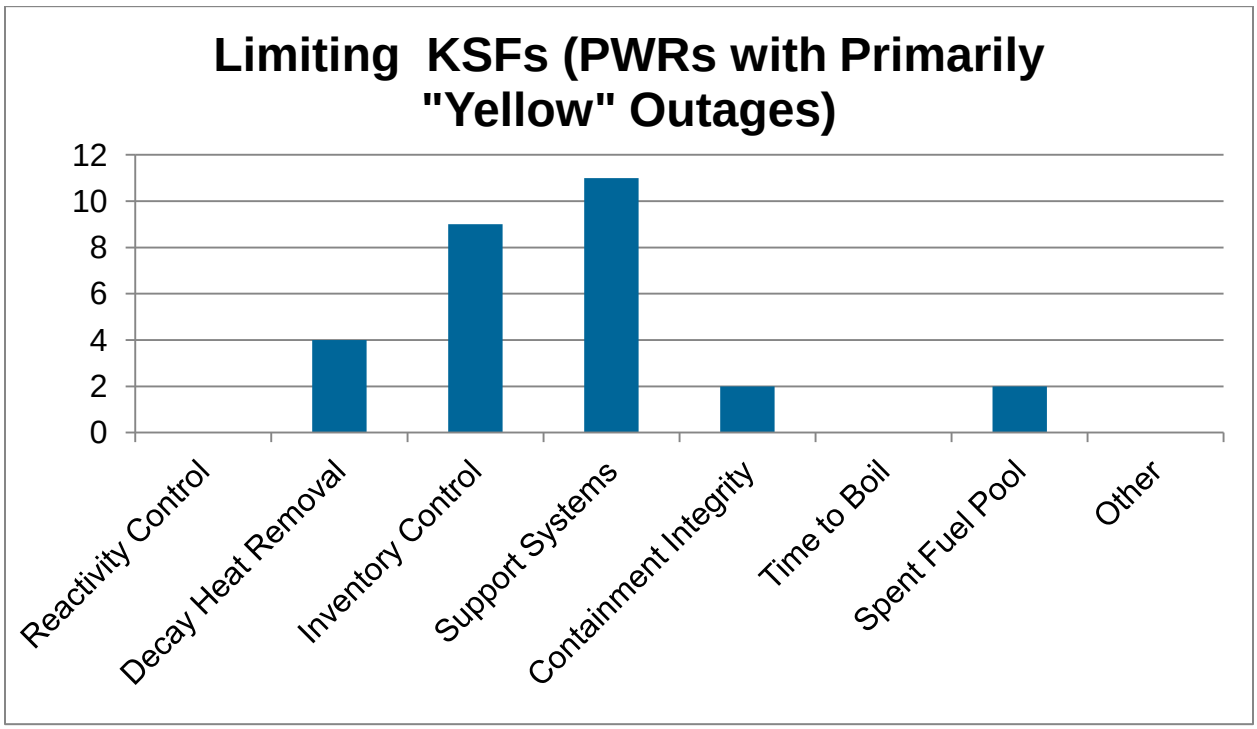

Figure 3-8
Limiting KSFs During Outage (PWRs with Primarily "Yellow" Risk Outages)

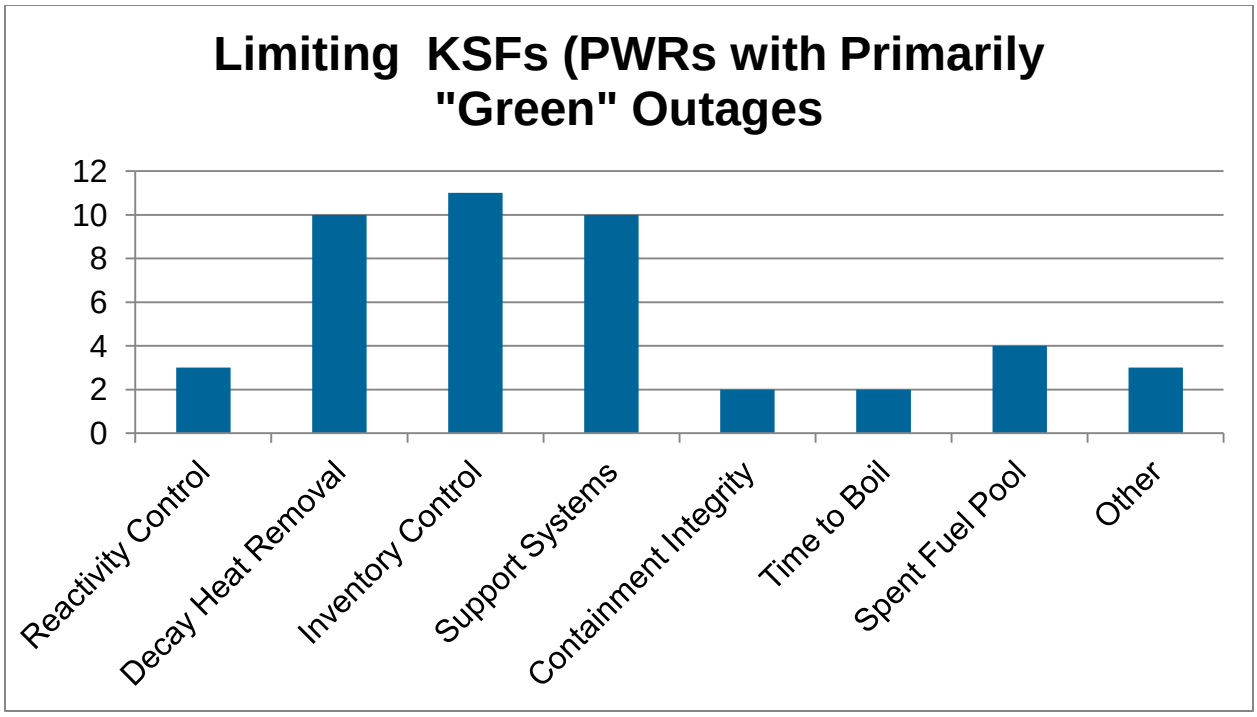

Figure 3-9
Limiting KSFs During Outage (PWRs with Primarily "Green" Risk Outages)

As the analysis of limiting KSFs indicated there were some differences due to plant type. A further subdivision based on plant age and type was also investigated. For plant age, the Three Mile Island accident in February 1979 was used as the dividing point between "older" and "newer" units. Table 3-1 summarizes the distribution of outage types vs. plant age and type.

For PWRs, the older units show a larger number of plants with primarily "yellow" outages than "green" outages, whereas the numbers are equal for the newer plants. For BWRs, there doesn't appear to be such a large difference between the number of plants with primarily "yellow" vs. "green" outages. (Note that since there are only two older units with "yellow" outages and one older unit with a "green" outage, there isn't sufficient data to tell whether there is a significant difference between the number of plants in each outage category).

A review of the limiting KSFs reported for each plant in each category didn't reveal any significant differences amongst the types of limiting KSFs.

Lastly, it should be noted that for each of the five PWR units that reported the use of a quantitative shutdown CRM model, all reported that their outages were primarily in the "green" risk color zone. It is generally considered that qualitative defense in depth models tend to be more conservative than the use of an integrated and realistic quantitative PRA model for shutdown conditions, since the DID models do not consider probability of failure and tend to weight all of the KSFs equally. The fact that the 5 PWRs with PRA models indicated that most of the outage configurations result in a "green" risk color would be consistent with that view. It should be noted that the survey did not ask that risk color thresholds used for these quantitative models be provided. The specific thresholds used would directly influence the outage risk results.

Table 3-1
Outage Risk Color Percentages as a Function of Plant Age

Outage Category	Older (Pre-1979) Units	Newer (Post-1979 Units)
PWR Units		
Number of Units with Primarily "Yellow" Outages	9	6
Number of Units with Primarily "Green" Outages	4	6
Number of Units with Outages that are 50% "Green" and 50% "Yellow/Orange"	0	2
BWR Units		
Number of Units with Primarily "Yellow" Outages	2	3
Number of Units with Primarily "Green" Outages	1	3
Number of Units with Outages that are 50% "Green" and 50% "Yellow/Orange"	2	1

Addenda Survey Results

The addenda survey was issued to inquire about the consideration of mitigating factors in online spent fuel pool risk evaluations and in shutdown risk evaluations.

For on-line spent fuel pool evaluations, mitigating factors are considered in about half (15 out of 31 units). For shutdown risk evaluations, nearly all (29 out of 31 units responding) consider such factors.

Concerning the specific types of mitigating factors used, the following summarizes the responses:

- About two-thirds of respondents apply more restrictive success criteria for shutdown decay heat removal with high decay heat, compared to having low decay heat
- About half of the respondents use a criteria such as maintaining "Time to 200˚F" greater than 72 hours for on-line SFP evaluations
- About half of the respondents consider the availability/ unavailability of SFP makeup sources in their on-line evaluations
- Nine respondents (~ one-third) apply less restrictive success criteria for shutdown decay heat removal when the refueling cavity is flooded compared to when it is not flooded
- Three units (about 10%) grant credit for additional means of fuel pool inventory control when the fuel pool gate is removed.

Appendix A also lists several other types of mitigating factors that are considered at some plants. They include requiring two independent fuel pool cooling trains be available when spent fuel pool decay heat is high.

4
INVESTIGATION OF PLANT-SPECIFIC MODELING APPROACHES

To further investigate the possible causes for the differences in limiting KSFs, a set of PWR and BWR plants were selected for additional review of the defense in depth logic used for the Decay Heat Removal, Inventory Control, Support System Availability, and other selected safety functions. Two similar BWRs were selected, and three similar PWRs were selected for further study.

For the BWRs, one plant reported that their outage is primarily in the "yellow" risk zone, with Decay Heat Removal and Support System Availability being the most limiting KSFs. The other BWR indicated that most of its outage remained in the "green" risk color zone and that Decay Heat Removal and Containment Integrity were the most limiting KSFs during their outage.

For the PWRs, two plants indicated that their outages spent most of the time in the "yellow" risk color zone; however, the limiting KSFs differed (Decay Heat Removal for one plant and Inventory Control for the other plant). The other PWR indicated that it spent most of its outage in the "green" risk color zone and that Containment Integrity was the limiting KSF.

Information was requested from each plant included the following:

- The success criteria used for the Decay Heat Removal (DHR), Inventory Control (IC), and Support System Availability (SS) Functions (i.e., what systems/trains need to be available to achieve a "green' status, as well as what reductions in system/train availability are needed to transition the KSF to "Yellow" or "Orange")

- For the KSFs that are limiting in the outage, what plant configurations result in the KSFs going to "Yellow" or "Orange" during the outage?

In general, each plant provided copies of their defense in depth logic for the three key functions noted above, as well as many of the other functions. Additional information as to what plant configurations resulted in the calculated risk color reaching the "yellow" or "orange" risk levels was also provided.

The review of this information (coupled with some follow-up questions) helped to identify some of the reasons for the different survey responses that were noted. Some of the variation is due to unique design features or differences in how shutdown risk is estimated. However, it was also recognized that some of the variation in the survey results may be due to how the questions concerning overall risk color were phrased.

Evaluation of PWR KSF Information

The review of the KSF defense in depth logic for the three main safety functions at the three PWR plants did not identify any significant differences in the success criteria used for the DHR, IC, and SS functions. However, two of the plants utilized Safety Function Assessment Trees (SFATs) to perform the defense in depth evaluation, whereas the third plant utilized an approach in which point "scores" are calculated for each KSF based on plant conditions and the number of

trains of equipment that is available. This third plant noted that its overall outage remained primarily in the "green" risk color zone.

The Containment Integrity KSF was the limiting KSF for this plant, and the scoring approach used for this function seemed reasonable. In addition to the KSF scoring sheet, a listing of the risk color calculated for each of the plant's KSFs throughout the outage was also provided. This was very helpful, as it showed that while most of the other KSFs remained "green" for the large majority of the outage, the Containment Integrity KSF was evaluated as "yellow" for the majority of the outage. It was noted that this plant does not assign an overall "outage color" at each point in the outage. In responding to the survey question, the analyst reasoned that since most of the KSFs remained "green" (other than Containment Integrity), it was appropriate to consider the overall outage risk as primarily "green". Note that if the plant adopted an approach that assigns the overall outage color to be that of the most limiting color at each point in the outage, then the response to the survey question would have been that the plant remained primarily in the "yellow" risk color zone during its outages. This may be another reason for some of the observed variation in the response to the survey question. Two plants could have very similar risk color results for individual KSFs; however, the manner in which they arrive at an "overall risk color" could cause their answers to differ. The survey did not ask about how the individual KSF colors were aggregated, so it cannot be determined how much of an impact the aggregation approaches could have on the reported survey results.

For the two plants using SFATs, a further analysis of the results identified that additional KSFs play an important role during the outages. Both plants reported they their outages were primarily "yellow" and the additional information did not change that determination.

At one plant, Inventory Control was cited as the limiting KSF and it was limiting because it resulted in an "orange" result during mid-loop conditions (based primarily on a programmatic requirement to consider such conditions to be high risk). However, the total amount of time that IC was the limiting risk color was quite short. The plant also has an additional KSF to monitor the status of the Control Room Ventilation Envelope, since the plant has a dual-unit control room and unavailability of some of the ventilation systems could have a significant Technical Specification impact on the operating unit. This Control Room Ventilation KSF (which could also be considered to be a programmatic requirement as it pertains to the online unit's Technical Specifications) remains "yellow" throughout most of the outage, so this function would also be "limiting" in terms of time during the outage in which the elevated risk condition is present.

The other plant indicated that DHR was the limiting function. Again, this was based on this function achieving the highest risk color ("orange"), but for a limited amount of time. Similar to the case above, the plants Support System Availability SFATs for Electric Power and Cooling Water remained at the "yellow" risk level for a significant portion of the outage, so these SFATs were "limiting" in terms of duration impact on the outage. The cooling water systems, in particular, are shared with the other unit; hence, changes in cooling water configuration can impact the operating unit during an outage and this impact is reflected in the SFAT logic.

So, for the PWR plants, the results indicate that the survey questions may not have been as specific as was required to fully understand the conditions at these plants. In the case of the plant with the primarily "green" outage, a different approach for determining an aggregate risk color for the outage would have indicated that this plant would have had a primarily "yellow" outage instead.

For the other two units, the KSFs that are limiting in terms of overall duration on the outage in an elevated risk condition were not the ones reported in the survey (as the survey asked which KSFs resulted in the highest risk color). The limiting KSFs in terms of duration impact on the outage risk colors were generally plant-specific attributes of support systems (cooling water and control room ventilation).

Evaluation of BWR KSF Information

Two BWR plants were examined further, as noted above. Both plants indicated that DHR was a limiting KSF. However, one plant's outage risk color is primarily "green" and the other's is primarily "yellow". The plant with the "green" outage also noted that Containment Integrity was a limiting KSF, while the plant with the "yellow" outage indicated that Support System Availability was a limiting KSF.

Both plants utilize SFATs to evaluate shutdown risk. However, one plant uses a "point system" to determine the risk color associated with the DHR SFAT. In this system, points are awarded based on the number of mitigating trains, etc. available on each SFAT path. The total point score for the path determines the risk color assigned to that path. This point system is applied only to the DHR SFAT (which is the most complex of the SFATs in the shutdown model).

In comparing the DHR SFATs between the two plants, it was noted that the risk color criteria is in some ways more stringent in the plant with the "green" outage than the plant with the "Yellow" outage. For example, a "yellow" risk color requires two of the four RHR subsystems (along with required support systems) to be available at the "yellow outage" plant, but three subsystems are required to be available to achieve a "yellow" condition at the "green outage" plant. However, the "green outage" plant also credits alternate DHR via the core spray and LPCI pumps. The "yellow outage" plant performs its outages removing two divisions of RHR/ECCS at a time ("A" and "C", followed by "B" and "D"), which results in a "yellow" condition for most of the outage. The subsystems removed from service also appear to affect the use of alternate DHR; however, this could not be verified from the model information given. The "green" plant does not remain in a "yellow" condition for as long a time period during its outages. So, the difference in risk contribution of the DHR KSF appears to be driven primarily by outage practices.

The "yellow outage" plant is also limited by the Support System Availability function. The cooling water systems and electric power systems are cross-connected between the units at this station, and key pumps are located on cross-connected buses. As a result, KSFs for electric power and cooling water are evaluated as a "yellow" risk color for a significant portion of the outage.

The "green outage plant" monitors Electric Power availability as a KSF, but doesn't include a cooling water function. The potential for inter-unit impacts of the electric power and cooling water systems appear to be more limited, so the Electric Power KSF is not limiting at this plant. Therefore, the differences in risk color for the SS KSFs appear to be driven by plant-specific features.

The "green outage" plant also noted that the Containment Integrity KSF is also a limiting function. The periods in which this KSF is "yellow" appears to be those where either fuel movement or an operation with potential to drain the reactor vessel/cavity are underway without both trains of Standby Gas Treatment (SBGT) and Reactor Building HVAC systems available.

A “yellow” can also be obtained if primary containment is not intact and a train of SBGT is not available. While this KSF is a limiting one, the overall duration when this KSF is “yellow” is relatively short.

So, for the two BWRs that were examined in more detail, the differences in overall outage risk color performance appears to be driven by differences in some outage practices and plant design features. Key examples include:

- Differences in how divisional outages are scheduled
- The ability to credit alternate decay heat removal paths
- Impacts of shared system outages on risk to the shutdown and operating units in a two-unit station
- Programmatic treatment of shared system outages, particularly with respect to risk and Technical Specification impacts on the operating unit

Differences in how the cross-connected systems were modeled might also impact the results; however, the underlying models used to evaluate the support systems were not reviewed for this study.

At the individual KSF level, the DHR function is limiting at both plants, but the amount of time the function is evaluated as being in an elevated risk state varies. Support system impacts are more important at one plant due to inter-unit impacts. Containment Integrity is a limiting KSF at one plant for portions of its outage, but does not appear to be so at the other plant. As the Containment Integrity model for the second plant wasn’t provided, it was not possible to do a comparison of the success criteria for this KSF.

Summary of Results

The limited set of comparisons performed as part of this project revealed details that were not apparent from an analysis of the survey results alone. While a detailed review of a larger group of BWRs and PWRs would probably reveal further insights concerning the variations, this limited review does help to validate the reasons for many of the observed variations. In particular, this review identified the following potential causes for similar plants reporting different risk results:

- Use of differing approaches for performing the risk evaluations (i.e., use of Safety Function Assessment Trees vs. Defense in Depth evaluations that assign points to various configurations). It was also noted in Section 3 that the five PWRs that use quantitative risk evaluation methods all indicated that their outages remained primarily in the “green” risk color throughout the outage, which may be a consequence of using an integrated risk model with quantitative data. However, the quantitative risk color thresholds used at these five plants were not investigated in this study.
- Use of differing methods for aggregating the individual KSF risk results into an “overall risk color”. Plants with similar KSF results might obtain different overall colors depending on the aggregation method used.

- Outage practices appear to have played a significant role in influencing the risk results. A plant that utilizes a more aggressive approach to outage maintenance would be expected to have higher KSF and overall "risk colors" than a plant that utilizes a more conservative approach (i.e., keeping additional means of satisfying the KSFs available during the outage).

- Plant-specific design differences, particularly in key support systems, can also influence the risk results. In the cases reviewed here, impacts on the operating unit when a shared support system was out of service were of particular concern. Where such shared system impacts could affect an operating unit, there is currently no standardized guidance as to how to assign this risk between the shutdown unit and the operating unit. Two plants may assign these risks differently, which could result in two plants reporting different risk color results for an outage

5
CONCLUSIONS

The additional survey of industry shutdown CRM practices obtained some useful information about the current state of the art of outage risk management programs. The primary objective of the survey was to attempt to better understand the reasons for the observed variations in outage "risk color", and at least some partial insights were obtained concerning these variations. These insights include:

- There does appear to be some differences in the evaluated risk colors for PWRs vs. BWRs, with PWRs being more likely to spend the majority of the outage in a "yellow" risk condition. In addition, it appears that older PWRs may be more likely to have outages that are mostly in the "yellow" risk color. As newer PWRs may include additional design features that may provide increased number and diversity of mitigating system paths, this might explain the reduced periods of increased "risk color" in those plants.

- While it was hypothesized that plant-specific administrative limits and other programmatic factors might be the cause of some of the observed variation, the survey respondents didn't think that such factors (if they existed at their plants) had more than a minor impact on the resulting risk colors that were calculated during the outage. However, the focused review of several BWR and PWR plants did identify a few programmatic items that could influence the overall risk color results.

- The survey results did indicate that there were differences in which Key Safety Functions (KSFs) were limiting at various plants. Decay Heat Removal was a dominant KSF at most plants, with Inventory Control and Support System Availability also being dominant at many plants. However for BWRs, whether Inventory Control or Support System Availability was dominant varied corresponding to the plant reporting having a "mostly green" or "mostly yellow" outage risk color, respectively.

- The focused review of several representative PWR plants showed that differences in how the qualitative risk evaluations of each KSF were aggregated into an overall "risk color" could also affect the reported survey results. In this case, one plant that did not routinely aggregate the KSF results responded to the survey as having an overall "mostly green" risk color based on judgment, but had the highest KSF risk color at each point in the outage been considered to be the overall risk color, then a "mostly yellow" result would have been obtained.

- The focused review of the PWR plants also indicated that differences in qualitative risk evaluation methods could also impact the report risk results. The survey did not inquire as to the type of qualitative models were used at each plant; however, whether a plant uses Safety Function Assessment Trees or uses a "point system" to evaluate each KSF could result in differences in assigned risk colors during various phases of the outage. It is noted that there is now a history of over 20 years of development of qualitative risk assessment methods, and multiple generations of risk monitoring software. The software capability is mature and widely used. While DID point sheets may have a sound technical basis, in general the use of modern risk monitoring software provides a higher level of capability to model at the component level, address dependencies, and represents commonly deployed and current

practice. While not included in the survey questions, it should also be noted that many plants use their shutdown risk assessment model dynamically, re-evaluating the outage schedule at some frequency during the outage. This provides assurance that the outage schedule is not drifting from the pre-outage risk assessment and is another advantage offered by modern risk monitoring software.

- The focused review of several BWR plants demonstrated how differences in outage work practices and system design differences (particularly, differences in system cross-connections between units) could have a noticeable impact on the reported results. In the case of the two BWRs that were reviewed, the shutdown CRM models for each plant appeared to be properly considering the risk impacts at each unit, based on the criteria used to develop the defense in depth models. However, the assignment of risk impacts to the shutdown unit due to potential effects on the operating unit has an impact on the risk results. This suggests that there may be some double-counting of the risk impact if the operating unit's CRM evaluation also considers the risk impact of the unavailability of the shutdown unit's portion of a shared system. While declaring an elevated risk result on the shutdown unit serves to highlight specific outage actions that may require special attention, other approaches may be more appropriate so as not to conservatively penalize the shutdown unit's risk profile. As there is currently no industry guidance as to how to properly allocate risk between the units in such situations, this may be an area for further investigation

Among the other information that was gathered in this survey, the following key insights are noted:

- A number of plants reported specific situations in which a single configuration change could cause the risk color evaluation to change from green or yellow to red. Such conditions indicate situations exist in which an acceptable level of risk can transition directly to an unacceptable risk (i.e., a zero defense-in-depth condition) as a result of a single configuration change. These configurations raise the question of why they are not designated as orange. In general, one level of defense-in-depth is not in accordance with industry guidance [4, 5], which emphasizes the objectives of providing backup for key safety functions and optimizing safety system availability. In many cases, containment integrity was involved in these configurations and some respondents also included multiple failure scenarios in their answers (e.g., loss of offsite power or two trains of shutdown cooling). While there are specific situations in which such a condition may be justifiable due to factors other than the number of active redundant systems, any maintenance configurations that could result in a transition from acceptable to zero defense-in-depth should be understood and evaluated for compensatory actions before they are entered.

- It appears that most plants review and update their shutdown CRM models on a regular basis (e.g., every outage or every other outage) and incorporate operating experience into their CRM models. This indicates a commitment by the industry to ensure that these models accurately reflect the current as-built/as-operated plant.

- There is some variation within the survey responses as to how HREs and shutdown initiating events are considered within the shutdown CRM risk evaluation process. The approaches varied from explicit consideration within the model, separate qualitative evaluations performed separately, or in some cases, only very limited consideration of the potential risk impacts of these events. This may be another area for additional investigation.

- There is also considerable variation among the survey respondents as to who runs the shutdown CRM models, with many plants noting that several groups were responsible for the risk evaluations. The survey did not further investigate as to whether all groups performed similar evaluations (e.g., all evaluations performed using Safety Function Assessment Trees), or if more detailed evaluations were performed prior to the outage by one group with other plant groups performing less rigorous evaluations on a frequent basis during the outage. How these various groups interact to evaluate the outage (and the types of evaluations performed before and during outages) could also affect the reported risk results. This is another area that may benefit from additional investigation.

The evaluation of shutdown risk is quite mature in the US nuclear industry. The details of the survey results show that these evaluations are detailed, consider the key risk contributors, and the models are frequently reviewed and updated to ensure consistency with the as-built, as-operated plant.

The results of this study have shown that there are many possible reasons for the reported variation in risk results. Each plant's results, looked at individually, appear to be following the evaluation method identified. However, the limited investigation performed here indicates that differences in modeling approach, risk color aggregation, and how shared system risk impacts are allocated between units could impact the reported results. Differences in plant design and in outage practices also represent valid reasons for risk color variations and the focused review of several plants did identify some instances where these factors did explain some of the observed variability. The effort identified some issues that may warrant additional research and/or guidance:

- Aggregation of the risk metrics from the KSFs can have an impact on the overall result.
- Evaluation of the risk impact on the shutdown unit of cross-connected systems is an area that has not been explored in detail. There may be additional insights on this issue to be identified. Guidance in this area may also be of benefit to nuclear plant operators.
- Additional research and/or guidance may be appropriate to address maintenance configurations that are one failure away from the loss of a KSF. Understanding the nature of these configurations, and corresponding risk management actions would clarify their safety implications and identify potential gaps in available guidance.

6
REFERENCES

1. *A Survey of Current Practices for Configuration Risk Management at Nuclear Power Plants: EPRI Configuration Risk Management Forum - 2011 Research Task,* EPRI, Palo Alto, CA: 2011. 1022999.
2. *Configuration Risk Management Risk Transition Thresholds: EPRI Configuration Risk Management Forum – 2012 Research Task.* EPRI, Palo Alto, CA: 2012, 1025292.
3. *An Approach for Evaluating Heavy Load Lifts and Related Maintenance Tasks in Maintenance Rule (a)(4) Risk Evaluations,* EPRI, Palo Alto, CA, December 2008. 1016744.
4. *Guidelines for Industry Actions to Assess Shutdown Management,* Nuclear Management and Resources Council Inc, Washington, DC: 1991. NUMARC 91-06.
5. Institute of Nuclear Power Operations (INPO). *Guidelines for the Conduct of Outages at Nuclear Power Plants.* Atlanta, GA: 2011. INPO 06-008.

A
COMPILATION OF SURVEY RESULTS

A.1 Summary of Results

The table below summarizes the number of units that responded to the survey and its addenda. A total of nineteen surveys were received (providing data for 40 units), plus 13 addenda responses (addressing practices at 31 units):

	BWR Units	PWR Units
Responses to Initial Survey	13	27
Responses to Addendum	2	29

Note: The totals above include 6 non-US units (all PWRs). (Four of these submitted both initial surveys and addenda, while two units responded only to the addenda)

The responses to each survey question are listed below. The names of the responding units are not provided. However, the identification code provided for each response (e.g., P5, B21) correspond with the identification codes used in previous CRMF industry surveys (see [1], for example).

A.2 Responses to the Main Survey

A. General information about your shutdown risk model

1. Is your shutdown risk model primarily qualitative (e.g., Defense in Depth) or quantitative in nature?

☒ Qualitative (Defense in depth) – **34 units [B6, B8, B9, B10, B18, B20, B21, B22, P1, P4, P5, P8, P9, P10, P21, P27, P31, P37**]

☒ Quantitative (i.e., based on PRA) – **5 units [P38, P44, P45]**

☒ A Blend of Qualitative and Quantitative Methods – **1 unit [B4]**

2. Who typically performs the shutdown CRM evaluations?

☒ Outage Scheduling Group – **9 units [B4, B6, B8, B10, P27]**

☒ Work Control Group – **9 units [P8, P9, P10, P21]**

☒ Operations Personnel – **16 units [P1, P4, P5, P8, P9, P10, P37]**

☒ Onsite Risk Management Personnel – **6 units [B9, B18, P44, P45]**

☒ PRA Group- **22 units [B20, B21, B22, P1, P8, P9, P10, P21, P31, P38, P44, P45]**

☒ Other (please describe): **- 5 units [B9, B21, P31]**

- **STAs – composed of Ops personnel**
- **The OCC Risk Assessor is a position in the Outage Control Center that is staffed for refuel outages. This individual performs shutdown risk assessments with EOOS, on a daily basis, for the refuel outage. The OCC risk assessor typically has a background in work groups such as Work Management or Ops Training. PRA personnel provide oversight and technical support for complex issues (e.g., LCO 3.0.4.b, NOED, qualitative risk assessments), as needed.**
- **PRA engineer performs the pre-outage quantitative risk assessments and writes this up for the outage risk assessment report**
- **Prior to the outage, risk assessments are run by the Operations Outage Support group. During the outage, they are run by the on-shift Shutdown Risk Manager in Outage Control Central.**
- **The Shift Technical Advisors (STAs) complete the evaluation at least once per 12-hr shift.**
- **Site Work Control Group is tasked with conducting the outage risk assessment. The assessment is facilitated by a member of the fleet outage management that has no role in development of the outage schedules. The team that is formed consists of Site Operations, Engineering, Maintenance, and Radiation Protection. The assessment is supported by fleet PRA, industry peer, sister sites Operations and Work Control.**
- **Shutdown Safety Manager. Risk Management and Shutdown Safety Manager work together during the outage.**
- **Pre-outage, the evaluations are performed by the PRA group. Once the outage begins the work control group assumes the responsibility of performing the evaluations.**
- **Prior to the outage, the PRA group performs a quantitative assessment of the planned outage schedule. This is completed as part of a broader qualitative and quantitative outage risk evaluation performed by a shutdown risk review team. During the outage, PRA group meets once per day with outage management and operations (shutdown risk team) to perform a qualitative 3-day schedule look-ahead at the planned defense-in-depth. PRA group also performs a quantitative assessment of the revised outage schedule once per 12 hr shift as a confirmatory check that the planned plant configuration risk is as expected.**
- **The shutdown risk evaluation is performed for every planned outage as well as for every OLM activity at any NPP unit. The risk assessment and profiles are performed prior to each outage/OLM, monitored during outage/OLM**

performance and evaluated subsequently to compare planned risk profile against the real shutdown/OLM risk, as required and send to the local regulatory body for their information/review.

3. When was the shutdown CRM model last reviewed/updated for consistency with current plant design and outage practices?

☒ Within the last year – **31 units [B6, B8, B10, B18, B20, B21, B22, P1, P4, P5, P8, P9, P10, P21, P37, P45]**

☒ Within the last three years – **1 unit [B9]**

☒ Within the last 5 years – **7 units [P27, P31, P38, P44]**

☒ Within the last 10 years – **1 unit [B4]**

☐ A consistency review has never been performed since the initial model development

Comments (if desired):

- **Most often a revision to the model is made to reflect temporary modifications that are in effect during a specific refueling outage to support non-routine or infrequent maintenance activities. For example, when the main fuel oil storage tank which supplies the EDGs was OOS to support inspection and repair of the bottom head, a temp mod was installed to maintain the EDGs in an AVAILABLE status using a FRAC tank filled with fuel oil that was connected to the fuel oil transfer pumps suction.**
- **The model reflects the approved defense in depth procedure.**
- **CRM Model is revised whenever Site Outage Shutdown Safety Procedure is revised.**
- **Miscellaneous minor changes made as needed, but shutdown model based on PRA Rev.4 from 2005**
- **We review for model changes prior to each outage. Good comments are usually received during our Shutdown Risk Assessment Team review of the outage schedule.**
- **The shutdown risk process is updated to reflect the current plant.**
- **There is a shutdown working group that meets at least semi-annually to discuss the current version of the Nuclear Site Directive (NSD) that directs shutdown risk management. Each site provides a member from Operations, Work Control, and Engineering. Fleet PRA and fleet outage management also provide members. This group maintains the NSD up to date, discusses industry OE, and provides input into identified outage risk issues for correction. This team also reviews the Defense in Depth sheets for needed changes. Changes to the NSD have been made prior to the spring and fall outage seasons for the past two years.**

- **The plant's model has been updated as things have changed. Major changes have not been necessary. Change is an incremental process, some driven by actual need, others driven by what is desired by the organization.**
- **Every outage the current practices are reviewed against the CRM model and changes are made as appropriate. Additionally, any lessons learned from the previous outage are incorporated.**
- **There is a legal requirement to maintain Living PSA/Safety Monitor models in at least 5 year time interval, as well as within the PSR frame (10 years). In fact, PRA/SM models for the plant are updated annually (as there are major design/operational changes ongoing at the plant – related to the plant lifetime extension activities), models for our other plant are updated as required (less amount of plant design/procedure changes), at least in 5 year time interval.**

4. Has the shutdown CRM Model been updated to reflect plant-specific operating experience?

☒ Yes – **33 units [B4, B6, B8, B18, B20, B21, B22, P1, P4, P8, P9, P10, P21, P27, P37, P38, P44, P45]**

☒ No – **5 units [B9, B10, P5]**

Comments (if desired):

- **Shutdown CRM model maintained current with plant the same as online CRM model, generally there is a Shutdown update before each outage**
- **Models used to be regularly updated; however, plant procedures and practices changed (at which point model updates ceased)**
- **CRM Model is based on Defense in Depth. Plant Operating Experience typically does not change the CRM logic**
- **Specific plant configurations added / addressed as needed**
- **We review for lessons learned and recommendations for improvement prior to each outage. They are usually received as corrective action documents from the Shutdown Risk Managers.**
- **The CRM models for both facilities are maintained and regularly updated to reflect real plant configuration and operational experience. Based upon this operational experience and feedback, new slightly modified POSs were introduced in the PSA/CRM shutdown models for example, as well as mutual shared impacts of different units at both sites, modeling of time dependent vs. time independent IEs during some POSs.**

5. What is the level of detail of your shutdown model? For example, is it a system-level model, a train-level model, component-level model, or some combination of these?

☐ System-level

☒ Train-Level – **9 units [B6, B18, P5, P21, P27]**

☒ Component-Level – **14 units [B4, B9, B21, B22, P27, P31, P38, P44, P45]**

☒ A combination of the above – **21 units [B8, B10, B20, P1, P4, P8, P9, P10, P27, P37]**

☐ Other (please describe):

6. Is transition mode risk explicitly assessed within your CRM program?

☐ Transition Modes are not explicitly evaluated

☒ Transition Modes are evaluated using the At-Power Model – **10 units [B4, B8, B9, B18, B21, B22, P5]**

☒ Transition Modes are evaluated using a specific model for these modes. Model is:
☒ Quantitative - **5 units [P38, P44, P45]** ☒Qualitative – **11 units [B6, P8, P9, P10, P31]** ☒ Blended Approach – **2 units [P27]**

☒ Transition Modes are evaluated in another manner. – **14 units [B8, B10, B20, P1, P4, P21, P37**
Please describe: **The responses generally indicate that these modes are evaluated using a combination of at-power (for some modes or conditions) and shutdown models (for other modes/conditions)**

- **Mode change items such as aligning shutdown cooling and de-inerting primary containment are addressed in the online model. Other transitions, like status of primary containment, vessel floodup, and refueling gate status are modeled in the shutdown model.**
- **Startup is handled in the online model with limitations on PRA calculation until at pressure (until HPCI, RCIC and FW are viable), some Start up specific qualitative Safety functions. HSD is in the outage model.**
- **Transition modes are evaluated using both the S/D and at-power models, and the most bounding risk level is assigned to any given configuration.**
- **Note, Modes 1 and 2 are assessed using the on-line model. Other modes/plant states assessed using the shutdown model. Modes/Plant States may alter credited systems and point counts.**
- **Modes 1 and 2 use EOOS and the PRA. Modes 5, 6 and defueled use ORAM (defense in depth). Modes 3 and 4 identify what method to use for each individual key safety function. The choices are EOOS, ORAM or a unique defense-in-depth for the mode.**
- **Modes 1 & 2 are covered by our quantitative on line risk CRM model. Modes 4-6 and defueled are covered by our qualitative shutdown CRM defense in depth model.**
- **Modes 1, 2, and 3 are evaluated in online risk monitor model. Modes 4, 5, and 6 are evaluating using the shutdown risk process.**

- **Online PRA quantitatively assesses MODES 1, 2, & 3. MODES 4, 5, 6, and defueled, and the various "flavors" of MODES 5 & 6 are evaluated in a qualitative DID model whose requirements vary depending on RCS / Plant condition (e.g., partially drained, normal level in pressurizer, hot leg vent, mid-loop, at the flange, etc.)**
- **Modes 1 and 2 are considered online, and are a combination of qualitative and quantitative evaluations. Modes 3, 4, 5 and Defueled are evaluated qualitatively.**
- **Modes 1 and 2 are evaluated using the at-power model. Modes 3 and 4 are evaluated using a combination of insights from the at-power model, the shutdown defense in depth model and tech spec equipment requirements blended together.**

B. Specifics of Shutdown CRM Models

1. How are High Risk Evolutions handled in your shutdown CRM Model? Please describe:

- **No action required if going from Green to Yellow. However, going from Yellow to Orange, a contingency plan is required to be developed by the shift manager using multi-displinary support. The contingency plan shall be approved by the Risk Assessment Team (RAT). Evolution to Red condition is not allowed.**
- **From a CRM standpoint, an activity with EOOS risk level of Orange or Red would be considered a high risk evolution. Per the Integrated Risk Management process, the HRE would then be required to pass through more stringent planning requirements, challenge boards, including additional risk management actions.**
- **They are at the beginning of the safety function tree and generally if 'yes' either degrade the color/ risk level by one or increase the defense in depth requirements (more trains/systems needed)**
- **Identification of all higher risk evolutions as defined in site procedure X and/or fleet procedure Y is performed to assess the impact on Key Safety Functions. An HRE is defined as…"A plant configuration, external condition or other non-routine activity which is judged by the evaluator to sufficiently increase the likelihood of an initiating event (e.g. reactor scram, loss of power, turbine trip, LOCA, flood, fire, etc.) or degrade the plant coping capability such that increased awareness and risk management attention is warranted."**
- **Identified in outage schedule, increased management attention, approved contingency plans required.**
- **Typically would decrease plant defense in depth count. May or may not result in color change, depending on plant state and defense in depth count.**
- **Additional defense-in-depth is required or the risk level is increased.**
- **Traditionally, they are not included in ORAM. However, the plant has recently implemented a HRE for LOOP in the electric power KSF/SFAT. If a HRE for LOOP exists, the electric power KSF is raised to YELLOW. If the KSF is already YELLOW, it stays YELLOW.**

- **No specific requirements -- captured in quantitative risk assessment**
- **The risk from High Risk Evolutions is managed by providing an additional layer of Defense In Depth of mitigating equipment for an impacted shutdown safety function, by implementing Risk Management Actions to reduce the probability or severity of the potential initiating event, or by using a combination of these two methods. The method selected is based on the risk to the plant associated with the High Risk Evolution.**
- **YELLOW risk (reduced redundancy) authorized by shift manager. ORANGE risk (minimum redundancy) authorized by PORC or plant manager. RED risk (no redundancy) is not voluntarily allowed.**
- **Written Risk Management Plans are required for all HREs, unless an Infrequently Performed Test or Evolution (IPTE) is assigned. For planned HREs, these plans are prepared prior to the pre-outage independent risk assessment for review. There is a form in our outage nuclear safety procedure for the risk management plans to ensure all phases of the activity are considered. HREs are identified on our Plan of the Day (POD) and on our EOOS Daily Report. HREs result in an automatic Yellow for the key safety function that could be affected.**
- **Our Defense in Depth sheets contain Green, Yellow, Orange, and Red based on a point system. The sheets also have points assigned to whether the unit is draining to Reduced Inventory.**
- **They generally result in a reduction of the DID color, i.e., goes from a Green to a Yellow, unless the DID is large.**
- **Typically, high risk evolutions raise the shutdown risk one color level, and there are separate DID trees for certain high risk evolutions, such as switchyard work. Other than that though, high risk evolutions that are primarily high risk due to the nature of the RCS condition or available equipment, are addressed in DID trees and do not need further assessment applied outside the shutdown risk model. For example, midloop conditions with fuel in the vessel is treated as an ORANGE risk condition, which requires Risk Management Actions, most of which are already incorporated in plant processes and policies. Likewise for most other situations, where typically, guarded/protected equipment is used on a daily basis for either online or shutdown risk, or for example Infrequently Performed Tests or Evolution assessments and briefings, etc.**
- **High risk evolutions are accounted for within the quantitative risk assessment. These can also be assessed qualitatively for risk insights and any appropriate risk management actions.**
- **Based on the way our outages are scheduled, the high risk evolutions associated with a refueling outage are primarily due to low inventory configurations early in the outage. This is reflected in our CRM model through the use of time to boil, which is typically less than 15 minutes and equates to an ORANGE configuration.**
- **High Risk Evolutions usually drive a Safety Function Yellow, and possibly worse depending on other unavailable SSCs. They may also impact more than one safety function.**

- **The high risk evolutions are analyzed and either reasons for are identified, analyzed, discussed and recommendations are being made to prevent high risk configurations for the future operation/shutdown or as a feedback risk monitoring models are corrected or modified in case of some failure/incorrectness/inaccuracy in modeling is discovered as reason for high risk.**

2. Are potential shutdown initiating events (e.g., loss of shutdown cooling, inadvertent draindown/diversion, etc.) addressed in your model?

☒ Yes (please describe) – **20 units [B4, B6, B8, B9, B18, B20, P1, P4, P21, P38, P44, P45]**

- **OPDRV and others are treated as HRE**
- **Modeled as HRE event types which are applied to those scheduled activites that were judged to represent a higher-risk evolution. For example the Integrated ECCS Test is identified as an HRE-ACD since it simulates a loss of normal power to the Essential AC buses, forcing load shed and start/load of both EDGs.**
- **Increases number of trains required to reach Green, Yellow, or Orange.**
- **Treated as High Risk Evolution (HRE)**
- **Loss of SDC, OPDRV, Draindown (~LOCA) all addressed**
- **Through High Risk Evolutions.**
- **OPDRVs are explicitly modeled**
- **The initiating events were considered in constructing the DID model and are reflected in the desired mitigating capability vs risk level.**
- **Initiating events considered in the quantitative model include:**
- **Modes 2 & 3: initiators are essentially the same as Mode 1 except Rx trip and ATWS not considered in Mode 3.**
- **Modes 4, 5, 6: initiators include: (a) Loss of DHR (includes consideration of loss of cooling, loss of RHR flow), (b) Loss of Inventory Control (includes small, medium and large LOCA and drain-down events), (c) Loss of Offsite Power and (d) Loss of AC Bus.**
- **The high risk evolutions are analyzed and either reasons for are identified, analyzed, discussed and recommendations are being made to prevent high risk configurations for the future operation/shutdown or as a feedback risk monitoring models are corrected or modified in case of some failure/incorrectness/inaccuracy in modeling is discovered as reason for high risk.**
- **All these, and other low power/shutdown initiating events are considered in the both plants SPSA. Standard Shutdown PSAs are performed for both stations, identifying plant-specific shutdown IEs.**
- **The initiating events were considered in constructing the DID model and are reflected in the desired mitigating capability vs risk level.**

☒ No – **20 units [B10, B21, B22, P5, P8, P9, P10, P27, P31, P37]**

3. How are spent fuel pool systems and initiating events treated in your shutdown CRM model?

☒ Currently address SFP risk. – **40 units [B4, B6, B8, B9, B10, B18, B20, B21, B22, P1, P4, P5, P8, P9, P10, P21, P27, P31, P37, P38, P44, P45]**

Please briefly describe the process used:

- **The model includes failures of SSCs needed to keep SFPC function successful. It also included failure of respective support systems, possible alternative flowpaths, and/or makeup sources**
- **SFP risk is only considered when the cavity is flooded and decay heat removal is through the fuel pool cooling heat exchangers. It is not analyzed for the fuel pool alone.**
- **SFP inventory and heat removal are explicit safety functions evaluated during Shutdown, Also they are evaluated online qualitatively.**
- **Decay heat generation rates (based upon both core inventory and SFP inventory) are determined for various key shutdown configurations which are scheduled in the refueling outage (e.g., RPV head removed, cavity flooded, SFP gates removed). This information is used to determine capability requirements for various combinations and alignments of available decay removal systems (e.g., RHR/SDC trains, normal SFPC trains, standby SFPC trains, etc.). Then, the maintenance activity schedules are adjusted as necessary to ensure adequate defense-in-depth is maintained for the decay heat removal key safety function.**
- **Maintain defense in depth during shutdown modes, paying particular attention to defueled condition.**
- **Defense in depth for Decay Heat and Inventory make-up assessed. >24 hours to boil (not typical with new fuel off-loaded) is credited similar to a train.**
- **Defense-in-depth evaluation**
- **We have traditionally addressed SFP cooling in ORAM. We have recently added a new KSF and associated SFAT for SFP inventory.**
- **Separate calculations for SFP boiling risk and core damage. (Apply at power as well as shutdown.)**
- **Included in defense in depth model. Look at inventory control, decay heat removal, and electrical power.**
- **Offsite power supplies to SFP cooling pumps, onsite diesel backup power to SFP cooling pumps, temporary power to SFP cooling pumps, SFP temperature.**
- **A defense in depth approach to SFP risk for decay heat removal is instituted. Fuel Pool Cooling and Cleanup is identified on our EOOS Daily Report as another Key Safety Function and colors reported. Credit is given for the FPCC system, natural circulation, RHR fuel pool assist mode, and RHR split-flow mode.**
- **DID safety function assessment tree, not specific IEs**
- **SFP risk is considered a key safety function and provides input to the overall shutdown risk level (which is the highest risk of the associated KSFs). It considers the number of SFP cooling trains available, support for those trains, whether freshly off-loaded burned fuel is in the SFP, SFP temperature, etc.**

- **A separate quantitative SFP risk model is used to gain SFP risk insights for the various plant configurations that could impact the reliability of the SFP safety functions. In addition, during shutdown a daily "qualitative" risk assessment is performed by operations personnel. SFP qualitative risk is assessed at least weekly during non-shutdown periods.**
- **It is addressed for one station (the older) while for the other newer station it is not. The reason for is that unlike the older plant, there is much more time left for newer plant's SFP boiling off and Spent Fuel uncovery even in case of RPV emergency core unloading. The Spent Fuel uncovery time is exceeding 24 hrs mission time, unlike for the older plant's SFP design. Despite this, there will be, in the light of Fukushima event, regulatory requirement to include SFP analysis into the PRA scope anyway. Despite the low risk contribution it is planned to incorporate SFP into the newer plant's PRA model in the near future.**
- **Addressed from a defense in depth perspective based on the core offload configuration and the number of spent fuel pool cooling trains available.**
- **Defense-in-depth is evaluated based on the number of trains/systems required to cool the pool. Defense-in-depth is also evaluated for the number of trains/systems available to provide inventory to the SFP.**

☐ Not addressed. No plans to address in the near term.

☐ Not currently addressed, but plan to incorporate into the CRM process in the near term (e.g., within the next refueling cycle).

4. If your plant uses a four-color risk scheme (Green, Yellow, Orange ,Red), please describe any conditions that your risk monitoring method designates as Green or Yellow, that will transition to Red with one failure having no compensatory actions or other considerations (Green or Yellow conditions with no DID).

Yes, there are such transitions – **29 units [B6, B8, B9, B10, B18, B22, P1, P4, P5, P21, P27, P31, P37, P38, P44, P45]**

- **This is not included in the model, but it is being discussed during regular RAT meetings where qualitative review of schedule identifies such condition. Similar review is performed by STA on shiftly basis.**
- **Generally not but if you do not have secondary containment on the fuel floor and go into a OPDRV you go to red even if you have SGTS available (no OPDRV is yellow)**
- **Loss of containment integrity while moving fuel with known fuel failure**
- **If loss of one train causes risk to be Red, it must be designated no better than Yellow. We do not perform a special analysis on Yellow conditions that could get us to Red with loss of one SSC.**
- **Loss of secondary containment integrity, loss of 2nd train of SDC**
- **For Electrical Power - all other modes with one source of offsite power, 2 of 3 EDGs available & capable of being refueled, and only one of two methods of refueling EDGs available, we will be YELLOW if the station gas turbine**

generator is available or RED if the station gas turbine generator is not available. If only 1 of 3 EDGs available and capable of being refueled and TS requirements for electrical power are met, we will be YELLOW if the station gas turbine generator is available or RED if the station gas turbine generator is not available. For Control Area Ventilation, there are multiple instances where number of chillers or availability of opposite unit emergency control area air conditioning system transitions directly from YELLOW to RED. For Fuel Pool Cooling with med/high heat load, there are two instances - both involve heat exchanger availability. Greater than or equal to one heat exchanger is YELLOW. No heat exchanger is RED. Each unit has two SFP pumps and one SFP heat exchanger. The systems can be cross connected such that the opposite unit heat exchanger is used to cool the pool with the unit's own SFP pumps. For Service Water in multiple plant operating states, GREEN is both SW/CCW trains are available, YELLOW if one SW/CCW train is available and RED if neither SW/CCW train is available. For Service Water in the defueled plant operating state, YELLOW if 2 SW pumps available with one backed by an EDG, or RED if not (loss of EDG or SW Pump causes the RED). Shutdown Cooling mimics Service Water conditions (GREEN is both SW/CCW trains are available, YELLOW if one SW/CCW train is available, RED if neither SW/CCW train is available)

- **Containment Integrity - it must be intact or with a closure plan for any open penetrations, otherwise it is RED.**
- **Some examples: 1) Loss of both trains of RHR could result in yellow to red condition for reactivity. 2) Total loss of offsite power could result in yellow to red condition for power availability. 3) Failure to maintain containment closure checklist could result in yellow to red condition for containment.**
- **If an ECCS pump or diesel generator was being credited for defense in depth and the other division was OOS, a failure of the credited ECCS pump/diesel generator would result in Red. That is why credited equipment is identified in the POD and is part of the protected equipment program.**
- **One SDC failure during high high decay heat (until day 6)**
- **In MODE 4, losing containment integrity (G to R). In MODE 5 incapable of natural circulation; Shutdown cooling with loss of one of two trains of RHR; or Electrical Distribution on loss of one train of DC & 4kV AC. In MODE 6 <23 feet of water over the fuel; Shutdown cooling, loss of one of two RHR trains; Loss of containment closure capability; Electrical Distribution on loss of one train of DC & 4kV AC. In MODE 6 refueling cavity flooded/full; Shutdown cooling, loss of one of two RHR trains; Loss of containment closure capability; loss of containment refueling integrity; Electrical Distribution on loss of one train of DC & 4kV AC.**
- **Yellow to Red: 1) Original Configuration (Yellow): 1 RHR Loop unavailable, FP gates in; Final Configuration (Red): 2 RHR Loops unavailable, FP gates in. 2) Original Configuration (Yellow): 1 offsite source unavailable; Final Configuration (Red): No offsite sources available.**

- **Green to Red: 1) Original Configuration (Green): No SSCs unavailable, FP gates in; Final Configuration (Red): SDC common suction fails closed, FP gates in.**
- **General philosophy is N=minimum required amount of equipment and results in a YELLOW risk. N+1 is minimum amount of equipment plus one more train/DID=GREEN. ORANGE is minimum requirements met but management expectations for configuration not met (e.g. one train available and DID is not in place). So for some configurations there is no ORANGE transition from YELLOW to RED, however these are typically part of lower risk safety functions.**
- **With the plant in Mode 6 – RCS vented, level at the flange (for Rx head removal), and with high core decay heat – the risk threshold is within the YELLOW region with both A and B trains of RHR operating. The risk would transition to RED if one RHR train failed or became unavailable.**
- **In principal all different front-line or support equipment combinations OOS, for at power common ECCS sump (RWST) but with high reliability as a passive component, for shutdown modes of operation POS with drained RPV down to the mid-loop level and failure of LHI pump running for decay heat removal.**

No, there aren't such transitions – **9 units [B21, P8, P9, P10]**

5. If your plant uses a three-color risk scheme (Green, Yellow , Red), please describe any conditions that your risk monitoring method designates as Green, that will transition to Red with one failure having no compensatory actions or other considerations (Green conditions with no DID).

N/A for all respondents

6. Are there programmatic aspects (such as procedures, guidelines, policies, or expectations) that impact the risk results? For example, "the plant should not enter the 'yellow' risk zone", "plant risk shall be 'red' whenever time to boil is less than X minutes", etc.?

Please Describe Examples:

- **Procedures forbid voluntary scheduling of RED configuration. Orange configurations requires management approval and official contingency plan**
- **KSF risk level = RED: This condition is not to be entered voluntarily, unless pre-approved by the GMPO and the Site VP. If the condition occurs due to an emergent condition, immediate and significant actions shall be taken to alleviate the problem. In practice, pre-approval from the GMPO and Site VP have never been obtained. Rather, temporary modifications have been implemented to preclude these situations.**
- **Risk color is orange while in mid-loop and fuel in vessel.**
- **AC Power counts off-site power sources, but requires at least 2 EDGs to be Green and requires diverse power sources to be Yellow.**

- **Infrequently performed test or evolution (IPTE) is considered a high risk evolution (HRE)**
- **Plant risk is at least ORANGE when in mid-loop. Other requirements throughout our Shutdown Safety procedure - for instance, all sources of offsite power should remain available during higher risk evolutions (ORANGE or RED)**
- **Plant does all it can to avoid Orange**
- **Reduced Inventory/Mid-loop operations with time to boil less than 60 minutes but greater than 30 minutes will be Yellow. Reduced Inventory/Mid-loop operations with time to boil less than 30 minutes will be Orange. We also don't schedule an Orange or Red condition, since this indicates a loss of defense in depth.**
- **Site is not allowed to intentionally enter RED.**
- **Non-written policy that there will be no planned Orange conditions.**
- **Should not enter Orange, cannot intentionally enter Red**
- **Red is not to be entered**
- **Our procedures do not allow us to enter orange risk situations without additional management review and approval. Red is not to be entered.**
- **Similar to most other plants, we do not "plan" any configurations within the ORANGE and RED risk thresholds. Given the plant's safety system redundant design/separation and use of the "protected train" approach to protect important equipment being relied upon, planning to stay below the ORANGE or RED risk thresholds has not had a significant impact on the development and implementation of the outage schedule.**
- **The plant is not allowed to plan an entry into a Red risk configuration. All other colors are allowed with varying levels of controls.**

How much do these programmatic aspects influence the overall outage risk results (in terms of "risk color" levels, modification of schedule activities, etc.)?

☒ Have a significant impact (e.g., impacts throughout the outage) – **2 units [B18, B20]**

☒ Have a moderate impact (e.g., impacts only certain portions of the outage, but that impact can be significant) – **5 units [B8, P4]**

☒ Have a minor impact – **19 units [B6, B9, B22, P1, P5, P21, P27, P37, P38, P44, P45]**

☒ N/A (programmatic aspects not imposed) – **13 units [B10, B21, P8, P9, P10, P31]**

7. Are heavy load activities considered explicitly as part of your shutdown CRM Program?

☒ Yes – **34 units [B4, B6, B8, B9, B10, B18, B20, B21, B22, P1, P4, P5, P8, P9, P10, P21, P27, P37, P38]**

☒ No – **6 units [P31, P44, P45]**

If Yes, is the approach presented in EPRI Report 1016744 (CRMF Guidance for Evaluating Heavy Loads Activities) being used?

☒ No, a different approach is used. - **9 units [B21, B22, P5, P21, P37]**

Please briefly describe:

- **Heavy loads are reviewed within the integrated risk management process and consider the requirements outlined in NEI 08-05. A qualitative, written risk assessment is used to assess risk of these evolutions. Heavy load risk impacts are not incorporated within the EOOS shutdown risk model.**
- **Safe load paths are proceduralized or established prior to outage.**
- **Plant uses designated safe load paths for heavy load lifts.**
- **Heavy load lifts are identified and declared HLAs to ensure a pre-job brief is performed prior to work activity.**
- **We only review heavy load lifts in containment that could impact equipment credited in the shutdown CRM. Assessments are performed to determine what additional defenses should be in place in the event of a load drop if the equipment below it is lost.**
- **The risk evaluation explicitly includes consideration of heavy loads by performing a qualitative check to ensure that the load lift is properly planned with adequate controls and management oversight to minimize the potential impact to the "protected" train equipment. In some cases the evaluation could include an assessment of the "consequence" of an assumed drop and development of associated risk management actions, which could range from: normal precautions are adequate to selecting an alternate lift pathway, alternate time to perform the lift or the need for additional physical protective measures.**

☒ The approach is partially based on the EPRI guidance. – **17 units [B6, B8, P1, P4, P8, P9, P10, P38]**

☒ The approach largely follows the EPRI guidance – **4 units [B9, B10, B18]**

C. Shutdown CRM Risk Results

1. Estimate the fraction of time that your plant risk status was in each color code or zone during the last typical refueling outage:

Risk profile is primarily in "Green": **17 units [B6, B10, B21, B22, P4, P37, P38, P44, P45]**

Risk profile is primarily in "Yellow": **18 units [B4, B8, P1, P5, P8, P9, P10, P27, P31]**

Risk profile is about 50% Green / 50% Yellow: **5 units [B9, B18, B20, P21]**

2. What key safety functions are typically the most limiting (i.e., result in the highest risk color) during typical refueling outages?

☒ Reactivity Control – **5 units [B18, B22, P4]**

☒ Decay Heat Removal – **16 units [B8, B9, B18, B20, B21, P1, P5, P38, P44, P45]**

☒ Inventory Control – **21 units [B6, B22, P4, P5, P8, P9, P10, P27, P44, P45]**

☒ Status of Key Support Systems (such as electric power and cooling water) – **22 units [B4, B8, B9, B18, B20, P5, P8, P9, P10, P31, P38, P44, P45]**

☒ Containment Integrity – **7 units [B4, B21, P31, P37]**

☒ Time to Boil – **3 units [P21, P38]**

☒ Spent Fuel Pool Cooling – **8 units [B10, P31, P44, P45]**

☒ Other (please describe): **- 3 units [P4] (spent fuel inventory control)**

Other comments:

- **Reactivity Control is the most common cause of Orange conditions due to not having the required number of SRMs operable. Inventory control is the most common cause of Yellow due to the number of HREs (flood-up, drain down, RPV pressure test, OPDRVs)**

A.3 Further Analysis of Questions C.1 and C.2

Because the responses to questions C.1 and C.2 provided specific insights into the causes for observed differences in risk color evaluations, the survey responses to Question C.2 were further subdivided based upon whether the responding plant spent most of its refueling outage in the "yellow" risk zone, most of its outage in the "green" risk zone, or spent about 50% of the outage time in "green" and 50% of the time in the "yellow" or "orange" risk zone.

C.1. Estimate the fraction of time that your plant risk status was in each color code or zone during the last typical refueling outage:

Risk profile is primarily in "Green": **17 units (10 PWR, 7 BWR)**

Risk profile is primarily in "Yellow": **18 units (15 PWR, 3 BWR)**

Risk profile is about 50% Green / 50% Yellow: **5 units (2 PWR, 3 BWR)**

C.2A. What key safety functions are typically the most limiting (i.e., result in the highest risk color) during typical refueling outages? **[For units with mostly "yellow" outages]**

☐ Reactivity Control

☒ Decay Heat Removal – **6 units (4 PWR, 2 BWR)**

☒ Inventory Control – **9 units (9 PWR)**

☒ Status of Key Support Systems (such as electric power and cooling water) – **14 units (11 PWR, 3 BWR)**

☒ Containment Integrity – **3 units (2 PWR, 1 BWR)**

☐ Time to Boil

☒ Spent Fuel Pool Cooling - **4 units (2 PWR, 2 BWR)**

☐ Other (please describe):

C.2B. What key safety functions are typically the most limiting (i.e., result in the highest risk color) during typical refueling outages? **[For units with mostly "green" outages]**

☒ Reactivity Control – **4 units (3 PWR, 1 BWR)**

☒ Decay Heat Removal – **12 units (10 PWR, 2 BWR)**

☒ Inventory Control – **14 units (11 PWR, 3 BWR)**

☒ Status of Key Support Systems (such as electric power and cooling water) – **10 units (10 PWR)**

☒ Containment Integrity – **4 units (2 PWR, 2 BWR)**

☒ Time to Boil – **2 units (2 PWR)**

☒ Spent Fuel Pool Cooling - **4 units (4 PWR)**

☒ Other (please describe): SFP Inventory Control – **3 units (3 PWR)**

C.2C. What key safety functions are typically the most limiting (i.e., result in the highest risk color) during typical refueling outages? **[For units with 50% "green" outages]**

☒ Reactivity Control – **1 unit (1 BWR)**

☒ Decay Heat Removal – **3 units (3 BWR)**

☐ Inventory Control

☒ Status of Key Support Systems (such as electric power and cooling water) – **3 units (3 BWR)**

☐ Containment Integrity

☒ Time to Boil – **2 units (2 PWR)**

☐ Spent Fuel Pool Cooling

☐ Other (please describe):

A.4 Responses to the Survey Addenda

This section provides the individual responses to the survey addenda, which concerns the use of mitigating factors used in shutdown risk evaluations and spent fuel pool cooling risk evaluations.

Does your plant consider mitigating factors when considering online or shutdown risk colors as follows?:

1. For **online** Spent Fuel Pool Cooling risk evaluations:

   ☒ Yes - **15 units [B22, P8, P9, P10, P21, P27, P37, P38]** (Please select the factors used from the list in question #3, or describe the factors here if not listed below):
   - **Have capability to account for online SFP risk but it is not proceduralized or incorporated in online version of EOOS. Would need to assess off-line. SFP risk available through EOOS is a defense-in-depth logic both shutdown and at power. Quantiative SFP risk shutdown (or at-power, although that has not been done) is an off-line calculation.**

   ☒ No – **16 units [B4, P1, P4, P11, P30, P31, P44, P45, P46]**

   - **While INPO requirements are tracked, the SFP is not tracked for Maintenance Rule a4 risk on line, since no maintenance activities are in progress (no changes to control of pool inventory or cooling and no changes that would increase decay heat load). Cask Loading activities fall under a different rule (10CFR72).**

2. For **shutdown** risk evaluations:

   ☒ Yes – **29 units [B4, B22, P1, P4, P8, P9, P10, P11, P21, P27, P30, P31, P37, P38, P44, P45]** (Please select the factors used from the list in question #3, or describe the factors here if not listed below):

   - Require two independent cooling trains when decay heat is high vs. one train if decay heat is low.
   - Require multiple makup whose loss would necessitate contingency plan with operability assessment.
   - Fuel pool heat up rate isn't directly in the color determination, but the fleet procedure for shutdown safety management includes the following with regard to defense in depth: "Whenever the time for spent fuel pool heat up to 200°F is less than 72 hours, establish controls to identify and protect systems and equipment required to maintain the functions of spent fuel pool decay heat removal and inventory control"

   ☒ No - **2 units (P46, note: a non-US plant)**

3. Examples of mitigating factors would include consideration of such conditions as (check all that apply):

- ☒ Whether or not "Time to 200°F (or your value of °F)" is greater than or equal to 72 hours (or your value of hours) for **online** Spent Fuel Pool Cooling risk evaluations. – **14 units [B22, P1, P11, P21, P27, P30, P31, P37, P38]**
- ☒ The availability or unavailability of makeup capability from other plant systems (e.g., Condensate) for **online** Spent Fuel Pool Cooling risk evaluations. – **14 units [P8, P9, P10, P21, P27, P37, P38]**
- ☒ More restrictive success criteria for **shutdown** decay heat removal with high decay heat, compared to having low decay heat. – **20 units [B4, P1, P4, P8, P9, P10, P21, P27, P31, P38]**
- ☒ Less restrictive success criteria for **shutdown** decay heat removal when the refueling cavity is flooded compared to when it is not flooded. – **9 units [B4, B22, P11, P30, P38, P44, P45]**
- ☒ Credit for more means of fuel-pool inventory control when the fuel-pool gate is removed, compared to when it is installed (applicable to **shutdown** conditions). – **3 units [B22, P27]**

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together…Shaping the Future of Electricity

3002003063

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com