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Review of Current Practices for Establishing Configuration Risk Management Thresholds for Nuclear Power Plants

EPRI Configuration Risk Management Forum – 2003 Research Task

Technical Report

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EPRI Configuration Risk Management Forum – 2003 Research Task

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REPORT SUMMARY

Background

A structured Configuration Risk Management (CRM) process using models based on the plant Probabilistic Risk Assessment is prevalent at U.S. nuclear power plants. CRM supports the planning and scheduling of equipment outages both at-power and during plant outages. CRM enables evaluation of equipment configurations from a safety risk standpoint and provides valuable information about possible risk management actions associated with the configurations. These models substantially improve both the safety and efficiency of plant maintenance activities. However, CRM models vary from plant to plant with respect to risk criteria, thresholds for risk categories, and models and methods for evaluations of individual configurations. Further gains in both safety and efficiency are desirable through refinement and benchmarking of the CRM processes and models.

Objectives

- To provide comparative information about risk criteria, thresholds for risk categories, and models and methods for evaluations of individual configurations used in individual CRM programs at-power
- To develop insights from this information that can be used by individual plants to improve the consistency and effectiveness of their CRM programs

Approach

A questionnaire to survey EPRI-member nuclear plant CRM programs was prepared and distributed under the auspices of the EPRI Configuration Risk Management Forum Steering Group. Questions about risk criteria, thresholds for risk categories, software, and models for evaluation of individual configurations were included. Results were compiled in a tabular form that facilitates easy review and comparison. Investigators with experience in developing and evaluating CRM programs prepared an overview of findings, emphasizing areas of consistency, areas of difference (along with the likely reasons for differences), and unique features reported by some programs. Insights were drawn from these observations that could improve the consistency and quality of the criteria, thresholds, and evaluations. Finally, areas for further fruitful investigations were proposed.

Results

The survey was completed by 40 plant sites, representing 60% of the U.S. nuclear units and one non-U.S. plant. A cross section of CRM methods is represented by the data. The results showed a high level of consistency. Instantaneous risk (Core Damage Frequency) was the most prevalent

measure. Thresholds for risk categories were quite consistent, even if developed by different methods. Cumulative or accrued risk is commonly used, in a variety of forms, together with instantaneous risk measures. Quantitative risk measures are universally used for internal events, and a majority also includes internal flooding. Other initiators are sometimes treated quantitatively or by a spectrum of qualitative approaches. A significant group of plants uses structured defense-in-depth models along with quantitative risk measures. Large Early Release Frequency (or probability) as a quantitative measure is also used by a number of programs. Insights are provided on the relative benefits and opportunities for improvements offered by some of the observed industry practices, specifically, quantification of external events, defense-in-depth models, treatment of non-modeled factors, treatment of cumulative risk, and use of Large Early Release measures.

EPRI Perspective

The use of CRM at nuclear plants is one of the greatest successes of risk-informed operations. Faced with the need to demonstrate effective safety risk management while moving to on-line maintenance and shorter refueling outages, nuclear utilities called upon EPRI to develop and demonstrate methods and models for CRM. This successful research and development was quickly adopted by utilities and supported by engineering service providers. The regulator encouraged the use of CRM and even required it for one aspect of the Maintenance Rule. The safety and economic benefits of CRM are unquestioned. The CRM process can support even more beneficial risk-informed changes, especially in the area of flexible Technical Specifications. To achieve these benefits, the CRM methods must continue to provide accurate, consistent results to maintain the confidence of management and regulators. This project provides the data and insights to advance this level of confidence. Furthermore, the Configuration Risk Management Forum, which identified this work scope and oversaw its completion, provides an opportunity for continuing advances in CRM technology and implementation.

Keywords

Risk/safety management
Probabilistic risk assessment
Configuration risk management
Risk-informed regulations

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1 INTRODUCTION

Background

Configuration Risk Management (CRM) has evolved over the past decade as a powerful tool to assist nuclear power plant personnel in planning and executing day-to-day maintenance and operations activities. The use of CRM practices has reduced the risk of accidents and transients at nuclear power plants. Also, CRM tools and methods have enabled plant operations and maintenance personnel to use the plant's Probabilistic Risk Assessment (PRA) model more directly in support of day-to-day decisions. This has also had the benefit of increasing the familiarity of plant staff with the risk insights from the PRA and facilitating the use of the PRA in support of a wide range of plant issues.

CRM typically uses a specialized version of the plant's PRA model to calculate risk measures based upon an actual plant-operating configuration. At many plants, the use of a PRA model is supplemented by the use of various qualitative measures to provide additional risk management insights (such as the preservation of defense in depth [DID]) or to evaluate the influence of factors that are not explicitly considered in the PRA model.

As the PRA models used to perform CRM have evolved, the available computational tools have evolved as well. These tools are used to evaluate the models for specific plant configurations, present the results to plant staff, and track/trend the CRM results over time. Although each of the tools can provide different functions and features and can use different approaches to perform the quantitative and qualitative evaluations, the use of the tools by the end users (and the interpretation of CRM results) remains quite similar.

For plant personnel, the most important information to be obtained from these tools and models is:

- Is the plant configuration that is being evaluated acceptable from a risk management standpoint?
- Do actions need to be taken to reduce risk (if risk is elevated), and what would be the impacts of any such actions on risk if these actions are performed?

In order to make the risk evaluations easy to understand and to provide unambiguous indications of what constitutes acceptable and undesirable levels of risk, most plants have established various risk metrics and a series of risk thresholds or zones to classify the risk levels. Typically, each plant has an acceptable risk region, one or more regions in which risk is elevated, and risk management measures should be implemented to reduce risk or minimize the time spent in these regions, and an unacceptable risk region, which would not be entered as a part of the planned work routine.

Some nuclear power plants began to use CRM models in the mid-1990s to justify on-line maintenance practices and to evaluate equipment configurations that enabled shorter refueling outages. Other power plants began to use these models during the late part of the 1990s, as part of the initial implementation of the Maintenance Rule [1]. At that time, relatively little guidance existed concerning the scope and metrics of CRM. However, other industry guidance that had been developed in support of risk-informed regulation [2] [3] was reviewed and adapted to meet the needs of CRM. With the revision of the Maintenance Rule in 2000 to require the use of CRM evaluations prior to performing a maintenance action, when 10CRF50.65(a)(4) came into effect, industry and regulatory documents were issued [4] [5] to provide additional guidance concerning how CRM evaluations were to be performed and interpreted for risk management. These guidelines have helped to create the overall framework for establishing risk thresholds, but they still provide some flexibility in setting plant-specific approaches and values (which is appropriate given that various methods and tools are in use throughout the industry).

As a consequence of the evolving and flexible nature of the CRM guidance and the fact that various plants adopted CRM models and tools at different times up to the time that 10CFR50.65 (a)(4) took effect, some variability has been observed in the types of risk thresholds that are used in the industry and the basis for how such thresholds are established on a plant-by-plant basis.

In 2003, EPRI established the Configuration Risk Management Forum (CRMF) as an industry vehicle for discussing and disseminating information concerning CRM practices and issues. A key topic that was identified for research was the development of a reference document that could be used by the industry to establish and compare risk thresholds. It is recognized, however, that such a document was intended to provide insights for such thresholds only, as plant-specific variations might still be warranted to reflect specific features and management philosophy at each plant.

In addition to the development of this reference document regarding at-power risk thresholds, other research topics are being addressed for the CRMF in 2003. These additional topics will be addressed in separate documents and include the following:

- Support for Risk-Informed Technical Specification Initiative 4b (Risk Managed Technical Specifications) in the following areas:
  - Develop guidelines regarding the definition of **configuration** consistent with existing CRM programs. Under Initiative 4b, the current approach to fixed allowed outage times (AOTs) in the Technical Specifications would be replaced by a dynamically calculated risk-informed configuration time that considers all risk-affecting activities occurring at a given point. A number of technical issues are associated with defining a configuration when multiple risk factors are present or some risk factors change when other factors are in effect.
  - Provide insights on the use of quantitative risk criteria in support of Initiative 4b. Support other ongoing EPRI research for Initiative 4b by reviewing current CRM practices to suggest how current (a)(4) practices can be adapted to support Initiative 4b, particularly in the selection of quantitative risk criteria for action levels.
  - Provide insights for Risk Management and Compensatory Actions in support of Initiative 4b. Support other ongoing EPRI research for Initiative 4b by reviewing current industry

good practices to identify insights for Risk Management Plans and Compensatory Actions that are triggered by the different thresholds for risk level or safety function status described in this document.

- Develop guidelines for consideration of non-quantifiable risk factors in CRM. Although model complexity has increased to provide more accurate assessments of configuration risk, it is still not practical to consider all possible risk factors in a quantitative risk model. Various non-quantifiable factors are often considered in CRM, but they can be treated in a different manner from site to site, and no overall guidance has been provided to date on when and how to credit non-quantifiable risk factors.

It is assumed that the reader is familiar with the concepts and terminology of Configuration Risk Management, the methods and tools used to perform CRM evaluations, the requirements of the Maintenance Rule, and the relevant industry and regulatory guidance documents. For more information about these topics, the reader should refer to the documents listed in the References in Section 6.

Although CRM is required to be performed for all modes of plant operations, the scope of this research task is limited to at-power risk management only. CRM risk thresholds under plant shutdown conditions are currently being studied by the ORAM-SENTINEL Users Group, and the results of these research tasks might be used in the future to develop similar guidance for shutdown and transition modes conditions. Also, the primary focus of this task is to develop guidance for establishing quantitative risk measures. Data were collected during the survey concerning the use of qualitative measures that support/augment the quantitative risk results, and insights obtained from the surveys about their use is described in Section 3. However, specific guidelines for establishing qualitative risk thresholds are not provided, nor are specific approaches for DID methods presented in detail.

Project Approach

It was recognized that the first step in this project should consist of a review of the current experience base in the industry concerning the establishment and use of at-power risk thresholds. A survey was prepared and distributed to all U.S. utilities to request information concerning current at-power practices. A significant portion of the U.S. nuclear plants responded to the survey, which helped to clearly define current CRM practices.

Section 2 presents an overview discussion of key risk threshold concepts and issues, which is helpful for establishing a common framework for presenting the survey results and specific recommendations for risk threshold determination.

Section 3 summarizes the information obtained from the industry survey. Key insights from the survey data are also provided concerning the primary topic of risk threshold development, as well as related topics, such as the use of qualitative measures in addition to quantitative measures, the scope of CRM evaluations, and so on. Appendix A presents a more detailed compilation of the survey results.

Suggested approaches for risk threshold development are provided in Section 4, based upon the results of the industry survey and information obtained from key industry and regulatory documents.

Conclusions from this research project are presented in Section 5, along with recommendations for possible future research tasks that could be conducted by the CRMF or other industry groups.

Section 6 presents the references used in this project.

2
OVERVIEW OF QUANTITATIVE CRM RISK THRESHOLD CONCEPTS

Before discussing the specific results and insights obtained from the industry survey on current CRM risk threshold practices, it might be useful to present an overview of some of the important concepts that should be considered when establishing quantitative risk threshold measures to support CRM activities.

Figure 2-1 illustrates a simple example of two proposed configuration changes. This example is purely hypothetical and is not intended to reflect the risk results for any particular plant. The dotted line (at a value of 8.0e-5/yr) indicates the annualized Core Damage Frequency (CDF) that is calculated by the PRA model, assuming average unavailability of plant equipment over the course of a typical operating year. The solid line indicates the configuration-specific annualized CDF over time. In this case, the no maintenance risk level is 5.0e-5/yr (about 63% of the average maintenance CDF), and two risk peaks are observed, with instantaneous annualized CDF values of 2.0e-4 per year and 1.0e-4 per year. (Note that the term instantaneous is used in this report to refer to the rate of risk that is accrued within a specific configuration.) Presumably, these two risk peaks are the result of proposed maintenance actions that will be performed during this time period.

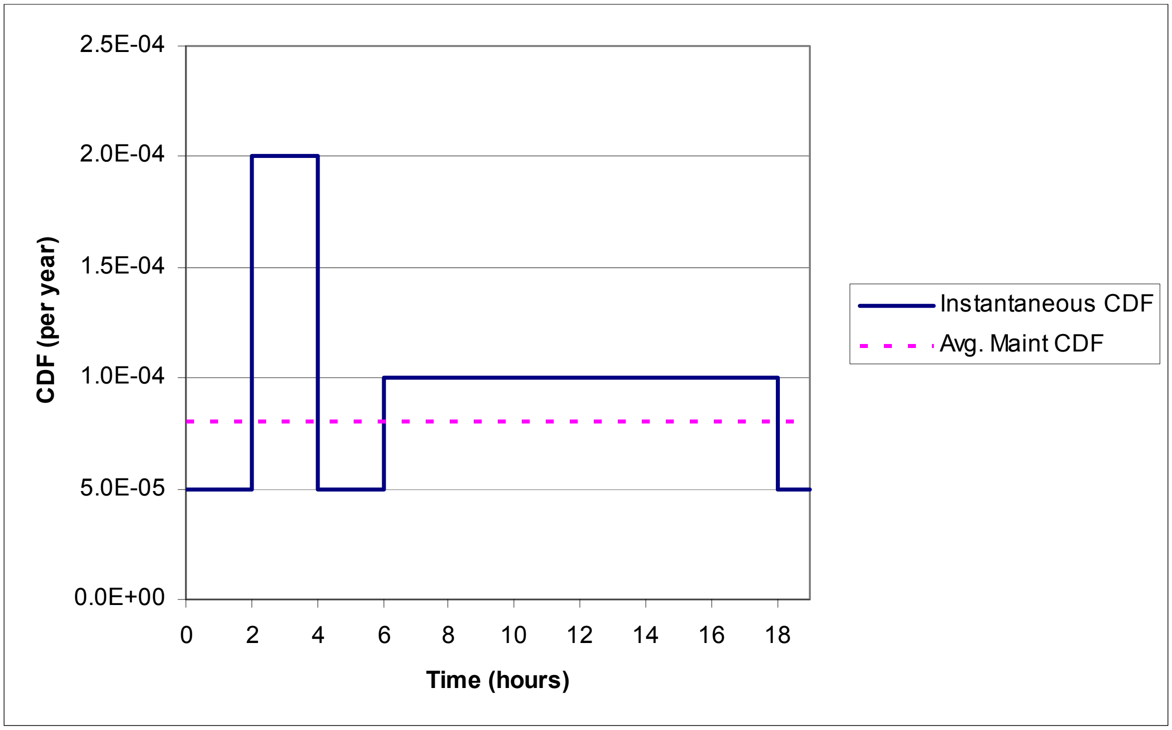

Figure 2-1
Example Risk Profile

To provide plant personnel with well-defined risk categories to support maintenance decisions, there are several types of measures that can be used to assess the risk impact of configuration changes. The most commonly used measures are those that assess the change in the instantaneous CDF resulting from an actual or planned configuration change, as displayed on the y-axis of the figure. By monitoring the magnitude of increases in instantaneous risk, accident risk is constrained by restricting plant configurations in which the rate of risk accrual is significantly higher than would be experienced under normal conditions. Usually, these measures are relatively independent of the expected duration of configuration (that is, a heightened risk level would be of concern if the condition existed for a few minutes or for many hours.)

Numerical limits can be placed on the instantaneous CDF for these measures or for other instantaneous measures, such as Large Early Release Frequency (LERF). For example, an instantaneous CDF of greater than 1.25e-4 per year might be considered to be an elevated risk level, which would dictate that risk management actions be considered to reduce risk. For the case shown in Figure 2-1, the first configuration risk peak (at 2.0e-4 per year) exceeds this risk threshold, so plant personnel would be alerted to the fact that the actions associated with this risk peak would need to be evaluated further. The second risk peak (at 1.0e-4 per year) also shows an elevated risk level; however, it would probably not be subject to the same risk management review as the first peak.

The second type of risk evaluation measure that can be considered for CRM applications is the use of cumulative (or accrued) risk measures. Such measures can be associated with the calculation of cumulative core damage probabilities (that is, the expected event frequency multiplied by the duration of the configuration). In particular for CRM evaluations, the incremental increase in accrued risk over the no maintenance risk is often used as a metric for such an evaluation. For the example illustrated in Figure 2-1, each day of operation in a no maintenance configuration has a Core Damage Probability (CDP) of 1.37e-7 (that is, 5e-5/year * 1 day/365 days/year). Each day of operation under average maintenance conditions has a CDP of about 2.2e-7 (that is, 8e-5 * 1/365).

NUMARC 93-01 [5] notes that a proposed configuration that results in an Incremental CDP (ICDP) increase of greater than 1.0e-6 might warrant the implementation of risk management actions. Using this criterion for this example, any configuration that resulted in an accrued additional risk equal to about eight days of operation with no maintenance under way (or five days of operation with typical average maintenance unavailabilities) would be identified as an elevated risk level configuration. It is interesting to note that for the cases shown in Figure 2-1, the ICDP for both risk peaks is significantly lower than this threshold. However, the ICDP for the second peak (which has a lower instantaneous CDF than the first peak but a longer duration) is actually twice as large as the first peak (that is, ICDP of 6.85e-8 versus. 3.42e-8 for the first risk peak). Other cumulative measures, such as incremental large early release probability (ILERP), can also be used in a similar manner.

The previous example illustrates why the use of multiple risk metrics can provide additional insights for plant personnel. The use of a measure that addressed only instantaneous risk would highlight the importance of the first risk peak but might not require additional scrutiny of the activities resulting in the second risk peak. On the other hand, the use of only a duration-based measure might indicate that both periods of increased risk are acceptable, but the second peak results in a significantly greater accrued risk increment than the first peak does.

A third type of risk measure can also be used to provide additional risk management insights. The previously discussed measures provide means of assessing the risk impact of a single period of increased risk level. However, over the course of a plant's operating cycle (or year, or other appropriate time period), the number of periods of increased risk level (as well as the magnitude and duration of each period) will directly affect the accrued risk from plant operations. The Maintenance Rule in 10CFR50.65 (a)(3) includes requirements to assess the impacts of maintenance activities on plant risk during each operating cycle. This requirement is often met by calculating a cycle-specific accrued risk (or CDP), considering the base risk plus the incremental risk additions from each elevated risk period.

In addition to performing such a per-cycle assessment, other measures could also be considered, such as calculating accrued risk on a rolling time-period basis. Examples of such rolling periods could include actual risk performance over the previous week or month or could include establishing limits for accrued risk for planned work weeks that are to be performed. In such a case, thresholds could be established to identify time periods in which the risk accrual would exceed desired levels, thus prompting the use of risk management actions to be taken to reduce the overall risk impact of current and future activities.

The last key concept to be noted concerns the issue of multiple overlapping risk increases. The example presented in Figure 2-1 consists of two discrete risk intervals that were separated by a period in which no risk-impacting maintenance was under way. However, maintenance activities sometimes involve situations in which multiple pieces of plant equipment are being worked on simultaneously. Also, situations can arise in which a planned maintenance activity is under way and an unexpected component failure occurs in another risk-impacting system. Figure 2-2 illustrates an example with overlapping risk-impacting configurations.

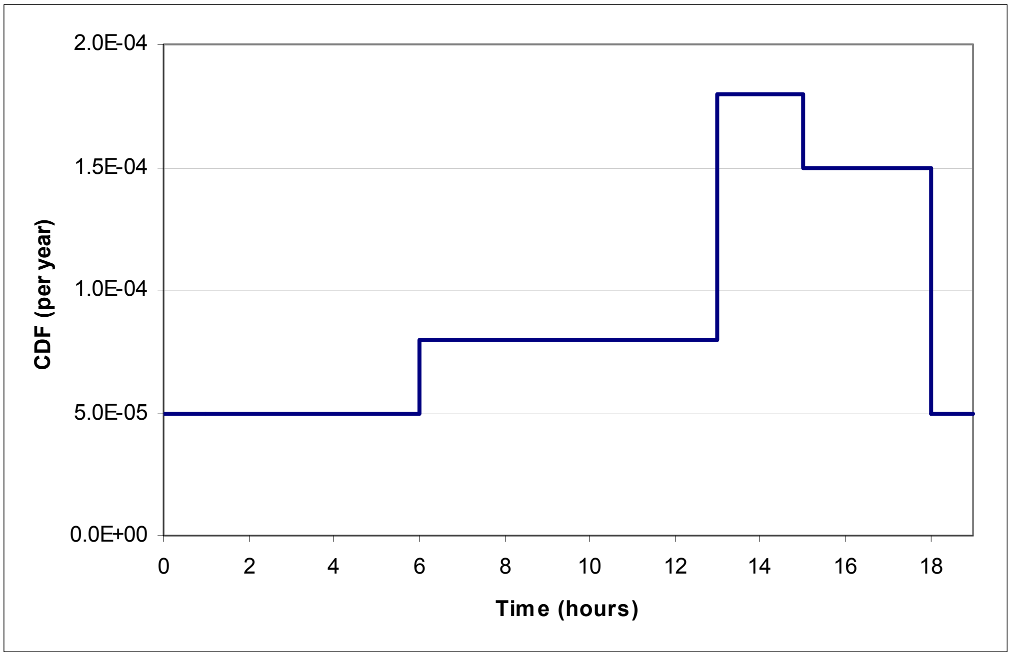

Figure 2-2
Overlapping Configuration Changes

In general, the same risk metrics (instantaneous risk level, ICDP accrued during a configuration, or CDP accrued over a fixed time interval) can be used to address such situations. However, consideration must be given to the combined impact of the overlapping activities.

An increase in the instantaneous risk level (resulting from an additional maintenance task commencing) would result in an increase in the ICDP that is accrued. Such an increase might result in increased use of risk management actions and management oversight.

A decrease in the instantaneous risk level, which might result from the completion of some of the maintenance activities or the suspension of risk-impacting activities resulting from a risk management action, would result in a reduction in the rate at which ICDP is accrued. However, the overall ICDP for the combined set of maintenance configurations might still require that risk management actions be continued in order to minimize the overall ICDP (that is, until the plant returns to a no maintenance state).

The examples presented in this section are idealized and simplified in order to assist in illustrating these key concepts. How each nuclear power plant evaluates and manages the risk of various maintenance configurations might vary, as will be discussed in the remaining sections of this report.

3
SURVEY OF INDUSTRY AT-POWER CRM PRACTICES

As a first step in the assessment of risk threshold approaches, a survey was prepared and distributed to all U.S. utilities to request information concerning current at-power practices. Sixty percent of the U.S. power plants provided responses to this survey. One EPRI-member non-U.S. utility also participated in this survey. This section presents an overall summary of the results and key insights obtained from this industry survey. Appendix A presents a more detailed compilation of the survey results.

The survey also requested information about other aspects of each plant's CRM activities in support of other CRMF research tasks. The information obtained from these other survey items is not discussed here but instead will be presented in other CRMF documents.

Eighteen utilities completed a total of 27 surveys, representing a total of 39 U.S. plant sites (63 units, or 60% of the units in the United States) and one non-U.S. plant. 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.

Configuration Risk Management Software Tools Currently in Use

The first section of the survey requested information on the CRM software tools currently in use. All of the survey respondents are currently using a CRM software tool (EOOS, ORAM-Sentinel, Safety Monitor, and/or other) for configuration risk management during at-power conditions. A large majority of those plants (85%) began using the at-power CRM software tool prior to the year 2000. The tools have been in use at the remaining plants since (a)(4) took effect in late 2000.

Although the primary focus of the survey was limited to at-power risk management, information was also collected on the use of CRM software tools for transition and shutdown modes. In this case, 20% of plants responding do not currently use a CRM software tool for transition modes, and 8% do not use a CRM software tool for shutdown modes (however, those plants might use another CRM method, such as a Shutdown Safety Assessment).

Although most common CRM software tools (for example, EOOS, ORAM-Sentinel, and Safety Monitor) are designed to evaluate risk for all modes, only six of the plants responding use the same single software tool across all modes. The majority (77%, excluding plants that do not use a software tool for CRM during transition or shutdown modes) use a combination of software or other CRM tools depending on plant mode. For example, a plant might use EOOS or Safety Monitor at-power and ORAM for shutdown, or a plant might use ORAM-Sentinel in conjunction with another PRA quantification tool at-power.

CRM Risk Zone Definitions

All of the plants responding to the survey currently use risk zones or colors to communicate risk. The majority (87%) use a four zone/color classification (typically green, yellow, orange, and red), although the remaining plants use a three zone/color classification (green, yellow, and red).

As noted previously, many of the plants use a different CRM tool for at-power, transition, and/or shutdown modes. In some cases, this means different risk zone/color classifications are used for the different tools. This situation was noted for several plants where a three-zone system is used with the at-power CRM software tool and a four-zone or other system is used with the shutdown CRM tool. The frequency of use for the various CRM tools can also vary with plant mode.

For all of the survey respondents, a configuration resulting in the highest risk level (red) is generally viewed as an unacceptable level of risk. If such a configuration must be entered (due to emergent conditions), additional review, approval, and oversight by upper plant management is typically required. In addition, compensatory measures, contingency plans, and/or other risk management actions must be implemented, as well as efforts to minimize the duration of the configuration.

It was noted that nearly half of the plants responding (48%) clearly state that a red risk configuration is never entered voluntarily (that is, it can be entered only due to emergent conditions). Other plants, however, do indicate that they have provisions for a planned entry into a high-risk red configuration. In general, those plants that use a three zone/color approach tend to permit entries into the red region with appropriate risk management actions and senior management oversight. Those plants using a four zone/color approach generally regarded the red region as one that should not be entered as part of a planned maintenance activity.

In addition, the plants that allow voluntary entry into the red zone tend to have lower relative red threshold levels (10 to 40 times baseline risk) than those plants that ban voluntary entry (20 to 400 times baseline risk). For pressurized water reactors (PWRs), the baseline risk level did not appear to drive whether the plant allowed voluntary entry into the red zone, but for boiling water reactors (BWRs), the baseline risk level was an order of magnitude higher for plants that do allow voluntary entry (between 2.5e-5 and 5.5e-5/yr compared with 1.5e-6 and 3.5e-6/yr for plants that ban voluntary red configurations). For the four zone/color plants, the entry condition for the red region was generally set equal to a CDF of 1e-3 per year, which is consistent with the guidance provided in NUMARC 93-01. In some cases, the entry threshold was set lower than the NUMARC recommended value.

The next lower risk zone (orange, where four zones are used) is characterized as having a risk significance ranging from degraded condition to moderate to significant to high. However, voluntary entry is allowed by all respondents (a few plants note entry should be avoided when possible) typically with prior approval of senior management, and senior management notification is needed upon entry due to emergent conditions. Again, compensatory measures, contingency plans, and/or other risk management actions are generally implemented, and efforts are made to minimize the duration of the configuration. One respondent provides specific limits for the duration of a configuration in the orange and yellow risk zones.

The respondents also view the next lower risk zone (yellow) as having a range of risk significance from acceptable to low to tolerable to medium with a corresponding range of required actions. Again, voluntary entry is allowed by all respondents with some (17%) indicating that approval by operations management is required with others (30%) indicating that only increased plant/operations awareness is needed. In addition, a majority of the plants (65%) specify that compensatory measures, contingency plans, and/or other risk management actions should be considered or implemented, although one specifies only normal work controls.

Finally, the lowest risk zone (green) also has a range of characterization by the plants responding from no/low risk to acceptable to minimum. No plants indicate that additional management approvals are required for configurations in this risk zone or that risk management actions beyond normal work controls are required.

As described in Section 2, the use of multiple risk metrics can provide additional insights for plant personnel. A risk metric based only on instantaneous risk will highlight the importance of a configuration in which risk exceeds the green zone, but this metric might not cause a plant to examine the duration of a longer configuration with risk within the green zone. Based on the survey responses, there is not a consistent consideration of duration when a configuration is perceived as low risk based on instantaneous measures. Half of the plants responding indicate that green maintenance configurations have no limits on duration or do not require that any specific actions be taken. In addition, some of these plants do not appear to use any cumulative measures when establishing the risk thresholds or to consider duration in making CRM decisions when the plant is in a green configuration. By considering duration for configurations with a low level of instantaneous risk, these plants might find that some configurations can be more significant contributors to cumulative risk than previously thought.

Approximately one-third of the plants responding indicate that they have not made any significant changes in risk zone definitions or thresholds since they began CRM. However, 30% of respondents have done benchmarking with other sites on risk zones/thresholds and have made changes to their own risk thresholds as a result. Roughly one-fourth of the plants have changed their risk zone definitions or thresholds following enhancements to the CRM tool, model, or data; one-fourth have made changes based on refinements in their CRM philosophy.

Quantitative Risk Thresholds

This section focuses on the insights obtained from the survey pertaining to the types of quantitative risk thresholds used and how these thresholds are set.

Evaluation Approaches Used

The survey results indicate that 83% of the plants use a blend of quantitative and qualitative risk criteria. The blended approaches described represent a range of methods and applications, such as the following methods used in addition to a quantitative CRM model:

- Safety Function Assessment Trees (SFATs) and/or Plant Transient Assessment Trees (PTATs) to assess the DID for plant safety functions and mitigation of transients, respectively. The approach (qualitative or quantitative) providing the highest risk result is used to specify the overall risk.

- Processes, procedures, and/or checklists to address DID, risk to power generation, and so on.
- Consideration of qualitative criteria (based on industry operating experience, personnel judgment, and so on) for systems, structures, and components (SSCs) not modeled in the PRA, fire, flooding, seismic, barrier impairments, degraded equipment, grid conditions, and Level 2 issues.
- Plant experience as a check on quantitative results, to assess conditions if PRA support is not available, or to determine the need for special restrictions or contingencies.

One respondent did note that even when procedures provide for use of qualitative criteria, application of these criteria can be difficult due to the somewhat subjective nature of the qualitative assessments (particularly those not performed using structured methods such as SFATs and PTATs).

Instantaneous Risk Thresholds

The survey shows that all the responding plants use at least one instantaneous risk measurement metric. The responses show that 88% of the plant sites use instantaneous CDF as their primary measure. An additional 25% of the plants use CDP, ICDP/large early release probability (LERP), or ICDP over a unit of time in addition to or instead of instantaneous risk criteria to establish the risk zone thresholds. The use of CDP is an extension of the instantaneous risk approach (that is, CDP is the combination of instantaneous risk and duration).

In addition, 33% of the plants currently use instantaneous LERF (another 17% are in the process of implementing instantaneous LERF as one of their quantitative risk criteria), although 8% use incremental LERP over a unit of time. Other plants consider LERF impacts using qualitative evaluation methods.

For the plants responding that use quantitative instantaneous risk measures, a majority (65%) use a combination of methods, such as baseline multiples, fixed risk values, duration limits, and/or risk with key components out of service to establish risk thresholds. Those methods include the use of:

- Baseline risk multiples (for example, 2x, 10x) for the second lowest and/or second highest risk zones (yellow, orange).
- Instantaneous risk values with combinations of major risk significant components out of service to establish yellow or orange thresholds. For example, if the most risk-significant component for a particular plant is a service water pump, a risk threshold might be established at the risk level calculated with that pump out of service.
- The NUMARC 93-01 [5] guideline values of 1e-6 CDP or 1e-7 LERP (or multiples of the guideline values for higher risk zones) accrued over a specified time period (such as a limiting Technical Specification allowed outage time or arbitrary durations, such as a week for lower risk zones or a day for higher risk zones). A plant can assume that the ICDP limit

of 1e-6 would be reached over a 7-day period when establishing a yellow threshold and then assume that same limit would be reached over a 24-hour period when establishing an orange threshold.

- The NUMARC 93-01 guideline values of 1e-3/year for CDF and 1e-4/yr for LERF for a specific configuration as the highest risk (red) threshold or fractions of those values for the next highest (orange) risk threshold.

Of the remaining plants responding, four have used multipliers of the baseline risk level as the sole method to establish each of the various risk thresholds. Three plants (each using a three color/zone classification) use a multiplier of 2x baseline risk for entry into yellow, and 10x baseline risk for entry into red. The other plant uses a four color/zone classification, with multipliers of 2x, 10x, and 20x baseline risk for the yellow, orange, and red thresholds respectively.

In general, baseline risk was defined as the no maintenance risk level for 92% of the plants. This approach is consistent with the guidance noted in NUMARC 93-01. The remaining 8% of respondents use the PRA average maintenance unavailabilities risk level as the baseline. The use of the average maintenance case results in a somewhat higher absolute baseline value; however, the actual threshold values used for each zone/color do not differ significantly from those plants that used the no maintenance baseline value. For example, whether a plant uses a no maintenance baseline value or an average maintenance baseline value, the instantaneous CDF value for transition from the green to yellow risk zone might still be at 1.0E-4 for each.

Finally, five plants indicate they use only fixed risk values from the EPRI PSA Applications guide [2], NUMARC 93-01 [5], or criteria developed prior to the implementation of the Maintenance Rule (a)(4), based on plant-operating experience to establish instantaneous risk thresholds.

Despite the variety of methods used to establish the instantaneous risk thresholds, the ranges of threshold values are comparable to the range of baseline CDF values. When allowing for the variations in plant type (PWR or BWR), model scope (internal events only or with flood, fire, and so on), and baseline configuration (average or zero maintenance), the instantaneous risk threshold values vary only by a factor of 3 to 9. For example, the second lowest (yellow) instantaneous CDF risk thresholds for PWRs with models that include internal and external events range only from 5.2e-5 to 1.6e-4 (a factor of 3). By comparison, the instantaneous CDF risk thresholds for BWRs with models that include internal and external events range from 6.3e-6 to 5.59e-5 (a factor of 9).

An insufficient number of responses were provided on instantaneous LERF risk thresholds to perform a meaningful comparison of those values. A majority of all plants responding (82%) have at least one single active component that will result in a risk transition when taken out of service under normal plant conditions.

For PWRs (63% of respondents), there are five plants for which the removal of any single active component does not result in a transition to a higher risk zone. Approximately half of the remaining PWRs responding had only one or two types of components that cause a transition to a higher risk level when taken out of service. Typically, these components are an emergency or auxiliary feedwater pump and/or an emergency diesel generator (EDG), which resulted in a risk within the second lowest zone (yellow). One plant has a single type of component (bus undervoltage/underfrequency relays) that will cause a transition to the highest risk zone (red) when taken out of service.

The other half of the PWRs responding have three or four types of components that cause a risk zone transition when removed from service under normal plant conditions. In most cases these components also include an auxiliary water feeder (AFW) pump and/or EDG, as well as one or more other component types, such as a cooling water pump (component cooling water [CCW], emerging service water [ESW], nuclear service water [NSW], and so on), reactor heat recirculator (RHR) train, or an injection pump. Generally, each of those results in a yellow risk level. One PWR identified a total of eight types of components that will cause a risk transition, two of which result in the second highest level of risk (orange).

Although seven of the eleven PWRs with zero, one, or two component types that cause a risk transition use a yellow threshold value more than double the baseline risk value, there was not a clear relationship identified between risk threshold values and the number or types of components that cause a risk transition. Similarly, there was no clear relationship identified between the PWRs with single component types that cause a transition to an elevated risk level (orange or red) and the value of the higher risk thresholds used at those plants. In fact, the plant with a component type that will cause a red risk classification when out of service has one of the highest threshold values for entering that risk level. Keep in mind that the plant-specific design and modeling assumptions will influence the number and type of components that cause a risk transition.

For BWRs (37% of respondents), there are two plants for which the removal of any single active component does not result in a transition to a higher risk zone. Half of the remaining BWRs responding have four or fewer types of components that cause a transition to a higher risk level when taken out of service. Risk transitions to yellow are caused by a wide variety of component types including an RHR train, high-pressure coolant injection/high-pressure core spray (HPCI/HPCS) pump, cooling water pump (shortwave or SW, ESW, reactor building closed cooling water or RBCCW, EDG, and so on). One of these plants has a single component type (HPCS pump) that will cause a transition to the second highest risk zone (orange) when taken out of service.

The other half of the BWRs responding have five or more types of components that cause a risk zone transition when removed from service under normal plant conditions. Again, for many of these BWRs, a risk transition to yellow is caused by the HPCI/HPCS pump, reactor core isolation cooling (RCIC) pump, cooling water pump, and/or EDG, in addition to several other types of components. Two BWRs identified several types of components (electrical buses, transformers, batteries, chargers, redundant heat exchangers, motor-operated valves or MOVs) that cause a risk transition to the two highest levels of risk (red and orange).

A large majority (80%) of the BWRs responding use a yellow threshold value of twice the baseline risk value, indicating that there is not a strong relationship between risk threshold value and the number or types of components that cause a risk transition. Similarly, there was no clear relationship identified between the BWRs with single component types that cause a transition to an elevated risk level (orange or red) and the value of the higher risk thresholds used at those plants. In fact, one of the plants with the most types of components that cause a risk transition when out of service has threshold values that are the greatest multiples of baseline risk. Conversely, one of the BWRs with the fewest types of components that cause a risk transition has threshold values that are the lowest multiples of baseline risk. As was observed with the PWRs, the plant-specific design and modeling assumptions influence the number and type of components that cause a risk transition.

Accrued Risk Thresholds

Although the approaches used in categorizing instantaneous risk changes were relatively consistent among the survey respondents, there was considerably more variation in approaches to assessing the impact of configuration duration on accrued risk. Also, many plants responded that they did not consider duration or cumulative risk even though they noted that duration considerations (such as ICDP) were used in the establishment of the instantaneous risk zone/color thresholds.

In reviewing the survey responses as they were provided, 43% of the plants directly consider the expected or actual duration of a configuration when making risk management decisions by:

- Calculating an allowable duration for the configuration based on a CDP or LERP limit (15%)
- Maintaining cumulative risk below a fixed limit for a specified time period (13%)
- Using a cumulative risk metric in conjunction with peak instantaneous risk (18%)

Forty percent of the plants responding did note that they consider duration indirectly, either when establishing the instantaneous risk zone threshold values as described above through a series of bounding calculations to determine the maximum duration within a given risk zone color that would still comply with the NUMARC 93-01 criteria, or through risk management guidelines that dictate methods to minimize the time in configurations with elevated risk levels.

About 18% of the plants also indicated that they employed some form of rolling average measure of accumulated risk over time to limit the total accrued risk (for example, over a weekly period). This type of risk measure is actually a cumulative risk measure, but the duration of each individual configuration change would directly impact the outcome of such a risk measure.

Finally, approximately one-third (30%) indicated that they do not specifically consider duration when making risk management decisions, or they do so only when a configuration results in an elevated risk zone (an orange risk level).

Cumulative Risk Thresholds

A majority of the plants responding (85%) indicate they do not establish risk zone thresholds for CRM actions based on cumulative, time-averaged, or duration measures (although many of these plants do consider duration or cumulative risk measures either directly or indirectly when using instantaneous risk thresholds, as described previously). Seven plants do establish thresholds for cumulative risk over a moving time period (typically one week).

The survey results indicate that fewer than half of the plants responding (48%) have some sort of cumulative risk target (monthly or annually). The targets used take a variety of forms, such as:

- A specific plant safety goal that is incorporated into the CRM software tool as a threshold value for instantaneous risk.
- Goals that are monitored on a periodic basis (for example, monthly or quarterly) but are not incorporated directly into the CRM software tool. The goal can represent the individual plant examination (IPE) CDF, the baseline CDF with average/nominal maintenance (possibly adjusted for unusual maintenance events or risk-significant system outages), EPRI *PSA Applications Guide* criteria for permanent plant changes, or some fraction or multiple of expected accumulated risk due to planned maintenance.
- Management of cumulative risk by limiting the increase in CDP for a specified period (daily or weekly) to ensure a certain risk level is not exceeded.

Quantitative Model Scope and Insights

The scope of the quantitative CRM model has an impact on the calculated baseline risk values, as well as any risk threshold values that are based in part on baseline risk. Model scope also influences the degree to which a blended (qualitative and quantitative) approach is needed to accurately assess risk. As expected, all of the plants responding include the internal events model for CDF in the scope of their at-power quantitative CRM model. In addition, a majority (55%) of plants includes internal flooding but not fire (only 18%) or seismic (5%) in the CRM quantitative model. Five plants also include other external events in the CRM model scope, and one plant includes internal flooding, internal fire, seismic, and other external events in the at-power quantitative CRM models for CDF and LERF.

Fewer than half of the plants responding (45%) include LERF in the at-power CRM quantitative model. For those plants, the scope of the LERF model is the same as the scope of the CDF model.

NUMARC 93-01 [5] does not require that quantitative CRM evaluations consider the risks from non-internal events. Consistent with this, none of the plants responding appear to consider non-quantified external risk contributors when establishing risk thresholds. For several of the plants, however, the scope of the quantitative CRM model does include risk-significant contributors other than internal events, which would thus be factored into the quantitative risk zone thresholds established. For the plants that do not include one or more external risk contributors in the scope of the CRM quantitative model, three noted that these contributors are assessed in some qualitative manner or controlled by other programs and have been considered in a bounding PRA evaluation. Two other plants indicated that although external contributors were not included in the CRM model scope or in establishing risk zone thresholds, they are factored into the calculated risk level.

Although it seems logical that if a quantitative model does not include certain risk contributors (for example, external events), those non-quantified contributors should not be factored into the established risk thresholds. The industry might wish to consider whether a blended approach to addressing non-quantified risk factors should also include a blended approach to establishing quantitative risk thresholds. For example, a plant with a baseline internal events CDF value of 5e-5 that establishes a yellow threshold at twice that value (1e-4) can factor non-quantitative external or other contributors for a given configuration into the quantitative results by assessing these other contributors as adding an additional 40% to the baseline internal events CDF (2e-5). If the plant entered a configuration that raised its internal events CDF to 9e-5 per year (which is still within the green risk zone), applying the external events factor would result in an estimated CDF of 1.1e-4 per year. The total CDF for the configuration from all contributors would then be yellow, which would be conservative because the setting of the threshold itself did not consider the baseline contribution of external events.

Qualitative CRM Models and Action Thresholds

The portion of the survey regarding qualitative models for CRM was intended to capture information regarding at-power CRM models; however, many plants also included information regarding their qualitative CRM models for shutdown and/or transition modes. The results summarized in the following paragraphs apply only to the use of qualitative models for at-power CRM.

One-third of the plants responding do not use any qualitative models (either exclusively or in conjunction with quantitative models) for CRM at power. However, nearly half (48%) of the plants use extensive qualitative CRM models (typically with SFATs to evaluate DID), which include all of the following safety functions (consistent with the recommendations of NUMARC 93-01):

- Decay heat removal
- Inventory control
- Status of key support systems
- Containment integrity
- Reactivity control

In addition, many (13 of 19) of these plants with extensive qualitative models also include color representation of their quantitative results and/or overall status for groups of other functions in the qualitative CRM model. A similar number also use PTATs to evaluate the interaction between a different set of systems and safety functions. Additional safety functions (such as a reactor coolant pump [RCP] seal cooling, secondary side heat removal, reactor coolant system [RCS] integrity, instrument air, radiation monitoring, external flooding, and so on) are considered in the qualitative CRM model by 10% of the plants.

A small number of plants (8%) include only one or two of the above items (such as status of key support systems, containment integrity, reactivity control, or overall status of function groups) in their qualitative CRM model at power. Finally, 15% of the plants do not have a qualitative CRM model as such, but they indicate they do include qualitative consideration of the safety functions/DID mentioned previously when evaluating maintenance configurations at power.

For the 13 plants that include overall status for groups of other functions in the qualitative CRM model, the majority (12) considers all of the functions within the group equally when determining the overall status, although one plant individually weights the individual functions to determine overall status.

For the plants responding to the survey that use some sort of qualitative tool (92%) for at-power or shutdown CRM or both, the two-thirds majority establishes the configuration color associated with each safety function based on the number of systems or trains available to perform the function (that is, N+2, N+1, N, N-1, and so on). (Note that due to wording ambiguities in the survey that led many plants to include information regarding their qualitative CRM models for shutdown and/or transition modes, the results summarized in this paragraph apply to the use of qualitative models for any mode.) Of the remaining one-third of plants that use a qualitative tool for CRM, most have established action colors using other methods, such as risk or DID matrices, Technical Specifications, procedural guidance, operational experience, and/or simple bounding calculations. The remaining few plants use a qualitative CRM approach that does not entail the use of action colors.

Finally, fewer than half (11) of the 29 plants that use both qualitative and quantitative risk measures at power have correlated the qualitative and quantitative thresholds or results. The plants that do correlate the qualitative and quantitative risk measures use varying degrees of rigor to obtain a direct correlation. The correlation effort ranges from special quantitative calculations (outside the CRM model) to estimate risk contributions of temporary alterations to comparison of qualitative and quantitative results from the respective CRM tools to determine if they are in agreement. Generally, qualitative measures based on DID (for example, using SFATs) do not have a direct correlation to quantitative risk measures, although qualitative measures based on defense against high-risk events (for example, using PTATs) can be correlated to PRA quantitative risk measures.

4

INSIGHTS FOR CRM RISK THRESHOLD DEVELOPMENT

Using the results that were obtained from the survey, as well as the current industry guidance documents, this section provides insights concerning how quantitative risk thresholds might be structured and defined for a typical U.S. power plant. Insights are also provided concerning using qualitative measures and blending these measures with quantitative results in a CRM evaluation.

Although the information and insights presented in this document focus on the mechanics of establishing risk thresholds, keep in mind that the most important information obtained from CRM software tools and their associated thresholds is whether risk management actions must be taken to reduce the risk of a given configuration. Only by considering the combined use of the CRM tools with the associated procedures and processes for risk management can the effectiveness of a risk management program be determined. The consideration of specific risk management actions triggered by different risk thresholds is beyond the scope of this report but is the topic of a separate research task being conducted for the CRMF.

As noted in the Introduction, the methods described here are possible approaches for establishing CRM risk thresholds. Where practical, several possible approaches (based on current good practices identified in the survey) have been presented to provide implementation flexibility. Each plant will need to consider its own specific needs when selecting the approach to use. In some cases, a plant might wish to consider alternate approaches; however, the methods described here might be used as a starting point for the development of a plant-specific methodology.

It should be noted that current industry practices (as described in Section 3) address the current needs of the Maintenance Rule and current risk-informed applications. The insights offered here might be used by an individual power plant to further refine its CRM approaches to support additional risk-informed initiatives. The approaches and good practices noted here can also be used by the industry to enhance the overall consistency of CRM thresholds and other related CRM issues.

Insights for Establishing Risk Zones

Each of the CRM tools currently being used displays to the plant staff the expected risk of various plant configurations through the use of a color-coded risk level scheme to address instantaneous risk increases. These colors/zones provide the plant staff with an easy-to-understand characterization of the risk of the current or planned maintenance actions. Procedural guidance can also be implemented to indicate what administrative actions need to be taken when the plant risk falls within each color/zone.

Survey respondents are successfully using either three or four risk colors or zones to classify the risk level from plant configurations. The primary distinction between using three or four zones appears to be the corresponding risk threshold and significance attached to the highest (red) risk zone. When four risk zones are used, it is possible to use a higher relative risk threshold for the highest risk level and designate that threshold as unacceptable, so that it should never be entered as part of the planned work routine. When using only three risk zones or when a plant has a higher baseline risk level compared with similar plants, it becomes more difficult to completely avoid the highest risk level, and provisions are needed to allow voluntary entry into this risk level (with appropriate risk management actions and senior management oversight).

Therefore, although the use of either a three-color or a four-color approach is reasonable, the four-color system would provide a more unambiguous means for defining a threshold that would not be exceeded for the purposes of any planned maintenance (although it might be entered because of emergent conditions).

Insights for Specifying Quantitative Risk Thresholds

Based on the survey response, use of instantaneous risk thresholds is the most common approach to CRM, although many plants also use some form of accrued and/or cumulative risk thresholds in addition to instantaneous risk. Insights for each of these types of quantitative risk thresholds are presented.

The NUMARC 93-01 [5] guidelines concerning the need for risk management actions based upon exceeding specific levels of ICDP and ILERP were developed by NUMARC/NEI through a consensus process using industry experts and have been endorsed by the NRC. As a result, the insights presented here make use of the NUMARC 93-01 limits as a key input. However, it is important to note that industry experience shows that these limits (for example, 1e-6 ICDP) are exceeded only infrequently. Nothing in this report is intended to imply that these NUMARC 93-01 limits are challenged routinely or that improvements in current CRM threshold methods are necessary in order to better comply with the NUMARC 93-01 guidelines.

It is recognized that a number of plant programs and administrative requirements limit risk, in addition to the quantitative risk threshold approaches discussed here. In particular, Technical Specification requirements and Maintenance Rule performance criteria limits on component unavailability can be more limiting in many situations. Also, many plants have established additional administrative requirements to limit unavailability of key plant components and systems. It is not practical to address the impacts of these external factors in this document. An individual power plant should consider the impacts of each of these other programs and requirements, as well as the insights presented here, when establishing CRM thresholds.

Similarly, there are often other factors considered when establishing quantitative risk thresholds that are not related to the risk levels specified in the NUMARC 93-01 guidelines. These other factors include items (noted in the Appendix A survey responses) such as a desire to use a common set of thresholds for all plants in the fleet, a desire to emphasize the impact of a key component, or a desire to maintain cumulative risk at an acceptable level per calendar year.

Because factors such as these reflect the risk management philosophy at a plant, they should also be considered by each individual power plant when establishing CRM thresholds.

In the course of developing the insights provided, it was noted that for some risk metrics it might be appropriate to distinguish (for some or all of the threshold measures) between situations in which configuration changes occur solely as a result of planned activities and those changes that are at least partially the result of unplanned changes (for example, unexpected component failures that occur while planned maintenance activities are under way). The existing industry guidance does not highlight the potential for combinations of planned and unplanned activities. However, these situations occur during plant operation, so it is appropriate to consider them within CRM activities.

The purpose of distinguishing between situations due to planned or unplanned maintenance is not to establish a different set of thresholds or actions for each. (When in a high risk configuration, the consideration should be what actions are needed to reduce risk, not how that configuration was entered.) Rather, the purpose of the distinction is to determine which risk management actions would be most effective. For example, if an unplanned configuration change that occurs prior to the start of a planned maintenance activity results in an ICDP/ILERP for the combined configuration that exceeds NUMARC 93-01 limits, the best risk management action might be to delay the planned maintenance until the unplanned event is resolved. But if the unplanned configuration change occurs while planned maintenance is under way, early termination of the planned maintenance might not be the best action.

Once the CRM thresholds have been established, it is a good practice (followed by a majority of survey respondents) to verify that the thresholds remain valid following a change in the CRM models or a change to the CRM software tool capabilities. One particular reason to re-evaluate a plant's current thresholds would be a change in the scope or level of detail of the CRM model. In general, as the scope of the model is increased, a change in the quantified CDF would be expected, and this change must be reflected in the established thresholds. Should plant management's CRM philosophy be refined over time (or should industry or regulatory guidance be revised or expanded), the thresholds might also need to be re-evaluated for these reasons as well.

Instantaneous Risk Measures

The survey summary in Section 3 notes that use of instantaneous risk measures for CRM is the most common approach. However, Section 3 also notes there is some variation in the methods for defining the risk levels for each risk zone. The following insights for establishing instantaneous risk thresholds reflect the current industry practices mentioned by survey respondents and provide a framework for implementing a consistent basis across the industry.

In general, either of the following two approaches could be used to establish consistent instantaneous risk thresholds:

- Use of the temporary risk increase guidelines from NUMARC 93-01 [5] and the EPRI *PSA Applications Guide* [2] for configuration-specific ICDP and ILERP accrued over a specified time period to calculate the moderate (orange and yellow) risk zone thresholds. This would entail assuming that the ICDP and ILERP limits of 1e-6 and 1e-7, respectively, are reached over an assumed duration. For the transition from the lowest risk zone to the next highest risk zone, the proposed duration limit could be based on the current Technical Specification limiting conditions for operation (LCO) for systems important to risk or a fixed time period (for example, a 72-hour LCO period, one-half of an LCO period, or a 7-day period). For the transition to the orange risk zone (if a four-color zone approach is used), a more limiting duration (such as 24 or 48 hours) should be specified. The NUMARC 93-01 upper limit of 1e-5/1e-6 for voluntary configuration changes should also be considered as a limiting case when setting this orange threshold (that is, the orange threshold should be more restrictive than the NUMARC upper limit). The use of the NUMARC ICDP and ILERP limits has the advantage of incorporating the impact of duration of the configuration into the instantaneous color assessment. For example, assume that a plant has yellow color threshold that is based upon exceeding the 1e-6 ICDP limit within 7 days and an orange color threshold based on exceeding the limit within 2 days. If the plant plans to perform a maintenance action that results in a yellow risk level and has a duration of 36 hours, then it is assured that the NUMARC 93-01 ICDP threshold will not be exceeded. Similarly, any configuration change that results in a green risk level will not exceed the ICDP limits unless its duration exceeds 7 days.

- Use of fixed multipliers of baseline risk (such as 2x, 10x, 20x) to define color boundaries. To be consistent with the guidance provided in NUMARC 93-01 [5], the thresholds should be set based on multiples of the zero-maintenance risk level. The values of the multipliers used should consider the NUMARC 93-01 guidance, so that a configuration that could result in exceeding the ICDP/ILERP limits is not inadvertently categorized as being in a low-risk zone. Based on the survey information, most plants using this approach have set the yellow risk zone transition at about 2 times baseline risk, the orange risk level at 10 times baseline risk, and the red level at 20 times baseline risk. The use of fixed multipliers can be most appropriate for plants that have a low CDF or LERF due to specific design features. For those plants, using the NUMARC 93-01 ICDP/ILERP limits could allow relatively long periods of equipment unavailability. For those plants, management might wish to select lower threshold values in order to maintain each plant's intrinsically low-risk levels and to ensure that maintenance configurations are kept to a minimum duration. The use of fixed multipliers might also help plant personnel to more readily understand the magnitude of risk changes as risk color increases. For example, a yellow risk might mean that risk is elevated between 2 and 10 times the normal baseline risk.

Some plants have established instantaneous risk threshold values based on combinations of major risk significant components being out of service. This approach can also be used, provided that the thresholds that are selected remain within the limits of the NUMARC 93-01 guidance (that is, that a plant would not inadvertently exceed a NUMARC 93-01 limit resulting from adopting such an approach to thresholds). This approach has the advantage of highlighting the risk impacts of key component outages directly to risk color zones and can provide a more tangible basis for the color definitions for plant personnel.

Regardless of which of the approaches is used, the temporary risk increase guidelines from NUMARC 93-01 [5] and the EPRI *PSA Applications Guide* [2] should be incorporated into the configuration-specific CDF and LERF for the highest (red) risk zone threshold. This corresponds to a red threshold of 1e-3/yr for CDF and 1e-4/yr for LERF. If a four-color risk zone approach is used, these limits (or a fraction of these limits, such as one-half) should be used to fix the transition into this highest risk region. If a three-color risk zone approach is used, the transition to the highest zone should be set to a value below these temporary risk increase limits, and procedural guidance should be established to address situations in which the instantaneous risk level exceeds the industry's temporary risk increase guidelines.

Lastly, it is recommended that the instantaneous risk thresholds apply equally to situations involving planned or unplanned maintenance activities, as well as situations that involve multiple overlapping plant configuration changes. The rate at which accident risk is accrued should be controlled in the same manner, regardless of the source of the increased risk (for example, an orange instantaneous risk level should be treated with a consistent level of management awareness and use of risk management actions, regardless of whether the configuration that caused this risk level was a planned or an unplanned one). However, as will be discussed, it might be appropriate to consider different approaches for considering planned and unplanned actions when evaluating other quantitative thresholds.

Accrued Risk Measures

As with instantaneous risk measures, accrued risk measures provide a means to assess the risk impact of a single plant configuration. For example, in Figure 2-1 from Section 2, an accrued risk measure would be calculated for the configuration in place between hours 2 and 4. A separate accrued risk measure would be calculated for the different configuration in place between hours 6 and 18.

As illustrated with the example in Section 2, even configurations that have the lowest (green) level of risk might result in a more significant accrued risk increment than configurations that have higher instantaneous risk levels. Some plants include risk management actions based on instantaneous risk thresholds that are designed to limit accrued risk to acceptable levels, even for green configurations (for example, completing planned work within the calculated allowed configuration time). However, several other plants note that low-risk configurations are unlimited, always acceptable, or have no associated time limitations and no management actions.

Therefore, consideration of configuration duration might be prudent in order to completely characterize the risk contribution for a given configuration. The industry survey results indicate there is a much greater variation in approaches to consider the impact of configuration duration. This is an area in which plants might wish to review their implementation of risk measures to manage accrued risk impacts, particularly if implementation of more advanced risk-informed applications (for example, Risk-Informed Technical Specifications) is planned. In addition, more advanced applications might also point to a need for more stringent accrued risk limits or for more active accrued risk monitoring/management.

The NUMARC 93-01 guidelines [5] provide ICDP/ILERP limits to determine if a given maintenance configuration is acceptable or if risk management actions should be implemented during this configuration. NUMARC 93-01 includes two thresholds: one (set at 1e-6 ICDP or 1e-7 ILERP) to determine when risk management actions are required, and one (set at 1e-5 ICDP or

1e-6 ILERP) above which voluntary maintenance actions should not normally be considered. As noted previously, current plant risk management practices effectively limit the number of times these NUMARC 93-01 limits are challenged at power plants.

While ICDP and ILERP could be calculated on a configuration-specific basis, it might not be necessary to do so. A series of bounding calculations could be performed to determine the maximum duration that could result from a given risk zone color that would still comply with the NUMARC 93-01 criteria. For example, consider a plant that has a baseline (no maintenance) CDF of 1e-5/year and instantaneous risk thresholds for entry to the yellow and orange risk zones of 3E-5/year and 1E-4/year, respectively. If a configuration resulted in an instantaneous risk level just below the yellow threshold, the NUMARC 93-01 ICDP limit would not be exceeded as long as the configuration lasted less than 0.05 years, or 438 hours (ICDP limit divided by the change in CDF over the baseline, or 1e-6 / 2e-5 = 0.05 years). Similarly, if a configuration resulted in an instantaneous risk level just below the orange threshold, the ICDP limits would not be exceeded as long as the configuration lasted less than 0.0125 years, or about 110 hours (1e-6 / 8e-5 = 0.0125). So, in lieu of calculating ICDP for each specific configuration, the plant's risk management procedures could indicate that any green configuration lasting less than about 18.5 days, or yellow condition lasting less than 4.6 days, would not need to be evaluated for further risk management actions due to the duration of the configuration. (Nearly 40% of the plants indicate they use this approach.)

If a plant wishes to directly calculate ICDP and ILERP limits as each configuration change occurs (or is planned), the two most direct methods for addressing configuration duration in risk management decisions are:

- Calculation of CDP/LERP (or ICDP/ILERP) for each configuration and comparison of that result to established limits. However, the ICDP/ILERP calculation might need to be re-performed if the actual configuration duration exceeds the assumed duration used in the original calculation. (The survey results indicate few plants currently use this approach.)
- Calculation of an allowable duration for the configuration, based on the established ICDP/ILERP limit. This allowable duration is sometimes referred to as an allowable configuration time (ACT). If the duration of the configuration remains less than this ACT, the ICDP/ILERP limits will not be exceeded. The CRM software could be used to calculate the allowed duration as the instantaneous risk level changes. (Approximately 15% of the plants responding use this approach.)

Although not required for any current risk-informed applications, it should be possible for CRM software tools in the future to assign a risk color to the duration of a given configuration in much the same manner as such colors are applied to instantaneous risk levels. For example, any configuration that has an ICDP of less than 1e-6 could be characterized as green for duration, whereas one that has an ICDP of 1e-5 would be characterized as red. Those with ICDPs between these values would be classified as yellow or orange, with the threshold between these two colors established in a manner consistent with how a plant sets this yellow-to-orange threshold for instantaneous risk. If such a software feature was implemented at a plant, each configuration could be assigned two risk colors (one for instantaneous risk and one for duration impact), or an overall color for each configuration could be assigned, based on the most limiting color determined by both measures.

During situations in which all maintenance activities under way are planned activities, the NUMARC 93-01 ICDP/ILERP limits should be adhered to, regardless of whether single or multiple maintenance activities are being performed. If a plant plans to conduct multiple maintenance activities simultaneously (similar to the example described in Figure 2-2), the overall ICDP/ILERP of the entire configuration change (that is, from the initial departure from the no maintenance configuration until all of the planned maintenance is completed) should meet the requirements for a single configuration change. If the accrued risk of the entire configuration change exceeds either of the NUMARC 93-01 limits, consideration could be given to separating the simultaneous maintenance tasks so that the risk accrued during each configuration is minimized. When separating the activities, however, the total integrated risk of the multiple activities should be compared to the total integrated risk of the simultaneous activities. If the tasks cannot be separated, risk management actions should be implemented based upon the calculated ICDP/ILERP for the combined configuration and should remain in place until all maintenance is completed.

This approach would also be used for situations in which an unplanned configuration change has occurred prior to the start of a planned maintenance activity. If the ICDP/ILERP of the combined configuration does not meet the NUMARC 93-01 limits, the planned maintenance task(s) should be delayed until the unplanned event has been resolved. However, the capability to reduce total integrated risk by simultaneously performing maintenance activities should be compared to the total integrated risk from performing the maintenance activities separately.

On the other hand, if an unplanned configuration change occurs while a planned maintenance activity is already under way, the accrued risk impacts of each configuration change should be considered separately. This approach is appropriate in this situation because the planned maintenance was begun based upon the best available information about the plant's state prior to the start of maintenance. The instantaneous risk thresholds would still be applied to the combined configuration (as noted in Section 3). Also, in cases in which the risk increase resulting from the unplanned change is significant, the ICDP/ILERP of the combined configuration should also be compared to the upper level NUMARC 93-01 guidelines (1e-5 ICDP or 1e-6 ILERP) to see if additional risk management actions should be implemented until either the planned or unplanned configuration change can be completed. Such actions might include early termination of the planned maintenance, accelerated maintenance for either the planned or unplanned items, or implementation of other compensatory measures.

Should a plant exceed the NUMARC 93-01 ICDP or ILERP limit for requiring the use of risk management actions, such actions would be implemented (similar to the approach used for instantaneous risk). Planned configurations whose ICDP exceeded the NUMARC 93-01 limit of 1e-5 should not be entered except under the most unusual circumstances. Within the region defined as acceptable risk, but risk management actions should be considered (ICDPs between 1e-6 and 1e-5), a plant might wish to administratively define a graded approach to obtaining management approvals for performing the configuration change and for implementing risk management actions. However, as noted previously, experience has shown that the NUMARC 93-01 ICDP limits are not frequently challenged when typical plant maintenance activities are performed.

Should a planned configuration exist for a time that was longer than planned, the increased time in the configuration should be assessed (either using a bounding method or performing an ICDP/ILERP calculation) to confirm that the accrued risk remains within its current duration risk zone. Should a situation arise in which a configuration's duration causes it to exceed one of the NUMARC 93-01 limits, then additional risk management actions might be needed. For example, if a planned configuration has a calculated ICDP of 7e-7 (acceptable duration), no risk management actions would be needed. However, if a delay in ending this configuration causes its ICDP to rise above 1e-6, risk management actions should be implemented as soon as it becomes apparent that the NUMARC 93-01 ICDP limit will be challenged. The type and degree of risk management actions to be taken would, of course, need to consider the specific situation in place at the time.

Cumulative Risk Thresholds

Cumulative risk thresholds provide the ability to assess the impact of configuration changes over a longer time period. As described in Section 2, the previous risk measures (instantaneous risk and accrued risk) provide the means to assess the risk impact of a single set of plant configuration changes. However, a plant could comply with these risk thresholds on a configuration-by-configuration basis and still accrue a larger-than-expected annualized risk if a large number of risk-sensitive configurations were entered over time.

The cumulative risk measure is a measure of total accrued risk. As such, it considers periods in which no configuration changes are performed as well as periods that have planned and unplanned configuration changes. (For example, in Figure 2-1, a single cumulative risk measure could be calculated for all configurations, including no maintenance periods, in place between hours 0 and 18.) This measure provides an overall assessment of how the plant's risk is varying over time resulting from day-to-day activities by operations and maintenance personnel.

The Maintenance Rule requires periodic assessments of the risk impacts of maintenance activities in paragraph (a)(3) of 10CFR50.65. These assessments are typically performed once per refueling cycle and would provide an after-the-fact indication of the adequacy of the overall CRM program. To provide more pro-active monitoring of CRM performance, a plant might want to perform cumulative assessments on a more frequent basis to identify trends (both positive and negative) that could influence future risk management decisions.

Fewer than 20% of plants responding to the industry survey noted that a periodic cumulative risk measure was currently used at their plants. Possible measures for consideration include:

- A periodic look-back assessment, similar to that used for Maintenance Rule (a)(3) purposes but on a more frequent basis (for example, on a monthly or quarterly basis).
- Calculation of a rolling measure of accumulated risk over a specified period of time (one week or one month) and the maintenance of that accumulated risk below a fixed limit. Such measures are often calculated automatically by the CRM software or an add-on program that evaluates the overall risk results. Calculation of accumulated risk can also be performed on a looking-forward basis, using the planned work schedule and setting administrative limits on

planned risk accumulation for each schedule period. Consistently performing these evaluations based on planned actions would be an alternative to performing a look-back assessment. However, the assessments might need to be reviewed after the completion of each work schedule to determine if unplanned maintenance actions, system alignments, or other external factors (such as severe weather that might have occurred during the work period) might have added an additional increment to the accumulated risk.

In setting an administrative limit for a cumulative risk measure, the overall objective would be to ensure that annualized plant risk remains in agreement with the time-average PRA risk result for the plant (assuming average component unavailabilities). In order to help meet that objective, some plants have set the administrative limits so that the risk accrued during the monitored time period is equal to or less than the risk that would be accrued had the plant operated at the time-average PRA risk level over that period. This approach is an acceptable approach for establishing a goal for the CRM program. However, using this approach to establish an administrative limit might be unnecessarily conservative, as requiring that each time period accrues less risk than the time-average value will result in the plant always accruing less risk than the calculated average value on an annual basis. If this approach is followed over several PRA data update cycles, the average annual risk target value will continually decrease. Although such a risk trend is desirable, it cannot be sustained over an extended period of time (that is, risk management of plant maintenance activities can control only a portion of the plant's total accident risk). In addition, such an approach does not allow for the fact that much maintenance is not random and some higher-risk activities might occur for some periods in the plant-operating cycle.

A more practical approach would be to set the administrative limit for a cumulative risk measure to be a small multiple of the time-average risk. In general, this multiple should be a smaller value as the length of the assessment period increases. For example, a plant that computes a weekly risk measure might establish an administrative limit for each week's accrued risk equal to perhaps several times the time-average value (in order to provide sufficient flexibility to plant personnel to allow for considerable variation in the weekly risk of maintenance actions). However, a plant that computes a quarterly risk measure might use an administrative limit of at most two times the time-average value, in order to help ensure that several quarters of relatively high risk levels do not add significantly to the annualized risk accumulation.

An approach used at some plants to establish an administrative limit for annual cumulative risk is to use the EPRI *PSA Applications Guide* [2] criteria for permanent plant changes when comparing actual cumulative risk to the average-maintenance PRA risk to determine if the cumulative risk is acceptable. Should the actual risk exceed the expected average maintenance risk by more than this amount, this might imply that the plant's maintenance practices have, in effect, modified the plant's operating basis in much the same way as a design change might.

Regardless of the methods used to monitor and control cumulative risk, plant management must be careful when addressing situations in which accumulated risk might approach or exceed the desired annualized target value. The concern is that plant personnel might begin to defer or modify maintenance actions solely for the purpose of keeping near-term risk accumulation to a minimum. However, such actions might have a longer-term adverse impact on the plant's operation. The fact that a plant might have exceeded the desired cumulative risk goal over a short-term or long-term period should trigger actions to consider how future periods of excessive risk accumulation might be avoided. However, the fact that risk might have exceeded a target value should never be used alone to change short-term maintenance or operations philosophy.

LERF/LERP Thresholds

The NUMARC 93-01 Maintenance Rule guidance specifies that the impacts of plant configuration changes upon both LERF and CDF should be evaluated. However, the industry survey indicated that only about one-half of the plants had or were adopting measures that quantitatively evaluated instantaneous variations in LERF (or LERP). The other 50% of plants are considering LERF/LERP impacts in a qualitative manner.

The survey results did not provide sufficient data to analyze current practices in the quantitative evaluation of LERF and LERP. However, the actual approaches to be used should parallel those described previously for core damage frequency/probability measures. In particular, the NUMARC 93-01 guidelines for incremental LERP would be used in a similar fashion to the ICDP limits discussed above.

For those plants that use qualitative evaluations of LERF or LERP impacts, there are some quantitative elements that could be considered as part of the qualitative evaluation. The LERP limits do not tend to be as limiting for most plants (particularly for PWRs). So, it might be possible to perform a series of bounding evaluations to determine the minimum change in CDF that would be required before a more detailed assessment of LERF impacts is necessary.

Also, because typically only a subset of core damage scenarios leads to large early releases, it should be possible to identify those specific types of configuration changes that can impact LERF in a disproportionately greater manner than CDF. Therefore, the PRA model might be used to identify those systems and components that, if impacted, would cause a significant increase in LERF. For example, PWR steam generator tube ruptures are often a significant contributor to LERF. These scenarios are usually most sensitive to changes in the reliability of high-pressure safety injection and auxiliary feedwater. If so, qualitative guidance could be developed that would result in configuration changes affecting these two systems to receive particular review for potential LERF impacts. Conversely, if a proposed configuration change does not impact those systems and components most important to LERF, a specific qualitative review of expected LERF impacts would not be required. More research might be done in this area to see if a series of straightforward decision rules could be developed to rapidly screen expected LERF impacts.

Observations Concerning the Use of Qualitative Risk Measures

Guidance in NUMARC 93-01 [5] recommends that CRM for the Maintenance Rule should consider the impact of a configuration on key safety functions (for example, considering the remaining degree of redundancy for trains or systems supporting the key safety function). Nearly half of the plants responding to the survey use extensive qualitative CRM models (either exclusively or in conjunction with a quantitative model) to evaluate the status of key safety functions while at power. In addition, a few plants evaluate one or two key safety functions, and a few more include qualitative consideration of safety functions without the use of a model.

The use of a qualitative CRM model and tool can provide an objective, consistent approach to evaluate the impact of configuration changes on key safety functions while at power. This model would be analogous to the qualitative CRM model many plants use for shutdown modes, and similar to those shutdown models, risk zone thresholds can be established based on the number of systems or trains available to perform the safety function. If a rigorous qualitative model is not used (for example, SFATs), a specific checklist of items to be considered in the qualitative evaluation should be implemented to ensure consistency and completeness of the evaluations.

When a qualitative model is used in conjunction with a quantitative model for CRM, some degree of correlation between the two sets of results would be prudent to avoid conflicting results or risk management actions. At a minimum, this correlation should involve a comparison of quantitative and qualitative results for consistency and determine which dictates the most limiting outcome. This approach of selecting the most limiting quantitative or qualitative result for decision making is used by one-third of the plants that use both qualitative and quantitative risk measures at power. If risk levels from one approach are significantly more limiting than those of the other approach, changes to the models might be considered in order to bring the two approaches into better agreement.

Observations Concerning the Use of Blended Approaches to CRM

The survey results identified a wide range of interpretations for a blended approach for risk assessment and in the risk elements to which a blended approach is applied. The descriptions for a blended approach range from a loose, subjective consideration to a semi-quantitative evaluation, which might be applied to elements such as factors not included in a quantitative model to the preservation of DID.

As a minimum, a blended approach could be expected to include subjective consideration of quantitative CRM results based on plant experience, in order to determine if special restrictions or contingencies are needed. This type of blended approach goes hand in hand with the expectation that utilities do not run the plant strictly by the numbers from a CRM evaluation.

In many cases, however, a more rigorous and less subjective blended approach might be warranted to ensure that all significant risk contributors are evaluated (such as those not within the scope of a quantitative CRM model) and that all pertinent aspects of risk are accounted for (in addition to CDF, such as preserving DID). For some CRM applications, such as the Maintenance Rule, this type of blended approach might need only to result in a risk color determination that reflects all the relevant risk contributors/aspects for a configuration. For other more rigorous applications, such as risk-informed Technical Specification Initiative 4b, the blended approach might need to provide an overall quantitative risk measure.

5 CONCLUSIONS

The industry survey to which a large fraction of U.S. plants responded demonstrates that CRM is a highly formalized process at U.S. nuclear power plants, but there are variations within the industry on implementation. The industry survey provided a large body of knowledge about current practices. In addition to supporting the needs of this report and other CRMF research tasks, the survey results (presented in Appendix A) should also be a valuable resource for nuclear power plants that might wish to benchmark their practices against others.

In summary, the survey shows that there is a high level of consistency in the approaches used to CRM across the industry. The bases for the plant-specific approaches also appear to be well founded, regardless of the degree to which a particular plant's approach compares to that of other individual plants. However, the survey also shows that the industry would benefit from further efforts to obtain consistency in its CRM practices, in order to allow each plant to better compare its CRM programs to others, as well as to increase regulatory credibility.

The survey indicated that instantaneous risk measures are widely used as a primary method of assessing configuration risk. The methods used to assess and categorize this risk (that is, the number of risk zone categories, how those categories are defined in terms of actions that must be taken upon entry to each zone, and the quantitative thresholds used to delineate each risk zone) are very similar across the industry. CDF and/or ICDP Probability were the most widely used metrics for assessing configuration risk.

The use of duration-based measures for configuration changes can serve as a useful complement to an instantaneous risk measure. However, the degree to which these duration-based measures are used and the methods used to define and evaluate these measures showed significantly more variation throughout the industry. A relatively small fraction assesses the impacts of duration on an ongoing basis. However, a number of other plants have performed quantitative bounding evaluations to identify limits to maintenance duration to ensure that excessive amounts of risk are not accrued or have factored duration impacts into their definitions of instantaneous risk thresholds. Also, it is noted that other regulatory and administrative requirements impose practical limitations on the length of maintenance outages on important plant equipment. So, although there is considerable industry variability as to the specific approaches used, it is believed that the industry is properly controlling risk accrual due to planned and unplanned maintenance activities.

Variations in approaches for addressing LERF/LERP and the scope of the quantitative CRM model were also observed. These are areas that might benefit from further study to determine if additional measures could be useful for some or all plants.

Based on the results of the survey, a consistent set of approaches is described to define risk thresholds for quantitative at-power CRM evaluations. These approaches consider instantaneous risk, accrued risk, and cumulative risk. The approaches address the needs of the existing regulatory guidance and are generally consistent with current industry practices. So, these approaches should be able to be implemented at a U.S. power plant without significant effort. However, plant-specific features and issues need to be considered prior to adopting the approaches presented here, and these might justify use of other approaches.

While the industry survey gathered information about the use of at-power qualitative evaluation methods, this project was primarily focused upon at-power quantitative risk threshold measures. However, the information gathered about qualitative methods indicated that there is significant variation in the industry concerning the extent to which qualitative measures should be used and how these measures are blended with quantitative insights to arrive at risk management decisions. Further research into these topic areas might be of general interest and benefit to the industry.

Suggestions for Further Research

The current CRM methods and criteria in use in the industry are certainly beneficial to the work management process and are adequate to support the needs of the Maintenance Rule. But, the responses to the survey also identified areas that can lead to potential challenges should plants attempt to implement some of the more advanced risk-informed applications, such as risk-informed Technical Specifications. These challenge areas include the following:

- The use of different CRM software or other (non-software) tools for the different plant modes (power, transition, and/or shutdown). The absence of a consistent tool might make it more difficult to compare results and insights among the different plant modes, particularly if different risk zone classifications are used for the different tools. As an alternative to the use of a single tool, further efforts to correlate the results of the different tools might need to be undertaken to allow for comparison of CRM impacts in different plant modes.
- The scope of many of the current CRM models, which is limited to internal events, without quantitative treatment of significant external contributors. Current risk-informed applications require objective treatment (quantitative or qualitative) of external events, and more advanced risk-informed applications might require more quantitative treatment (or a more disciplined approach based on risk insights) in these areas. Cost-effective approaches for performing such evaluations would be of benefit to the industry.
- The wide variation of approaches to address risk impacts that are not quantified (both external events, as noted above, and other plant impacts). Advanced risk-informed applications will require a more complete assessment of all configuration-specific risks. Development of consistent approaches to evaluate these non-quantified factors would benefit the industry.
- The effectiveness of using accrued risk measures (CDP/ICDP and LERF/ILERP), compared to use of risk management actions based on instantaneous risk measures, in order to limit risk below industry guidelines.

- Quantitative and qualitative alternatives for evaluation of CRM impacts on LERF. A portion of the surveyed plants rely on qualitative assessments of LERF impacts, and others have no formal treatment of LERF. Simplified approaches might be developed that would allow plants to more easily determine the impacts of configuration changes on LERF.
- Benefits of quantitative CRM evaluations for transition and/or shutdown modes. Advanced applications might require explicit consideration of quantitative risk impacts in non-power modes.

Further investigation of these areas might be beneficial to support the use of CRM models, tools, and techniques to maintain the current and next generation of risk-informed applications.

6
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4. U.S. Nuclear Regulatory Commission. *Assessing and Managing Risk before Maintenance Activities at Nuclear Power Plants*, Regulatory Guide 1.182. Washington, DC, 2000.

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A
SUMMARY OF SURVEY RESPONSES

This Appendix provides more detail about the specific responses provided to each question for the portions of the industry survey that pertained to this research task. (Other portions of the survey will be discussed in other technical reports.) By reading the actual responses from the participants, users of this report might be able to use the survey information for other CRM benchmarking purposes. However, none of the information in this Appendix should be used without verification from the specific plant(s) that the information remains current and that it is acceptable to use the plant-specific information for other purposes.

The responses are largely provided **as is**. However, some responses were edited and interpreted by the authors to clarify specific items or to limit the length of the response. In a few cases, the original responses were re-grouped when it appeared (from other descriptive responses provided) that the intent of a question might have been misinterpreted. One example of this is Question 12, which was intended to survey the use of qualitative models for at-power CRM evaluations. Due to non-specificity in the question wording, some plants interpreted the question to be inquiring about the use of qualitative measures in any mode (such as shutdown). The responses to other questions were used to edit the responses to reflect only the actual use of such measures at-power.

In some cases, acronyms were used in the responses. In general, the acronyms used are those frequently used in the industry. However, no attempt was made here to develop a glossary of these terms.

Survey Respondents

A total of 27 surveys was completed by 18 utilities, representing a total of 39 U.S. plant sites (63 units, representing 60% of the units in the U.S.) and one non-U.S. plant. In the summary of the survey that follows, the designation P*x* is used to represent each PWR plant site (25 total), and B*x* represents each BWR plant site (15 total). Surveys were completed for the following utilities and plants:

- Ameren: Callaway
- American Electric Power: D.C. Cook
- Arizona Public Service: Palo Verde
- Constellation Energy: Nine Mile Point
- Dominion: Millstone

- Dominion: North Anna
- Dominion: Surry
- Duke Power: Catawba, McGuire, and Oconee
- Entergy: Grand Gulf
- Entergy: River Bend
- Entergy: Waterford 3
- Entergy Northeast: Indian Point 3
- Entergy Northeast: James A. FitzPatrick
- Exelon: Byron, Braidwood, Clinton, Dresden, LaSalle, Limerick, Oyster Creek, Peach Bottom, Quad Cities, and Three Mile Island
- First Energy: Davis-Besse
- First Energy: Perry
- Nuclear Management Company: Kewaunee
- Nuclear Maangement Company: Monticello
- Progress Energy: Brunswick
- Progress Energy: Crystal River
- Rochester Gas & Electric: Ginna
- South Carolina Electric & Gas: V. C. Summer
- Southern California Edison: San Onofre
- Southern Nuclear Operating Company: Farley, Hatch, and Vogtle
- TXU, Inc.: Comanche Peak
- Wolf Creek Nuclear Operating Company: Wolf Creek
- Eletronuclear: Angra 1 (Brazil)

Summary of Survey Responses

All percentages are based on total number of plant sites that responded (40). Percentages do not always total 100% due to multiple answers for some plants or plants that did not provide answers for all questions. In general, the percentage responses given should be used as a guide, but the actual responses, by plant, should be reviewed by the reader to ensure that it is understood how the responses affected the percentage calculations shown.

General Information Questions

Configuration Risk Management Software Tools Currently Being Used

At-Power Conditions	**Transition Modes**	**Shutdown Modes**
☒ EOOS **(38%)** P4, B13, P18, B2, P11, B3, B4, P12, P20, P5, P23, B14, B15, P24, P25	☒ EOOS **(20%)** P18, B13, P5, B14 B2, P11, B3, P12-Mode2/3	☒ EOOS **(10%)** P5, B4, P18, B14
☒ ORAM-Sentinel **(33%)** B5, B6, B7, B8, B9, B10, B11, P8, P9, P10, P13, P14, P15	☒ ORAM-Sentinel **(40%)** B2, B3-Mode4, B5, B6, B7, B8, B9, B10, B11, P8, P9, P10, P11, P13, P14, P15	☒ ORAM-Sentinel **(48%)** B2, B3, B5, B6, B7, B8, B9, B10, B11, P1, P8, P9, P10, P11, P13, P14, P15, P21, P23
☒ Safety Monitor **(28%)** P1, P2, B1, P7, P6, P16, B12, P17, P19, P21, P22	☒ Safety Monitor **(20%)** P1, P2, P7, P6, P16, P17, P19, P21	☒ Safety Monitor **(13%)** P2, B1, P7, P6, P17,
☒ Other **(28%)**: **B5, B6, B7, B11, P13, P14** - CAFTA **B9, P15** - NUPRA **B8, B10** - Riskman **P3** - CDF is calculated with SAPHIRE and the risk curves (instantaneous risk and cumulative risk) done with EXCEL	☒ Other **(30%)**: **P4** - Qualitative for Mode 3 or lower **B5, B6, B7, B8, B9, B10, B11, P13, P14, P15**– No further details **P16 -** Mode 3/4 PSA run in CAFTA, plan to use Safety Monitor	☒ Other **(30%)**: **P2** - Shutdown Safety Assessment (NUMARC 91-06), **P4** - Qualitative for Mode 3 or lower, **P8, P9, P10** - ORAM used for planning. DID sheets used as "official" risk assessment during execution, **P12**- ORAM-Dial CAFTA, **P16 -** DID and Shutdown PSA model, risk level is the higher of either, **B13** – PRAQuant, **P19** – DID, **P20** - EOOS based deterministic DID (not a PRA) **B15** – EOOS model under development **P25** – EOOS model under development
☐ None **(0%)**	☒ None **(20%)** B1, B12 , B15, P20 , P22, P23, P24, P25	☒ None **(8%)** B12, P3, P22 (official assessment done on paper, software used for info only)

For the CRM tools noted above for at-power, transition, and shutdown evaluations, did your plant begin using these tools prior to the time that (a)(4) took effect?

At-Power Tool:	☒ Used prior to 2000 **(85%)** B1, P7, P6, P5, P8, P9, P10, B2, B3, B4, P12, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, P16, B12, B13, P18, P19, P21, P22, P3, P23, B14, B15, P24, P25	☒ Used since (a)(4) took effect **(15%)** P1, P2, P4, P11, P17 , P20,
Transition Tool:	☒ Used prior to 2000 **(55%)** P1, P7, P6, P8, P9, P10, P11, B3, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, P18, P19, P21, B14	☒ Used since (a)(4) took effect **(20%)** P2, B2, P11, P12, P16, P17, B13, P5
Shutdown Tool:	☒ Used prior to 2000 **(83%)** P1, P2, P7, P6, P5, P8, P9, P10, B2, P11, B3, B4, P12, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, P16, B13, P18, P19, P21, P23, B14, B15, P24, P25	☒ Used since (a)(4) took effect **(5%)** P17, P20,

Characterization of At-Power "Risk Zones"

1. Does your plant use "risk colors" or "risk zones" to communicate configuration risk? If so, what type of color/zone classification does your plant use?

   ☐ N/A - Colors/Zones are not used **(0%)**

   ☐ 2 colors/zones are used (a "go/no go" approach) **(0%)**

   ☒ 3 colors/zones are used (such as "green, yellow, and red") **(13%)**
   P2, B1, P21, P22, P3

   ☒ 4 colors/zones are used (such as "green, yellow, orange, and red") **(87%)**
   P1, P4, P7, P6, P5, P8, P9, P10, B2, P11, B3, B4, P12, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, P16, B12, P17, B13, P18, P19, P20, P23, B14, B15, P24, P25

   ☐ Other **(0%)**

2. If different risk communication systems are used for at-power than those used for shutdown conditions, please describe those systems here:

P1 - Information is provided to the plant population by bulletin board postings and e-mail communications. Risk status is provided on report headings for daily status information and other items.
P2 - Shutdown Safety Assessment (NUMARC 91-06 defense-in-depth) is used to assess plant risk during plant shutdown conditions - 3 color system
P5 - At-power risk is quantified using PRA, shutdown risk is measured in terms in defense-in-depth.
P12- At-power EOOS used by schedulers daily, and Operations as needed for emergent conditions. Shutdown risk assessment used by outage scheduler; shutdown operations protection plan used during outage (not directly risk-based).
P16 - The basic tools are the same or very similar, the frequency changes. While shutdown, a risk evaluation is made at least every day and sometimes multiple times a day. When operating as long as the "weekly risk summary" is valid, no new paper is generated. Any unscheduled activities that change risk level are communicated when it is known.
B13 - Schedulers use EOOS online, and PRA group uses PRAQuant for outages
P19 - Defense-In-Depth Sheets prepared for the outage and updated as necessary
P20 - Same "system" (EOOS) is used but shutdown EOOS is not quantitative and is not the a(4) basis
P21 – ORAM uses 4 colors for shutdown
P22 - Safety Monitor (with three colors/zones) and a checksheet completed by work planners used for at-power. For shutdown and transition modes, a DID type procedure (which assesses plant as a level 1=normal, 2=moderate, 3=high risk, where the levels do not correspond to the quantitative risk thresholds) is the risk tool of record backed up by Safety Monitor.
P3 - At power use 3 risk colors (based on PSA). During Outage use 4 risk colors (deterministic approach based on INPO 92-005 - Shutdown Safety).
B14 - At power is 4 color with breaks based on ICDP in 7 days. Shutdown uses Procedure-based rules based on Defense in Depth, incorporated in EOOS

3. If you use a multiple-color risk category system, briefly describe what each zone "means", in terms of your plant's operating philosophy:

☐ N/A – Risk colors/zones are not used (skip to the next question) **(0%)**

Risk Zone	**Meaning of this Zone**
Highest risk zone (for example, "Red")	**P1 -** Unacceptable without further review and approval. Evaluate to determine if plant configuration can be revised to reduce or eliminate the Red risk significance. Risk significant configurations are not entered voluntarily. **P2** - Key Safety Functions severely threatened. Immediate actions required to restore acceptable plant risk. Planned entry not allowed without P2 Plant Manager approval. **P4** - Very limited maint activities lead to RED **B1 -** Should not be entered voluntarily. If it cannot be avoided, minimize exposure time and establish compensatory measures. **P5** - Cannot be entered voluntarily. **P7, P6 -** Should be avoided. Near-continuous management updates **P8, P9, P10** - Key safety function is immediately and directly

Risk Zone	Meaning of this Zone
	threatened. Not normally allowed and will not be scheduled without PORC approval and a written risk management plan. If plant is unexpectedly placed into red, immediate remedial action required to return plant to lower risk configuration. If due to emergent conditions, Operations shall ensure a PIP is written to evaluate the conditions. Restoration of equipment should not be delayed due to conducting the risk assessment. **B2** - Unacceptable risk; should not be entered voluntarily. Duty Plant Manager notification is required upon entering from emergent activities. Specific actions considered **P11, B3** - Never entered into voluntarily **B4** - Risk significant, do not enter voluntarily. **P12** - Unacceptably high risk, no voluntary entry **B5, B6, B7, B8, B9, B10, B11, P13, P14, P15**– Unacceptable to voluntarily enter, if emergent condition causes unplanned entry immediate actions taken to restore/protect SSCs used to mitigate events, contact station duty manager for direction. **P16 -** Never plan to enter, but there are conditions that could result in its use. Requires highest approval (VP) and must consider a plant shutdown. Requires all actions of Yellow and Orange plus other such as significant management involvement and oversight required, and contigency plans and briefs. Absolute minium of time in condition. **B12** >=1.0E-3 CDF/rc-yr **P17 -** CDF > 1.0E-03/yr **B13** - avoid, if possible, and get out of it as soon as possible if entered **P18** - No voluntary entry. Risk Management review required for entry. **P19** - Should not be entered voluntarily, "Shall" Implement Risk Management Actions (NUMARC 93-01), Complete planned work within calculated ACT **P20 -** Plant Safety Review Committee is required before entering this risk zone, at power. **P21** - Relatively high level of risk, not normally entered voluntarily, but can be entered with company executive management approval. Actions may include deferring the work until plant conditions are more favorable or compensatory measures. Time spent in these plant conditions is minimized. **P22** - Generally not entered voluntarily. Can be entered voluntarily if absolutely necessary with approval of plant management and evaluation of possible compensatory actions. **P3** - This zone should never be entered voluntarily. **P23** - Very high risk, would not be entered voluntarily **B14** - Red Risk Management Actions (High Risk Activities) High-risk activities may be scheduled provided Plant General Manager's concurrence is obtained, however, these activities are not normally scheduled online. Plant General Manager (or his designee) shall approve scheduled on-line maintenance

Risk Zone	Meaning of this Zone
	that presents a risk to the plant that falls into this category. **B15, P24, P25** - Highly risk significant; reschedule work, other activities or shift in-service trains to reduce RAW. Nuclear Plant General Manager Approval required to authorize work.
Next lowest risk zone (for example, "Orange")	**P1** - Risk to nuclear safety or likelihood of plant transient/trip is significant. Entry requires Operations Director approval and appropriate contingency plan. **P4** - limited to 36 hours per week **P5 -** Need a signed contingency plan to minimize risk. ACT (ICDP>1E-06) cannot be exceeded. **P7, P6 –** Should be avoided when possible and minimized otherwise. Contigency actions may be appropriate. Management updates once per shift **P8, P9, P10** - Key safety function is in a degraded condition, and steps shall be taken to manage this condition. When entering, must have a written Risk Management Plan overseen by the Work Control organization. **B2** - Duty Plant Manager approval for voluntary entry, or notification upon emergent entry. Specific actions considered. **P11, B3** - Requires approval of the Station Management **B4** - Potentially risk significant, contingency plans needed. **P12** - High risk, requiring Duty Plant Manager approval for voluntary entry, or notification upon entry into emergent activities. Written guidance/contingency plans prior to voluntarily entering this condition **B5, B6, B7, B8, B9, B10, B11, P13, P14, P15**- Requires prior senior management review/approval. Compensatory measures to reduce risk (limiting unavailability time and establishing contingency plans for restoration/ protection of SSCs). IF an emergent condition causes unplanned entry notify station duty manager. **P16 –** Requires Plant Manager approval. Normally once or twice a year. All actions on Yellow plus significant planning and contingency plans required, worked around the clock until complete. Duration of time established and measured against. Unplanned entry into Orange have a series of actions to exit as soon as possible. **B12** >=10x No-Maintenance CDF < 1.0E-3 **P17 -** baseline CDF + [1.0E-05]*365/7 **B13** - Allowed, but compensatory actions should be considered by operations **P18** - Voluntary entry with Plant Management approval only. Risk Management review required for entry. **P19** – "Should" implement risk management Actions, Complete planned work within calculated ACT **P20 -** Plant Manager Approval is required before entering this risk zone, at power. **P21** - Relatively moderate level of risk, can enter voluntarily but upper management approval is required. Actions may

Risk Zone	**Meaning of this Zone**
	include deferring the work until plant conditions are more favorable or compensatory measures to reduce the level of risk. Time spent in these plant conditions is minimized. **P23** - High risk, require plant manager approval to schedule activities that would create this condition **B14** - Orange Risk Management Actions (Additional Controls) **P24** - Medium risk or Degraded condition. Operations Shift Superintendent and Operations Manager (Emerg. Dir.) concurrence required to authorize work. **B15, P25** - Medium risk or Degraded condition. Operations Manager or Plant Operations Assistant General Manager approval required.
Next lowest risk zone (for example, "Yellow")	**P1** – Risk to nuclear safety or likelihood of plant transient/trip is increased. At the discretion of the Operations Shift Manager, contingency actions may be specified. Risk management actions should be considered. **P2** - Key Safety Functions degraded and steps should be taken to minimize the amount of time in this condition. Contingency Plans are required prior to planned entry. Results due to entry into a TS LCO that requires immediate actions to maintain Key Safety Function, or entry into a plant and equipment availability condition that does not support the 'N+1' defense-in-depth criteria. **P4** - linited to 72 hours per train per week **B1 –** Entry in to this zone is acceptable with compensatory measures when applicable. **P5 -** Heightened risk awareness. ACT (ICDP>1E-06) cannot be exceeded. **P7, P6 –** Limited preplanning to minimize duration Operations shift awareness **P8, P9, P10** - Reduced safety condition. Risk management actions focus on providing increased risk awareness. **B2** - Acceptable risk. Measures taken to ensure subsequent maintenance activities do not increase risk . **P11, B3** - Normal maintenance with heightened awareness to special configurations **B4** - Acceptable risk increase, increase awareness of maintenance advised **P12** - Medium risk, requiring only Shift Manager approval. Measures should be taken to ensure that subsequent maintenance activities do not increase risk. The length of time spent in a yellow condition should be minimized. **B5, B6, B7, B8, B9, B10, B11, P13, P14, P15**- Limit the unavailability time or take compensatory measures to reduce plant risk. **P16 –**Frequently used, many of the Tech Spec equipment with 72 hour action statements result in Yellow Risk. Planning required and minimize time, verification of redunent train or equipment that performs the same safety function.

Risk Zone	**Meaning of this Zone**
	B12 >=2x No-Maintenance CDF <10x **P17 -** baseline CDF + [1.0E-06]*365/7 **B13** - Operations informed of condition and should exercise a heightened level of risk awareness. **P18 -** OK. Risk Management consideration required. **P19** – Complete planned work within calculated ACT, Normal work controls apply **P20 –** Operations Manager Approval is required before entering this risk zone, at power. **P21** - Relatively low level of risk. Can be entered voluntarily but management approval is required and appropriate compensatory measures must be applied. Time spent in these plant conditions is minimized. **P22** - Plant awareness of higher than normal plant risk configuration. Compensatory actions such as protected train signs, assignment of specific work task project manager and work the task around the clock. **P3** - Higher risk condition, but tolerable. Not planned to stay in this condition for long time. Assess non quantifiable factors. Establish risk management actions. **P23** - Elevated risk, review activities for compensatory actions, increased communications **B14** - Yellow Risk Management Actions (Predefined Controls) **B15 -** Caution or Low risk. Shift Superintendent or Unit Superintendent approval required. **P24** – Caution or Low risk. Shift Superintendent approval required. **P25** - Caution or Low risk. Unit Superintendent approval required.
Lowest risk zone (for example, “Green”)	**P1** - Risk level is acceptable. No contingency plan is required. Normal work controls. **P2** - Key Safety Function is at minimum risk. Plant and equipment availability conditions exceed N+1 criteria. **P4** – unlimited **B1 –** Always acceptable **P5 -** No actions required. ACT (ICDP>1E-06) cannot be exceeded. **P7, P6 –** Low Risk -- requires no action **P8, P9, P10** - Minimum risk. No additional risk assessment actions are required from plant personnel. Normal work controls would be employed. **B2** - Normal work controls are sufficient. **P11, B3** - No/low risk significant activities **B4** - Two times the baseline CDF. **P12** - Minimal risk configuration and requires no additional approvals. Normal work controls are sufficient **B5, B6, B7, B8, B9, B10, B11, P13, P14, P15**– No specific actions. **P16 –** No management actions required and no time

Risk Zone	Meaning of this Zone
	limitations. **B12** <2x No-Maintenance CDF **P17 -** baseline CDF **B13** - Relatively low risk condition **P18** – OK **P19** – Complete planned work within calculated ACT, Normal work controls apply **P20 –** No escalated approval is required **P21** - Low level of risk. Normal risk management measures **P22** - Plant considered in "Low" or "Normal" risk, no specific actions required. **P3 -** It means the plant could operate in this zone forever. Normal work controls. **P23** - Follow normal procedures and practices **B14** - No additional risk management actions are required. Normal work control process requirements are adequate. **B15, P24, P25** - Satisfactory or None. No special actions required.

4. If your plant uses quantitative risk criteria (for example, CDF, LERF, ICDP, etc.) to establish the risk zone/color, …

   a) What types of data are used?

☒ N/A – Quantitative risk criteria are not used **(3%)** B1	☒ Incremental CDP or LERP **(8%)** P4, P5, P23
☒ Instantaneous CDF **(88%)** P1, P2, P7, P6, P5, P8, P9, P10, B2, P11, B3, B4, P12, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, B14, P16, B12, P17, B13, P18, P19, P20, P21, P22, P3, P23	☒ Instantaneous LERF **(33%, 50% plan to)** P1, P2, P7, P6, P5, P18, P19, P20, P21, P22 **B5, B6, P14** –Projected Aggregate Risk Value required to be calculated for ORANGE. **B7, B8, B9, B10, B11, P13, P15**-Being added to determine risk color
☒ CDP over a unit of time **(5%)** B12, P3	☐ LERP over a unit of time **(0%)**
☒ Incremental CDP over a unit of time **(13%)** P17, B14, B15, P24, P25	☐ Incremental LERP over a unit of time **(0%)** B15, P24, P25
☐ Other: **(3%)** **B14** - Blended with deterministic reviews for non PRA (Level 1) elements	

b) Are the quantitative criteria used in conjunction with other criteria (a blended approach) or are qualitative criteria used exclusively? If so, describe.

P1 - Generally for Modes 1-3, we use quantitative criteria. In some instances, we use a blend of quantitative and qualitative means, such as special restrictions or contingencies for planned work that is infrequently done. For Modes 4-6 & defueled we rely on ORAM SFAT logic trees that represent a qualitative defense-in-depth approach.
P2 - PRAER evalaution was performed to factor in not exceeding 1E-6 per week and using the average T&M what our risk threshold should be.
P5 - Quantitative criteria only apply to SSCs modeled in PRA. A defense in depth review is used for SSCs not modeled, but no separate color criteria exists.
P8, P9, P10 - For online, quantitative criteria are used in conjunction with other more qualitative criteria (a blended approach). Safety SFATs used to assess various safety functions and the ability to respond or prevent certain transients. Highest results (quantitative or qualitative) are used as the overall plant risk. For shutdown, only the qualitative DID sheet assessment is used.
B2 - Uses blended approach to address Level 2 issues, fire and flooding.
P11, B3 - Work control procedures are in place which are used together with color-coded EOOS assessments
B4 - We stress "blended approach" along with quantitative criteria. Plant experience is very important as a check on the quantitative results.
P12 - A blended approach is used. Qualitative factors (such as industry operating experience, personnel judgment, etc.) must be used for fully assessing the effects of equipment out of service on plant risk. In addition, qualitative Level 2, External Events, and Non-PSA SSC considerations are considered.
B5, B6, B7, B8, B9, B10, B11, P13, P14, P15 – Blended approach with SFATs/PTATs for DID of plant safety functions/systems and of systems to mitigate transients. Overall color set by worst item – SFAT, PTAT, or CDF/LERF
P16 - Process and procedures allow use of qualitative criteria, but difficult to use due to different "subjective" opinion for various SRO on shift at a time.
B12 - A blended approach can be used when appropriate, for example, activities (scaffolding, hoses, electrical cords, etc.) in place <=90 days in support of maintenance. This qualitative input is considered with the quantified core damage frequency. Additionally, the risk increase assessed by transmission yard work is a quantitative increase imposed due to a qualitative input.
P17 - On occasion, depending on the test or activity, there may be a blend of quantitative and qualitative.
B13 - Generally, risk levels are strictly quantitative, but operations may need to qualitatively assess conditions if PRA support is unavailable, and they always have the option of declaring risk higher than the risk model identifies.
P19 - Quantitative criteria only.
P20 - as described in an Operations Administrative Procedure (OAP102.1)
P21 - A blended appoach is used. Qualitative considerations include barrior impairments, degraded equipment, EQ, fire, flood, grid conditions, etc.
P22 - Quantitative criteria are used in conjunction with a risk evaluation procudure checklist which considers Defense-In-Depth and commercial risk.
P3 - use a blended approach.
P23 - Yes, there are other plant conditions beyond EOOS which can cause risk levels above green (such as personnel or security issues). Also, the operations group has the ultimate responsibility and authority to set risk as appropriate based on input from EOOS and any other valid sources.
B14 - Blended with deterministic reviews for non PRA (Level 1) elements using a Risk Assessment Work Sheet.

B15, P24, P25 - Quantitative criteria and qualitative considerations are used as inputs to a blended approach to risk management.

5. How is the "baseline risk" defined for your plant (that is, the risk level that is used as a basis for comparison of each configuration-specific risk level)?

☐ N/A – Quantitative risk measures are not used **(0%)**

☒ The CDF (or LERF) calculated by the PSA (assuming average maintenance unavailabilities) **(8%)**
P2, B1, P22

☒ The CDF (or LERF) calculated based upon no plant equipment out of service **(92%)**
P1, P4, P7, P6, P5, P8, P9, P10, B2, P11, B3, B4, P12, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, P16, B12, P17, B13, P18, P19, P20, P21, P3, P23, B14, B15, P24, P25

☐ Other **(0%)**:

6. If your plant uses quantitative instantaneous risk measures, what is the basis for setting the risk zone thresholds?

☐ N/A – Instantaneous risk measures are not used **(0%)**

☒ Multiples of the baseline risk value (for example, 2X risk, 5X risk, 10X risk, etc.) **(48%)**
P2, B1, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, P16, B12, P17, B13, P18, P20, P22

☒ Fixed risk values (for example, based on Reg Guide or EPRI PSA Applications Guide values) **(15%)**
P4 - not to exceed 1E-06 CDP, P7, P6, P5, B12, P3

☒ Other **(70%)**:
P1 - For Modes 1-3 use the NUMARC 93-01 recommended 1E-6 CDP/ 1E-7 LERP expended over a 72 hour (P1 TS limiting AOT) time frame, and added to the base instantaneous risk value, to determine our green-to-yellow CDF/LERF instantaneous threshold values. Provides an instantaneous risk level, above the no maintenance baseline, that corresponds to expending the NUMARC CDP and LERP over the current allowed outage time. For yellow-to-orange use 5 times the NUMARC recommended values (for example, 5E-6 & 5E-7) in the same manner. Orange-to-red threshold is NUMARC recommended 1E-3/yr for any configuration specific CDF (1E-4 /yr for LERF).
P8, P9, P10 – Combination of fixed thresholds and multiples
B2 -

Green	>9.48 – 10	Minimum Risk	Lower bound is double the zero maintenance model
Yellow	>7.32 – 9.47	Acceptable Risk	Lower bound is worst single train out of service (SSW C)
Orange	>5.31 - 7.31	Potentially Risk Significant	Lower bound is 1E-03
Red	0.0 – 5.3	Risk Significant	Upper bound is 1E-03

P11 - Green-to-Yellow threshold ≤ 1E-6 assuming configuration exists for one full week. Yellow-to-Orange threshold ≤ 1E-6 assuming configuration exists for 24 hours. Orange-to-Red threshold is based on EPRI PSA Applications Guide value 1E-3.
B3 - Based on the color code definitions of major risk-significant component combinations taken out of service. Values are set relative to each plant.

B4 - Green to Yellow: 2 x baseline Yellow to Orange: One train of standby SW (SWP train A) OOS Orange to Red: SWP train A and EDG B OOS

P12 - COLOR RISK CDF BREAK POINT SETTING

COLOR	RISK	CDF BREAK POINT SETTING
GREEN	Low	ICDF < 2 x Zero Maintenance Risk
YELLOW	Medium	ICDF <= Most Risk Significant Component Unavailable
ORANGE	High	ICDF < 1E-3
RED	Unacceptable	ICDF > 1E-3

B5, B6, B7, B8, B9, B10, B11, P13, P14, P15- In addition to Orange < 20X baseline, 1e-4/yr (BWR) or 1e-3/yr (PWR) instantaneous risk not exceeded

P16, B12 - Red is set at 1.0E-3

P19 - Green/yellow: Consistent with P19's Safety Goal (8E-5); Yellow/Orange: 1/2 of NUMARC 93-01 Guidance (0.5 * 1E-3 = 5E-4); Orange/Red: NUMARC 93-01 value for instantaneous CDF (1E-3)

P21 - Combination of multiplication factors (applied to the average T&M model), risk values (based on AOT times) and most risk significant SSCs to ensure conservative threshhold values.

P23 - NEI-93-01 (mrule) guidelines are used

B14 - Green: Baseline to EOOS CDF value that is 7days to ICDP E-6
Yellow: Upper Green limit up to the EOOS CDF value that is 7days to ICDP E-5
Orange: Upper Yellow limit to <1E-3 CDF
Red: >1E-3 CDF or an ICDP between >1E-6 and <1E-5
An ICDP of >1E-5 should not normally be entered voluntarily.

B15, P24, P25 - For each risk zone threshold (color transition), incremental CDF (ICDF) and incremental LERF (ILERF) were added to the baseline CDF and LERF, based on a four-day duration. The CDF and LERF increments are derived from incremental CDP (ICDP) transitions set at 1E-6 for green/yellow, 5E-6 for yellow/orange and 1E-5 for orange/red.

What are the specific quantitative thresholds that are used (please provide the actual baseline values and threshold values) and their bases (please describe how the thresholds were determined)?

Plant	**CDF**				**LERF**			
	Base	**Yellow**	**Orange**	**Red**	**Base**	**Yellow**	**Orange**	**Red**
B1 (U1)	2.57e-5	5.1e-5 (2x)	n/a	2.51e-4 (10x)				
B1 (U2)	5.4e-5	1.1e-4 (2x)	n/a	5.4e-4 (10x)				
B2	2.18e-6	4.36e-6 (2x)	7.27e-5	1e-3				
B3	1.36e-6	6.30e-6	4.41e-5	1e-4				
B4	3.52e-6	7.04e-6 (2x)	1.34e-4	7.91e-4				
B5		2x	10x	20x or 1e-3		2x	10x	20x or 1e-4
B6		2x	10x	20x or 1e-4		2x	10x	20x or 1e-4
B7		2x	10x	20x or 1e-4		2x	10x	20x or 1e-4
B8		2x	10x	20x or 1e-4				
B9		2x	10x	20x or 1e-4				
B10		2x	10x	20x or 1e-4				
B11		2x	10x	20x or 1e-4				
B12		2x	10x	1e-3				

Plant	CDF				LERF			
	Base	Yellow	Orange	Red	Base	Yellow	Orange	Red
B13	4.37e-5	5.59e-5 (2x)	1.53e-4 (10x)	2.74e-4 (20x)				
B14		7.98e-5	5.49e-4	1e-3				
P1 (U1)	3.87e-5	1.6e-4	6.47e-4	1e-3	4.35e-6	1.65e-5	6.51e-5	1e-4
P1 (U2)	3.81e-5	1.6e-4	6.47e-4	1e-3	4.32e-6	1.65e-5	6.51e-5	1e-4
P2		2x	n/a	10x				
P3	2.7e-5	1.0e-4	n/a	5.0e-4				
P5		2e-4	4e-4	1e-3				
P6	8.79e-6	6.09e-5	1.30e-4	3.74e-4				
P7	2.11e-5	7.32e-5	1.43e-4	3.86e-4				
P8	3.55e-5	7.1e-5 (2x)	2.5e-4	1.0e-3				
P9	2.81e-5	5.62e-5 (2x)	2.5e-4	1.0e-3				
P10	4.03e-5	8.06e-5 (2x)	2.5e-4	1.0e-3				
P11	1.94e-5	5.2e-5	3.6e-4	1e-3				
P12	5.28e-6	1.06e-5 (2x)	1.99e-5	1e-3				
P13		2x	10x	20x or 1e-3				
P14		2x	10x	20x or 1e-3		2x	10x	20x or 1e-4
P15		2x	10x	20x or 1e-3				
P16		2x	10x	1e-3				
P17	2.44e-5	7.65e-5	5.46e-4	1e-3				
P18		3x	10x	30x or 1e-3				
P19	2.71E-5	8e-5	5e-4	1e-3				
P20	3.7e-5	1.0e-4	4.0e-4	1.1e-3	3.7e-7	1.0e-5	3.7e-5	1.1e-4
P21	4e-6 to 7e-6	3e-5	n/a	1.69e-4				
P22	5.5e-5	1.0e-4 (2x)	n/a	5.5e-4 (10x)				
P23				1e-3				

P2 - Yellow=2X baseline, red=10X baseline. PRAER evalaution was performed to factor in not exceeding 1E-6 per week and using the average T&M what our risk threshold should be.
B1 – Yellow=2X baseline, red=10X baseline
P5 - The P5 criteria is applicable to both operating units, one CE unit and one W unit. The criteria was developed prior to the (a)(4) rule based on operating experience at the time.
P6, P7 - See the paper "Probabilistic Risk Assessment in Support of On-Line Maintenance at Virginia Power", presented at PSA `99
P8, P9, P10 - Green upper limit/yellow lower limit is set at a factor of 2 above the zero-maintenance calculation. Because systems with a low impact on CDF have a multiplier of less than 2 on the base CDF. Guidance from PSA Applications Guide that if the incremental CDP exceeds 1.0E-06, then non-quantifiable factors should be considered. Practice of limiting maintenance to 50% or less of a LCO is used to establish the yellow/orange transition point. Many of the systems important to risk have an LCO of 72 hours. Therefore maintenance will normally be limited to approximately 36 hours or less. The plant could operate at an annualized incremental CDF of 2.4E-04/yr for 36 hours and not exceed the 1.0E-06 threshold. RED lower

limit is set at 1E-3/year, based on the PSA Applications Guide recommendation that no single activity should exceed 1E-3/year for instantaneous CDF.
B5, B6, B7, B8, B9, B10, B11, P13, P14, P15 - Green is < 2, Yellow < 10, Orange < 20. Based on industry survey, consideration of the effect on model fidelity when risk increases, and comparison to NEI 93-01 Integrated Core Damage Probability assuming plant remains in ORANGE condition for no more ~ 50% of a week
P17 - As described above (question #3). Routinely update model and depending on the baseline value, transition from green to yellow could be anywhere from 2x to 3x baseline risk. Similarly, the yellow to orange transition moves around also.
B13 – 2X, 10X,20X baseline without single event cutsets
P20 - Thresholds chosen by time to achieve CCDP of 1E-6 in <72 hours (yellow), <24 hours (orange) or <8 hours (red). Yellow threshold was then lowered to 1E-4 arbitrary margin vs. 1.6E-4 which would occur with the method above.
P3 – Red instantaneous threshold is the midpoint between the NRC non official value and the EPRI PSA Applications Guide (1.0E-03/y) (understand the value 1.0E-03/y as described in NUMARC 93-01 Section 11.3.7.2 is high to be used in planned maintenance).
Weekly Cumulative Thresholds for CDP, Yellow: 1.9E-06 (Based on the yellow CDF threshold =1.0E-04/52). Red: 3.9E-06 (calculated as 1/2{2.0E-06 + [(5.0E-04/52 X 0.6]} where 2.0E-06 is mentioned in EPRI 1000893.
Planned maintenance goal = 1.2E-06 (calculated assuming a 0.6 limitation factor on the yellow CDF threshold to account for uncontrolled contribution of unplanned maintenance = 0.6 x 1.0E-04 / 52)
P23 - Red = ICDF>10-3
Orange = ICDF which would create ICDP of 10-6 in 36 hours (1/2 typical LCO)
Yellow = ICDF which would create ICDP of 10-6 in 7 days (1 scheduled week)

7. If your plant uses quantitative cumulative, time averages, or configuration duration measures, what is the basis for setting the risk zone thresholds?

☒ N/A – Cumulative, time average, or duration measures are not used **(55%)**
P1, B1, P7, P6, P8, P9, P10, B2, P12, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, P18, P19, P23

☒ Cumulative risk accrued over a moving time period (for example, day, week, quarter) **(18%)**
P2, P3, P4, P11, B4, B14, P17 - Risk plots are normally issued for 1 week increments,

☒ Cumulative risk expected to be accrued during each planned configuration change **(3%)**
P22

☒ Other **(48%)**:
P5 - The ACT is calculated using Section 11 guidance of ICDP=1E-06. No color is applied to specific ACT values.
B5, B6, B7, B8, B9, B10, B11, P13, P14, P15 - Projected Aggregate Risk Value is calculated for ORANGE (rolling 12-month average based on actual and planned plant configurations)
B12 - The Desk Guide that governs the on-line risk assessment program provides the time required to exceed an aggregrate of 1.0E-6 ICCDP, for our maximum instantaneous risk plant configuration. Since it would take more than 7 days to exceed 1.0E-6 we do not calculate the ICCDP unless the configuration is scheduled for more than 7 days.
B13 - Durations are only used for SDP evaluations, not online or outage risk.
P20 - thresholds are based on time.
P22 - Cumulative risk accrued over each plant fuel cycle.

B14 - Duration until the restoration of long standing OOS equipment, for any ICDP analysis.
B15, P24, P25 - The threshold transitions are calculated based on the transition ICDP thresholds integrated over a four day period. This four day period was chosen as a duration that would effectively bound configurations that exist for several days, but not so long as to warrant consideration as permanent changes.

Do you have an “annual risk target” for cumulative risk (please describe):

No – P1, B1, P5, B3, B4, P17, B13, P21, P22, P3, B15, P24, P25
P2 - Report the integrated monthly risk to plant management on a monthly basis. Our goal is to maintain plant risk at our IPE CDF value.
P8, P9, P10 - Although not part of the CRM software, we do have goals associated with cumulative CDF that are monitored on a monthly basis. Green (meet/exceed expectations) – less than the average PRA CDF adjusted for unusual maintenance events (for example, one time large projects). Yellow (needs improvement) – Green + 20%. Red (does not meet expectations) – < 1.0E-04
P11 - Cumulative risk (that is, annual CDF) is managed by limiting the weekly increase in CDP based on Table 4-1 of EPRI PSA Applications Guide. Annual risk target is that baseline CDF (which includes nominal maintenance) should not increase by more than 18%. This allowable CDF is compared to the zero-maintenance CDF, and a target weekly increase in CDP is then calculated (3.4E-7).
B5, B6, B7, B8, B9, B10, B11, P13, P14, P15 - Quarterly CDF trending is done and aggregate risk compared against EPRI PSA Applications Guide criteria for permanent plant changes.
P16 – Target is 90% of the risk that will be accumulated due to planned maintenance. The planned accumulated risk is the calculated risk level due to all the PMs, known maintenance and testing.
B12 - An assessment is performed that considers the average daily risk over the planned operation for the calender year. The CDP associated with the major risk significant on-line system outages are then added to the total. This overall CDP is designated as the projection (target) for the year
P19 – 8e-5
P20 - Not as such, but data updates (to date) have shown that equipment unavailability to date has not increased CDF in the base model from what is assumed.
P23 - EPRI PRA applications guide is compared with cycle actuals.
B14 - No, but track the measure quarterly with reports.

8. If your plant uses “peak instantaneous risk” as a measure to determine the risk color, how is the expected or actual duration of a risk increase considered when making risk management decisions?

☒ N/A – Peak risk is not used **(10%)**
B4, B15, P24, P25

☒ An allowable time for the risk increase is calculated based on a CDP or LERP limit **(15%)**
P4, B1, P7, P6, B13, P19

☒ Cumulative risk is maintained below a fixed limit for a specified time period (for example, a week, a calendar quarter, etc.) **(13%)**
P2, P11, P16, B12, P3

☒ Peak risk is used in conjunction with a cumulative measure **(18%)**
P2, P5, P17, P18, P22, P23, B14

☒ Other **(50%)**:

P1 - 72 hour LCO time frame is used in conjunction with NEI guidance for ICDP/ILERP to calibrate the instantaneous CDF/LERF thresholds. Also instances where used ICCDP/ICLERP in conjuction with special Technical Specification allowances for extended outage times.
P8, P9, P10 - Duration was considered when the color thresholds were developed (see question #6).
B5, B6, B7, B8, B9, B10, B11, P13, P14, P15 - Projected Aggregate Risk Value calculated for ORANGE. Duration of higher risk configurations minimized by procedural controls.
P16 – TS Action Statements limit most of the equipment that results in a higher risk. A bounding calculation shows that if durations are limited to the tech spec time then 1E-6 CDP will not be exceeded. This helped establish the instantanous risk colors. Almost all equipment that could result in an Orange risk level is limited by a 72 Hour Tech Spec limit, and risk management actions require a planned Orange risk level to not exceed approximately 1/2 of the Tech Spec allowed outage time or 36 hours. A similar calculation was done for Yellow using the 30 day Tech Spec allowed outage time.
B12 - Accrued risk is monitored. Performance factors are based on monitoring the accrued risk below a pre-defined acceptance criteria.
P20 - While instantaneous is used, time is the basis for the color. No criteria is applied beyond the color however times in elevated colors are minimal. A green item could stay there for long periods of time which would attract attention in itself.
P21 - Work is not scheduled beyond 50% of Tech Spec AOT. Risk management guidelines dictate minimizing the time in yellow or red by working around the clock, etc.
B2 - Not specifically addressed.
P12 - Duration is not considered. CDP (CDF x duration) is very hard to calculate for changing maintenance configurations, and the guidance is inadequate.

9. What is the scope of your quantitative CRM model? (Check all that apply)

☐ N/A – quantitative models are not used **(0%)**	
☒ Internal Events CDF **(100%)** P1, P2, P4, B1, P7, P6, P5, P8, P9, P10, B2, P11, B3, B4, P12, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, P16, B12, P17, B13, P18, P19, P20, P21, P22, P3, P23, P24, P25, B14, B15	☐ LERF (internal events only) **(0%)**
☒ Internal Flooding CDF **(55%)** B1, P7, P6, P8, P9, P10, P11, B3, P13, P14, B6, B8, B9, B10, B11, P16, P17, B13, P18, P19, P23, B14	☒ LERF (same scope as CDF model) **(45%)** P1, P2, P4, B1, P7, P6, P5, P13, P14, P15, B6, B8, B9, B10, P16, P17, P18, P19
☒ Internal Fires CDF **(18%)** P4, B1, P8, P9, P10, P18, P19	

☒ Seismic CDF **(5%)** B1, P19	
☒ Other external events CDF **(13%)** P2, B1, P8, P9, P10	
☒ Other **(13%)**: **P1 -** Online Risk program (Modes 1-3) utilizes a quantitative approach, mixed with expert judgement; **P16 -** No description provided **P18** - Seismic, SSEL block (not CDF), SFP Cooling; **P19 -** No seismic or fire initiators included for shutdown risk **B14** - Limited Level 1 used in Work Management, but a Level 2 is used in modification design by PSA group	

10. NUMARC 93-01 does not require that quantitative CRM evaluations consider the risks from non-internal events. However, if the quantitative model does not evaluate other events that may be risk contributors for your plant (fire, flood, external events, etc), was the absence of quantitative consideration of the other events considered in the establishment of the risk color/zone thresholds discussed in the questions above?

☒ N/A – The model considers all risk-important events other than internal events **(5%)**
P18, P19

☒ No **(80%)**
P2, B1, P7, P6, P5, P8, P9, P10, B2, P11, B3, P12, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, B12, B13, P20, P21, P22, P3, P23, P24, P25, B15

☒ Yes. Please describe how other events were considered when establishing risk zone thresholds **(18%)**:
P1 - Vulnerability due to events that challenge our normal condenser cooling capability and ultimate heat sink due to fish, ice, or general debris, intrusion and have the capability to adjust event initiators based on assessement of lake/intake conditions utilizing an "environmental" factor that increases the frequency for transients. These were not considered in establishing the threshold, but are dealt with using judgment in the schedule review process and in day-to-day assessments. Have similar environmental factors for severe weather, fires near power lines, and grid loading, as well as general factors for RPS/SSPS or BOP testing.
P4 – Fire CDF only
B4 - Internal floods, seismic snubber OOS, severe weather or external flooding, and Level 2 are qualitatively evaluated.
P12 – Have qualitative guidance for assessing non-level 1 internal event risk.
P16 - External Flooding, Fire and HELB, Seismic Tornado are controlled using established programs and a "bounding" PSA calc. was done to encompass all routine maintenance activities. If the duration of maintenance that compromises the barriers or Fire systems (suppression, detection) are longer than 72 hours a separate risk evaluation is required, which may or may not be a formal quantitative evaluation.
P17 - When significant work occurs in the substation or with the incoming lines, this is factored into the calculated CDF as an increase in LOSP probability.
B14 – Via checklist for deterministic reviews.

11. Does the removal of any single active component (excluding buses, heat exchangers, etc.) result in a transition to a higher risk color/zone in your quantitative evaluations (under normal plant-operating conditions)?

☐ N/A – risk colors/zones are not used, or quantitative models are not used **(0%)**

☒ No **(18%)**
B1, B15, P7, P13, P14, P24, P25

☒ Yes. Please list the types of components that can result in a risk transition at your plant (and the expected risk "color" that would result): **(82%)**

P1 - Bus Undervoltage/Underfrequency Relays cause a "Red"
P2 - Major risk significant SSCs, that is, Turbine driven AFW pump, Component Cooling Water train, RHR pump, etc.
P4 – AFW pumps
P5 - Unit 2 - HPSI train / support system, motor-driven AFW pump will cause a yellow. Unit 3 - No transitions.
P6 – TDAFP changes to yellow
P8 - Orange - service water train; Yellow - Diesel, EFW TDP, Backup Seal Cooling
P9 - Orange - service water train; Yellow - Diesel, EFW TDP, Backup Seal Cooling
P10 - Orange - service water train; Yellow - Diesel, EFW TDP, Backup Seal Cooling
B2 - LPCI A or C pump; HPCS pump; RCIC; Standby Service Water Pump A, B, or C; DG A, B or C; CRD pump A or B. (all yellow)
P11 – AFW, EDG
B3 – HPCI, ESW
B4 – There are several things that when OOS go from Green to Yellow. Generally these are components that impact a pump like suction or discharge valves.
P12 – One DG OOS, one EFW pump OOS = yellow; one DG OOS + severe thunderstorm warning = orange; one EFW pump OOS + tornado warning = orange
B6 – Red/orange: DC Busses, Heat Exchangers, MOVs that defeat redundant trains. Yellow: HPCI and Isolation Condenser
B11- Red/orange: DC Busses, Heat Exchangers, MOVs that defeat redundant trains. Yellow: 125 Vdc Battery Chargers, Safe Shutdown Make-up Pump)
B7 - Red/orange: DC Busses, Heat Exchangers, MOVs that defeat redundant trains. Yellow: HPCS, LPCS, RHR A/B)
B5 – Red/orange: DC Busses, Heat Exchangers, MOVs that defeat redundant trains. Orange: HPCS, Yellow: RHR B, RCIC TDP)
B8 - Red/orange: DC Busses, Heat Exchangers, MOVs that defeat redundant trains. Yellow: HPCI, RCIC, RHR loop, CREFAS train, 4KV bus, ESW loop)
B10 - Red/orange: DC Busses, Heat Exchangers, MOVs that defeat redundant trains. Yellow: 1 of 2 digital FW controllers, LPCI loop, RCIC, HPCI, Diesel)
P15 - Red/orange: DC Busses, Heat Exchangers, MOVs that defeat redundant trains. Yellow: BAT, HPI train, EFW pump, Nuclear SW pump)
B9 - Red/orange: DC Busses, Heat Exchangers, MOVs that defeat redundant trains. Yellow: Diesel, isolation condenser, RBCCW pump, SW pump
P16 – MDFP, standby CCW pump (both Orange); AFP, spare CCW, HPI Pump, LPI Pump, PORV, Dilution Pump/Backup SW Pump (all Yellow)
B12 - YELLOW Risk:, HPCS or support systems (for example, room cooler, emergency service water pump, AC or DC power, etc.), RCIC, Diesel Driven Fire Pump, MDFP, ECCW Trains (provides cooling to ECCS room coolers), ESW Pumps, Division 1 or 2 DGs, and others.

P17 – EDG goes to yellow
B13 - main transformer, either EDG, CST, raised likelihood of offsite power loss, one train of RHR (HX)
P18 - Diesel Generators, Diesel Fire Pump, SFP Cooling Pump, Relay Room Fire Supression. All are Yellow.
P19 – MDAFP and TDAFP each cause yellow
P20 - Yellow for each of 2 DGs and TDEFP. CCW sometimes goes yellow based on the alignment of equipment. Tests that make the equipment non-functional is treated as the component unavailable.
P21 – EDG, TDAFP are yellow
P22 - Emergency Diesel Generators, Essential Service Water Pumps, Auxiliary Feedwater Pumps, RHR Pumps go to yellow
P3 - Auxiliary Feedwater Pump, Residual Heat Removal Pump, Positive Displacement Charging Pump go to yellow
P23 - components that disable system trains, such as major ECCS pumps
B14 – Red: service water valve, A/B battery, A/B charger, transformer (2), buses (13), breaker. Yellow: battery, charger, transformer (2)

12. If your plant uses [at-power] qualitative models (either exclusively or in conjunction with quantitative models), what safety functions are evaluated by the CRM tool? (Check all that apply)

☒ N/A – Qualitative models are not used [at-power] **(33%)**
P1, P2, P4, B1, P6, P7, P5, P11, B4, P16, B13, P19, P21

☒ Decay Heat Removal **(48%)**
B5, B6, B7, B8, B9, B10, P8, P9, P10, P13, P14, P15, P18, P22, P23, B14, B15, P24, P25

☒ Inventory Control **(48%)**
B5, B6, B7, B8, B9, B10, P8, P9, P10, P13, P14, P15, P18, P22, P23, B14, B15, P24, P25

☒ Status of Key Support Systems, such as Electric Power and Component Cooling Water **(53%)**
B5, B6, B7, B8, B9, B10, P8, P9, P10, P13, P14, P15, B12, P18, P20, P22, P23, B14, B15, P24, P25

☒ Containment Integrity **(50%)**
B5, B6, B7, B8, B9, B10, P8, P9, P10, P13, P14, P15, B2, P18, P22, P23, B14, B15, P24, P25

☒ Reactivity Control **(50%)**
B5, B6, B7, B8, B9, B10, P8, P9, P10, P13, P14, P15, P18, P20, P22, P23, B14, B15, P24, P25

☒ Quantitative CDF/LERF Results (expressed as a "risk color" only) **(30%)**
B5, B6, B7, B8, B9, B10, P8, P9, P10, P13, P14, P15

☒ One or more "overall" functions are provided which express the status of a group of other functions. These functions are ☐ individually weighted / ☐ considered equally
Weighted – B3 **(3%)**
Considered Equally - B5, B6, B7, B8, B9, B10, P8, P9, P10, P13, P14, P15**(30%)**

☒ Other (or comments on above selections) (Please describe):
P1 - Do not have a specific qualitative model, but the assessment of work/ configurations employs consideration/judgement regarding the impact of expected work on risk and safety functions, such as those listed above.
P8, P9, P10 - Other safety functions are considered: RCP Seal Cooling, Secondary Side Heat Removal, RCS Integrity, and Instrument Air (Maintenance Rule EP requirement). Also, a number of PTATs look at interaction of different systems/safety functions: Trip, LOOP, LOCA, Loss of Cooling Water, and Loss of Feedwater/Condenser.
B2, P12 - Qualitative guidance (colors) for various level 2 and external event conditions (at power); for shutdown, we use shutdown operations protecion plan (SOPP, a key safety function/defense in depth approach)
B4 - Items checked are evaluted using Shutdown EOOS model. A quantified number is not generated for these, only a color. The Shutdown EOOS model also provides a quantified risk number.
B5, B6, B7, B8, B9, B10, B11, P13, P14, P15 – PTATs used also.
P17 - Notes are annotated on the quantitative assessment to address any significant qualitative issues.
B13 - Qualitative assessments done manually for all configurations (online and outage)
P18 - Seismic, Fire, External Flooding, Radiation Monitoring
P20 - As described in Operations Admin Procedure (OAP102.1)
P3 - We have followed the qualitative considerations as described in NUMARC 93-01 section 11.3.4.2.
P22 – Safety functions (as well as commercial risk) are evaluated at power by planners/schedulers using a worksheet, in conjunction with the quantitative CRM software tool
P23 - shutdown uses NEI 96-01 key safety function assessments
B14 – procedural rules
B15 - For at-power models, the display maintains a close relationship with maintenance rule functions and includes heat sink, inventory control, containment integrity and reactivity control.
P24 - For at-power models, key support system displays available.
P25 - For at-power models, key support system displays available. However, the quantitative color code result is what is relied upon for risk actions.

13. What is the basis used for defining the "risk color" associated with each safety function? **[These responses reflect qualitative models used for shutdown and at-power conditions, due to wording ambiguities in question #12]**

☒ N/A – Qualitative models are not used **(8%)**
P1, B1, P21

☒ Number of available systems/trains to perform the function (that is, N+2, N+1, N, N-1, etc.) **(65%)**
P2, P4 (Modes 3 – 6), P7, P6, P5, B2, B4, P18, P16, P22, P23, B15, P24, P25
B5, B6, B7, B8, B9, B10, B11, P13, P14, P15 - Green is normal alignment (> N+2), Orange is N, Yellow is between Green and Orange, and Red is safety function not met
P17 - Applies to the shutdown safety assessment and not the Safety Monitor.
B14 - For Oram, the number and capacity of backup methods determines the color grade (judiciously determined by a lead SRO)

☒ Other (or comments on above selections) **(28%)**:
P8, P9, P10 - Prior to the use of ORAM-SENTINEL, the PRA group had developed a risk matrix. The risk matrix along with Tech Specs were used to develop the initial risk colors. (see

details in survey). The risk matrix interactions were based on the significant interactions in the PRA.
P11, B3 - Procedural guidance and operational experience.
P12 - Mostly judgment, some simple bounding calculations. For SOPP, defense in depth (level of redundency) is used to determine color.
B12 - Similar to N+1, a Defense-In-Depth Matrix.
B13 - As sanity check for whether a proposed configuration should be allowed
P19 - No colors used, just DID sheets
P20 - As described in Operations Administrative Procedure (OAP102.1)
P3 - Qualitative considerations are addressed to external events, to SCCs not in the scope or not modeled in the level 1 PSA, where PSA has presented limitations, when the CDF reaches the Yellow risk color

14. Have the risk thresholds/color zone definitions in use at your plant evolved over time? If so, what were the primary reasons for the evolution? (Check all that apply)

☒ N/A – The risk thresholds have not changed significantly since CRM began at the plant **(30%)**
P1, P2, B1, P5, B2, B4, P12, P17, P18, P20, P22, P3

☒ Changes were made as a result of enhancements to CRM models, tools, or data **(25%)**
P7, P6, P8, P9, P10, P11, B3, P21, P23, B14

☒ Changes were made as a result of refinements in management philosophy towards CRM **(25%)**
P4, P8, P9, P10, P11, B3, P21, B15, P24, P25

☒ Changes were made after benchmarking with other sites **(30%)**
P11, B5, B6, B7, B8, B9, B10, B11, P13, P14, P15, B12

☒ Changes were made for other reasons **(15%)**:
P16 - Corporate Common Process.
B13 – Changed from site-specific criteria to cookie cutter values to fall in line with the balance of industry
P19 - Changes to plant safety goal, Safety Monitor Software changes (3 color ranges to 4), NUMARC 93-01
B15, P24, P25 - Changes were made to standardize the approach across the fleet.

Please describe briefly what types of changes have been made:

P7, P6 - Added internal flooding, Bayesian updating, initiator updating, revised common cause failure models
P8, P9, P10 - The yellow/orange threshold used to be a multiple of base CDF. A change to the PRA was implemented that lowered overall CDF. However, the relative difference between the Base CDF and the CDF associated with a diesel out of service increased. At this time, it was decided that a fixed threshold would be more appropriate for the yellow to orange threshold.
B5, B6, B7, B8, B9, B10, B11, P13, P14, P15 - Thresholds were varied among sites. Now consistent across fleet.
P16 - Adjusted risk levels and method to determine acceptable cumulative risk per calender.

B12 - As a result of benchmarking it was discovered most plants use the x2 and x10 transition for risk characterization. It was also identified that most plants use a four color scheme vice a three color scheme for risk categorization.
B13 - Color thresholds formerly based on risk values corresponding to specific configurations (yellow for HPCI or RCIC unavailable, orange for EDG unavailable, red for EDG and HPCI). Now we use 2X, 10X, and 20X.
P20 - changes only with model revisions using the same methodology and the lower yellow threshold desired by operations as described above.
P21 - Thresholds are reestablished when major PRA model updates occur.
Adjusted yellow threshold so that a Diesel Generator out of service would result in a yellow risk category in all standard plant alignments.
B15, P24, P25 - The use of the ICDP and ILERP transitions based on a 4 day period was an effort to standardize the risk threshold methodology. In addition, we standardized the parameter, in this case RAW, to express the quantitative results.

15. If your plant uses both quantitative and qualitative risk measures for at-power CRM, have you correlated the quantitative and qualitative risk color thresholds?

☒ N/A – Both quantitative and qualitative measures are not used **(28%)**
P1, P4, B1, P7, P6, P5, B13, P11, P16, P19, P21

☒ No. The quantitative and qualitative measures have not been correlated **(45%)**
P2, P8, P9, P10, B2, B3, B4, P12, P17, P18, P20, P22, P3, P23, B14, B15, P24, P25

☒ Yes. The measures have been correlated (please provide any comments about the correlation process): **(28%)**
B6, B8 - correlate PTAT results after each update.
B5, B7, B9, B10, B11, P13, P14, P15 - PTAT results generally in agreement with CDF, but no rigorous effort to get a direct correlation. Generally quantitative color is equal to or lower than qualitative
B12 – Responses in other parts of this survey include information and examples on how B12 blends a qualitative (for maintenance activities assessed as temporary alterations to the facility in accordance with 50.59, that is, <=90 days duration) approach with the quantified risk (CDF) for a given plant configuration.

16. Please feel free to provide any additional comments or clarifications about your plant's use of at-power risk colors/zones here:

P1 - Although combined quantitative and qualitative measures are not used, expert or knowledgeable personnel judgment may in some cases be considered for configurations that are expected to arise. These judgments may be used with out any correlation, and generally are conservative with respect to the quantitative results alone. The issue is to assess and manage the risk through controls on the work or related plant configurations, not necessarily to rely on a generated number.
B5, B6, B7, B8, B9, B10, B11, P13, P14, P15 - PTAT risk logic is bumped up one color for High Risk Evolutions associated with that plant transient (example: work in the switchyard bumps up the Loss of Off-Site Power one color)
P16 - We also spend considerable effort on transient initiators and are incorporating risk to generation.
B12 - For risk categories other than Green, additional risk communication measures are employed, such as, the use of e-mail, the marquee, handouts at the protected area entrance, etc.

P21 - An optional risk matrix is available as an option to the Safety Monitor. The risk matrix is conservative and is normally used during the early stages of work schedule development. The risk matrix can also be used when assessing the impact of emergent work activities during off hours.

Program:
Nuclear Power

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