ELECTRIC POWER RESEARCH INSTITUTE

Application of Colors as Risk Metrics - Background and Effective Practices

2018 Configuration Risk Management Forum Research Task

3002012995

Application of Colors as Risk Metrics - Background and Effective Practices

2018 Configuration Risk Management Forum Research Task

3002012995

Technical Update, September 2018

EPRI Project Manager

D. Hance

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

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

ENERCON Services, Inc.

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

NOTE

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

ACKNOWLEDGMENTS

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

ENERCON Services, Inc.
500 TownPark Lane
Kennesaw, GA 30144

Principal Investigator
T. Morgan

This report describes research sponsored by EPRI.

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

Application of Colors as Risk Metrics - Background and Effective Practices: 2018 Configuration Risk Management Forum Research Task. EPRI, Palo Alto, CA: 2018. 3002012995.

ABSTRACT

This report examines the background and usage of risk color metrics in configuration risk management (CRM) programs. The history of the use of colors in CRM programs for both shutdown and at-power conditions is reviewed. Current practices involving the use of colors as risk metrics are also examined to compare among a cross-section of plants. The key issue that this report seeks to address is the purpose of the use of colors as risk metrics in CRM programs, and the influence of management expectations on the results.

Keywords
Configuration
Configuration Risk Management Forum (CRMF)
Risk
Probabilistic Risk Assessment (PRA)
Shutdown

Deliverable Number: 3002012995

Product Type: Technical Update

Product Title: Application of Colors as Risk Metrics - Background and Effective Practices: 2018 Configuration Risk Management Forum Research Task

PRIMARY AUDIENCE: Probabilistic Risk Assessment (PRA) engineers and PRA management

SECONDARY AUDIENCE: Plant management using PRA for decisionmaking

KEY RESEARCH QUESTION

This report explores the purpose of colors as risk metrics in configuration risk management (CRM) programs, and the influence of management expectations on the results. The history of the development of the use of colors as risk metrics is investigated for both shutdown and at-power risk assessment. Risk management practices are reviewed for a variety of plants representing multiple approaches.

RESEARCH OVERVIEW

Risk management reference documents, starting with NUMARC 91-06, were reviewed to investigate their intent and evolution since the 1990s. Risk management methods were also investigated to further understand the history of the use of colors as risk metrics. Interviews with risk personnel at seven utilities representing a substantial percentage of the US nuclear power plant fleet were also conducted to understand current practices.

KEY FINDINGS

- The CRM guidance documents recognize that typically defined yellow and orange conditions represent acceptable risk increases, provided that actions are taken to address non-quantifiable factors and establish risk-management actions that are appropriate to the configuration. Therefore, such configurations should not be treated as unsafe conditions to be avoided in all circumstances.
- Risk-limiting philosophies or management expectations to re-schedule maintenance tasks to reduce the risk impact are generally a good example of appropriate risk management actions consistent with existing guidance.
- Deferral of maintenance tasks to outages can have adverse consequences, including increased outage duration, outage labor costs, and the potential for failures if the deferred maintenance involves degraded equipment.
- The features of the Phoenix Risk Monitor software provide improved capabilities for the Incremental Core Damage Probability (ICDP) method that utilities have begun to realize, such as the explicit display of ICDP results, rather than an instantaneous risk display that implicitly uses the ICDP method. This enables display of "yellow at" a particular time and date, or "yellow soon".
- This report also concludes that although there are variations in approaches to at-power, quantitative CRM programs, the discipline is mature with well-established and effective practices. Similarly, the qualitative, defense-in-depth (DID) method for shutdown risk assessment is a well-established and mature method.

ELECTRIC POWER
RESEARCH INSTITUTE

EXECUTIVE SUMMARY

WHY THIS MATTERS

This report documents the basis for the relationship between colors as risk metrics and appropriate plant response. From the beginning, when colors were used to represent risk to plant staff other than risk analysts, the intent of their use was to provide appropriate risk management actions. This research effort affirms this historical understanding and explores the implications of deviating from it, the effectiveness of the risk assessment methods in use, and newer approaches in use by utilities.

HOW TO APPLY RESULTS

This report is useful to understand the connection between colors as risk metrics and risk management actions. Plant leadership teams, risk assessment staff, and plant staff should find it useful to enhance understanding of the intent of existing guidance, and support the development of new guidance. It should also be a useful resource to address questions that might arise regarding entry into a particular color as a risk metric.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- The annual Electric Power Research Institute (EPRI) Risk Technology Meeting provides an opportunity to explore CRM and PRA software issues. The Configuration Risk Management Forum (CRMF) meeting, the Integrated Risk Technologies (IRT) meeting addressing EPRI risk software, and the HRA Calculator User Group meeting are featured at this event. The Risk and Safety Management Program (RSM) Cockpit provides information on upcoming RSM events and meeting materials from past meetings, including the most recent Risk Technology Meeting. The RSM Program Cockpit URL is: https://www.epri.com/research/programs/061177
- The EPRI Phoenix Risk Monitor Software is available for download at the following URL: https://www.epri.com/research/products/000000003002026380

EPRI CONTACT: Doug Hance, Senior Technical Leader, dhance@epri.com

PROGRAM: Risk and Safety Management, 41.07.01

IMPLEMENTATION CATEGORY: Reference

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

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

One of the most beneficial uses of Probabilistic Risk Assessment (PRA) in nuclear power plant operations is the use of PRA models to evaluate the risk impacts of planned and emergent changes in the plant's operating configuration during at-power and shutdown conditions. Through the development and refinement of risk monitoring software tools and modern PRA models, plant operations and work management personnel can rapidly assess the impacts of removing equipment from service and placing the plant in various configurations (such as significant on-line maintenance evolutions and reduced-inventory operations during outages), as well as evaluating the impacts of other conditions in and around the plant that could affect risk (such as internal flooding and fire risk).

Following successful pilot implementations of configuration risk management (CRM) programs at various plants in the 1990s, the US Nuclear Regulatory Commission (NRC) mandated the assessment of risk impacts of maintenance activities in the Maintenance Rule, 10 CFR 50.65(a)(4) [1]. Since 2000, all US plants have had an active CRM program to manage the risks of at-power and shutdown plant maintenance activities.

The software tools that have been developed, such as EOOS [2] and the Phoenix Risk Monitor [3], are designed for daily use by plant personnel who are not experts in PRA technology. Information is entered using terminology familiar to plant personnel (such as component IDs or maintenance task numbers). While the underlying PRA risk results may be quantitative (such as core damage frequency), various metrics have been devised that translate these specialized risk measures into easier-to-understand terms. The most common technique is to translate risk results into "risk colors" (such as "red," "orange," "yellow," and "green") to represent the relative risk level associated with a specific plant configuration.

Plant procedures have been developed that govern the actions to be taken, including the use of Risk Management Actions (RMAs), increased management oversight, and modification of maintenance activities, when the calculated risk level exceeds various threshold levels. Risk results are monitored by NRC Resident Inspectors as part of routine inspection activity. Also, the Institute of Nuclear Power Operation (INPO) plant evaluations include review of the risk impacts of plant maintenance.

The Configuration Risk Management Forum (CRMF) was established in 2003 by EPRI to serve as a venue to discuss evolving issues in Configuration Risk Management (CRM) applicable to commercial nuclear power plants. The Forum's activities include performance of research on current and emerging CRM issues and an annual meeting attended by utilities (both US and international), regulatory personnel, and other individuals with an interest in CRM issues. At the 2017 and 2018 CRMF annual meetings, there were discussions about tensions between the use of colors as a risk metric and management expectations concerning the use of risk colors. As a result, the CRMF was urged at these meetings to provide guidance on this topic.

The purpose of this report is to investigate the use of colors as risk metrics for both at-power and shutdown methods for instantaneous and cumulative risk, to review the historical bases for the use of risk colors, to present actual plant practices from a cross-section of US utilities, and to identify effective practices currently used in the industry.

2
HISTORY OF RISK COLOR USAGE

Risk Color Usage in Shutdown Risk Management

NUMARC 91-06 [4] was perhaps the first industry guidance document that focused on the management of risk during maintenance actions. This document focused on qualitative risk assessment and risk management during shutdown conditions and identified a set of Key Safety Functions (KSFs) for which adequate defense-in-depth (DID) needed to be maintained to ensure plant safety.

To ensure that adequate defense-in-depth was being maintained throughout a plant outage, logic models were developed, such as the Safety Function Assessment Trees (SFATs) implemented in the ORAM-Sentinel software and described in the ORAM-Sentinel Version 3.4 User's Manual [5], to assess the degree of DID available. The concept of applying risk colors to represent varying levels of DID (e.g., adequate DID = "green," reduced DID = "yellow" or "orange," insufficient DID = "red") was applied as an easy-to-understand approach for outage planners and operations personnel. It should be noted that NUMARC 91-06 does not discuss the usage of DID models or risk colors to communicate risk levels; these concepts evolved as a result of the implementation of NUMARC 91-06 guidance.

In 2003, EPRI published an *Outage Management Configuration Risk Management Consistency Study* [6]. This report was published about 10 years following the broad adoption of NUMARC 91-06 and implementation of ORAM models throughout the industry. It included a detailed review of plant practices at the time concerning the establishment of the risk colors, by KSF and plant operating state, for both BWRs and PWRs. Table 2-1 below presents a table from that report which provides a generalized set of color definitions.

Section 6.5 of this report states, "The end state colors produced by the models are intended to represent the relative risk of a configuration and to define an action level, based on the site or corporate procedures."

Table 2-1
Color Definitions from EPRI Report 1008051 (Table 3-7)

Color	Definition
GREEN	Lowest risk level. Configurations with this color require no additional actions to manage risk. Defense-in-depth is very high or maximum. Color rules generally require at least 2 systems or trains above the minimum (that is, N + 2), or all trains available to support the function.
YELLOW	Slightly elevated, but relatively low level. Steps are often taken to minimize the duration of YELLOW work windows or compensatory actions are put in place to reduce plant risk (reduced, yet adequate defense-in-depth). Color rules generally at least 1 system or train above minimum (that is, N + 1). For sites with higher GREEN requirements (for example, all trains available), YELLOW can range from N + 1 to 1 fewer than all trains available.
ORANGE	Relatively high, yet acceptable risk level. Often requires senior management review and approval prior to entering this condition as part of a planned evolution. Compensatory actions are required to reduce risk, such as limiting unavailability time, establishing contingency plans for restoration, and protecting SSCs relied upon to mitigate events. Color rules generally define the minimum (N) SSCs needed for success of the function (that is, no defense-in-depth).
RED	The risk associated with this condition is considered unacceptably high and will not be entered voluntarily. Generally, the safety function cannot be met with the available trains (that is, fewer than N).

In 2006, EPRI published *Qualitative Risk Assessment Methods for Shutdown Risk Management* [7]. This report also provided a table describing the color metrics based on DID. While the precise words have differences from the 2003 report, they are consistent regarding level of DID and compensatory actions. Similar to the usage described in the 2003 report, the 2006 report emphasizes that "NUMARC 91-06 recognized and emphasized the need for contingency planning and compensatory measures to maintain or restore DID and minimize the potential for loss of SFs as a result of HREs. Risk Management Guidelines (RMGs) were identified as the means to capture compensatory actions. RMGs are to be developed and assigned to the appropriate end states so that contingency plans can be used either to reestablish DID if planned systems or equipment become unavailable or to protect available equipment."

Also discussed in this EPRI report [7] are two major approaches that evolved within the industry for determining the degree of adequacy of Defense-in-Depth for a given plant configuration. The most common approach defines "orange" as having only one success path or support system available for a given KSF. This is called the N+1 approach. Having at least two success paths is defined as "yellow" risk, and having more than two success paths available is defined as "green" risk. Having no available success paths available results in a "red" status.

In the second approach, called N-1, the maximum number of success paths or available systems supporting each KSF is determined to result in "green" status for that KSF. Having one less, or N-1, results in "yellow" status. Having two success paths less than the maximum number available, but with at least one success path still remaining to support the KSF, results in "orange" KSF status. Having no available success paths results in "red" status.

Because a risk color is determined for each KSF, the results for the set of KSFs is usually aggregated into an overall "risk color" for the plant. In most cases, the overall risk color has been defined as the risk color representing the lowest level of DID available for any of the KSFs. This approach can be conservative for several reasons:

- KSFs are typically defined for both front-line functions (e.g., decay heat removal) and support system functions (e.g., AC power availability). The impacts of support system DID degradation is usually already reflected in the front line KSF evaluations. So, there is some “double counting” of DID impacts. In addition, a support system KSF might indicate a heightened level, such as “orange,” but the front line KSFs may all be “green” or “yellow;” in this case plant risk could be assessed to be “orange” as a result of selecting the highest risk color.
- At least one of the KSFs pertains solely to containment integrity, and others pertain solely to core/fuel damage prevention. However, these KSFs are often lumped together to compute an overall risk level. For example, if all core/fuel damage KSFs are “green,” the overall plant risk level would be assessed as “yellow” if containment integrity is degraded.

CRMF recently developed recommendations for alternative approaches for aggregating risk colors [8]. These recommendations include assigning separate risk colors for core/fuel damage prevention and containment integrity to be more consistent with the at-power risk measures of Core Damage Frequency (CDF) and Large Early Release Frequency (LERF). It is also recommended that the core/fuel damage risk color be assigned based solely on the “front-line” safety functions (i.e. reactivity control, inventory control, and decay heat removal). These alternative approaches could help to assign a more accurate overall “risk color” during each portion of the outage.

In addition to the two approaches that evaluate safety function availability models, some plants utilize alternative methods to compute a DID “score” based on the number of available success paths for each Key Safety Function. The KSFs are sometimes weighted on the basis of each KSF’s significance to the current Plant Operating State. The overall “score” that results from the DID evaluation is used to define the overall level of risk (i.e., acceptable, reduced DID, or unacceptable DID), which are usually represented as a risk color (i.e., “green” through “red”).

Risk Color Usage in At-Power Risk Management

Quantification of at-power risks was recognized in the 1990s as a valuable risk metric, bringing the full capabilities of the plant-specific PRA to bear upon CRM and risk monitoring. However, the use of colors was and still is used for at-power risk management. The increasingly severe color codes of green, yellow, orange, red linked to contingency and management actions is also used for the quantitative results of at-power risk monitoring. The table below is an example from the EOOS 2.6 User Manual [9] of how colors might be used at a plant:

Table 2-2
EOOS 2.6 Association of Colors with Actions

PSI Condition	Operator Action
Low risk (green)	Proceed normally
Small increase in risk (yellow)	Include safety assessment insights in pre-shift meetings
Intermediate increase in risk (orange)	Invoke contingency actions Hasten the restoration of risk important equipment Notify plant management
Large increase in risk (red)	Notify plant management Suspend all new work orders Invoke contingency actions Hasten the restoration of risk important equipment

From the 1990s, risk monitoring software integrated both the quantified results and risk colors. EOOS and Phoenix offer various risk meters that provide both a quantitative index and a color designation.

Regardless of the risk monitoring software product used, a key question is the selection of the threshold value of CDF or LERF to transition from one risk color to another, such as "green" to "yellow or "yellow" to "orange." However, there is limited industry guidance concerning the setting of these transition thresholds. EPRI explored the technical details of the methods in use in a 2012 report [10].

The thresholds were initially set on the basis of a multiplier times the "zero maintenance" risk level (i.e., the plant's calculated CDF or LERF assuming that all equipment is in service) to assign colors to the instantaneous risk levels. Examples of thresholds that have been used are:

Table 2-3
Examples of Instantaneous Risk Color Transitions Using Multipliers

Risk Color Threshold	PWRs	BWRs
"Green" to "Yellow"	2 or 3 times the zero maintenance risk	3 to 5 times the zero maintenance risk
"Yellow" to "Orange"	5 times the zero maintenance risk	10 times the zero maintenance risk
"Orange" to "Red"	10 times the zero maintenance risk (or CDF of 1E-3/year, if more limiting)	20 times the zero maintenance risk (or CDF of 1E-3/year, if more limiting)

It should also be noted that while there is no explicit guidance for multipliers, the NUMARC 93-01 [11] guidance for determining safety-significant SSCs states, "An SSC would probably be considered risk significant if its Risk Achievement Worth shows at least a doubling of the overall Core Damage Frequency and should be provided to the expert panel as an input in risk determination." Thus, a factor of 2 has a precedent for consideration of risk significance. Therefore, it is plausible that this guidance has been influential in establishing the green / yellow threshold for some programs.

Also from the table above, note that the BWR thresholds have been typically set at somewhat higher multipliers than those employed at PWRs since the calculated BWR zero maintenance CDF is typically lower than that for PWRs.

Most single maintenance actions (i.e., removing a single piece of equipment or system train out of service) typically introduce only small risk increases over the zero maintenance risk level. However, maintenance activities on components with high risk significance can result in greater risk increases. Outages of multiple components in several systems can also result in larger risk increases. In setting a threshold for the transition from "green" to "yellow," the intent is to highlight for plant staff those specific single maintenance actions and multiple component outages that incur "larger than typical" risk increases. If the "yellow" threshold is set too high, then virtually no maintenance actions would trigger a risk color change, and this could lead to complacency concerning the risk impacts of day-to-day maintenance actions. On the other hand, setting the "yellow" threshold too low would result in frequent "yellow" risk levels, which typically would trigger the implementation of risk management actions and enhanced management oversight. This would result in essentially all maintenance actions requiring the same level of oversight, which would mask the need for greater attention to the larger risk increases. Therefore, the setting of the "yellow" risk level may be the one requiring the most forethought.

The "red" risk threshold signifies an unacceptable risk increase. As noted in the table above, NUMARC 93-01 [11] specifies a 1E-3/year instantaneous CDF as a risk level that should not be exceeded voluntarily. Some plants have set the plant-specific threshold at a lower value to provide additional margin to prevent exceeding the NUMARC 93-01 limits. Note also that no equivalent LERF limit was specified in NUMARC 93-01.

References [12], [13], and [14] present the results of industry surveys previously conducted in 2003, 2007, and 2011 by CRMF about configuration risk management practices. The survey results show how risk color definitions (and the metrics used to define the risk colors) have evolved over time. The 2003 and 2007 surveys [12] [13], in particular, include tables that provide the risk thresholds used at various plants as of the time of each survey.

The discussion above has focused on the use of risk colors to represent changes in the instantaneous risk levels (CDF and LERF). However, NUMARC 93-01 [11], Section 11.3.7.2 provides industry guidance concerning the monitoring and management of configuration risk in support of the Maintenance Rule using Incremental Core Damage Probability (ICDP) and Incremental Large Release Probability (ILERP). This section of NUMARC 93-01 quotes the guidance on temporary risk increases from the EPRI PSA Applications guide [15]. Quantitative risk metrics for establishing action levels are provided for risk evaluations using PRA models (primarily for at-power risk monitoring). NUMARC 93-01 does not discuss the usage of risk colors; however, from Table 2-4 below, the quantitative action thresholds provided do lend themselves to the assignment of risk colors and this is the typical industry practice.

Table 2-4
ICDP and ILERP Thresholds for Risk Management Actions

ICDP		ILERP
$> 10^{-5}$	- configuration should not normally be entered voluntarily	$> 10^{-6}$
10^{-6} - 10^{-5}	- assess non quantifiable factors - establish risk management actions	10^{-7} - 10^{-6}
$< 10^{-6}$	- normal work controls	$< 10^{-7}$

Source: NEI, NUMARC 93-01

In addition to the above, NUMARC 93-01 quotes the EPRI PSA Applications guide [15]: "Maintenance configurations with a configuration-specific CDF in excess of 10^{-3}/year should be carefully considered before voluntarily entering such conditions. If such conditions are entered, it should be for very short periods of time and only with a clear detailed understanding of which events cause the risk level." Accordingly, typical at-power CRM programs recognize a CDF of 1E-3/year as an upper limit regardless of the method (instantaneous or ICDP) used. It should also be noted that the PSA Applications Guide [15] considers an ICDP above 1E-5 (ILERP above 1E-6) to be "potentially risk-significant." An ICDP below 1E-6 (ILERP below 1E-7) is considered to be "non-risk-significant." The range of ICDP from 1E-6 to 1E-5 (1E-7 to 1E-6 for ILERP) is considered to be potentially risk-significant, but other non-quantitative arguments may apply which could still justify the increase as non-risk-significant. From the PSA Applications Guide, "Examples of non-quantitative arguments which might influence the decision include the qualitative factors not accounted for in the PSA, the anticipated frequency of having to enter this condition, recent plant performance of key systems or components, or the safety benefit obtained, but not accounted for in the PSA model."

NUMARC 93-01 also allows a plant to develop a comparable set of action thresholds based primarily on instantaneous CDF/LERF values; however, the report does not quote any specific CDF/LERF values to be used other than the 1E-3/year upper limit. There is no instantaneous threshold guidance concerning transition from normal work controls to the implementation of RMAs.

When a maintenance action is taken, plant staff has estimated the total amount of time that the plant will remain in that configuration. However, the actual work may require more or less time than predicted. An action that results in a small instantaneous risk increase but that remains in effect for an extended period of time could result in exceeding the NUMARC 93-01 threshold for implementation of risk management actions. However, if only the instantaneous risk increase is monitored, the level of risk increase might be "green."

The use of risk monitoring software began with instantaneous risk, which was later adapted to represent ICDP based on a fixed duration of time (e.g., 4 or 7 days). Phoenix Risk Monitor has incorporated increasing sophistication to represent the ICDP as a function of time while also including risk colors. In Figure 2-1 below, the Phoenix CDF risk metric shows when a yellow ICDP condition will be reached ("yellow at…") and the red arch above the "tank" graphic shows that an upper instantaneous risk limit has been exceeded. The LERF graphic is a conventional risk meter, showing an instantaneous risk color with cumulative or ILERP information below.

The Phoenix Risk Monitor Scheduler features also have the capability to display ICDP as a function of time.

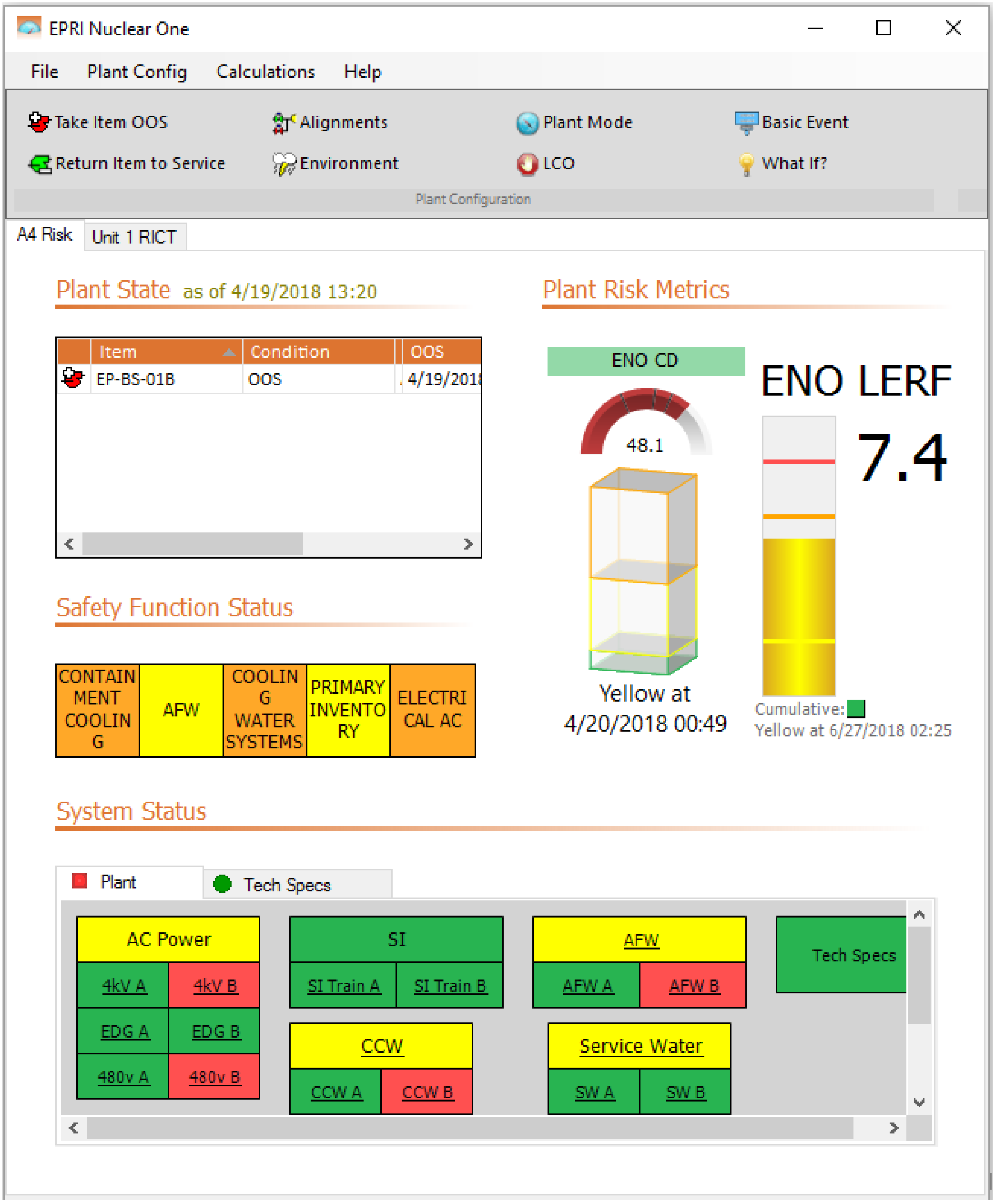

Figure 2-1
Phoenix Risk Monitor Operator Display

3
REVIEW OF INDUSTRY PRACTICES

This chapter summarizes the results of a review of current practices at several US utilities. This review is not comprehensive, but does include a sampling of practices at several large nuclear fleets, as well as input obtained from several individual power plants. The intent of this review was to summarize each utility's experience with risk color metrics, identify key issues may have resulted from the use of these metrics, and note any evolutionary changes that have occurred at these utilities over time.

Risk Color Metrics Experience and Insights at Utility "A"

This utility, which has a multiple plant fleet of both BWRs and PWRs, tracks instantaneous CDF/LERF risk during at-power conditions. Outage risk is managed using risk colors determined by qualitative Defense-in-Depth models.

The instantaneous risk thresholds are such that NUMARC 93-01 ICDP/ILERP limits for risk management actions, etc. are not exceeded except for the rare cases of risk-affecting equipment that is out of service for longer than a work week. However, instantaneous CDF and LERF are the primary measures utilized by plant personnel when planning and implementing maintenance activities. The current approach has worked quite well and has had few changes over past 20 years.

The instantaneous risk color thresholds are set as follows:

- The transition from the "green" risk level to "yellow" risk is based on the instantaneous CDF exceeding two times the average baseline risk (i.e., the CDF/LERF including average maintenance unavailability values).
- The transition from the "yellow" risk level to "orange" risk is set to be 5% above the CDF determined by running the "zero maintenance" risk model with only the most risk significant single train removed from service. The most significant single train of equipment is determined from those systems for which normal periodic test/maintenance is expected to occur at least once per quarter during power operation. For example, this has generally been one train of the Standby Service Water system at one of the plants in the fleet.
- The transition from the "orange" risk level to "red" risk is set as an instantaneous CDF exceeding 1E-3 per year (consistent with the limitation in NUMARC 93-01).

The transition thresholds for LERF are similar and are generally set at one order of magnitude below the values assigned for CDF. It was noted that for those plants with a relatively low baseline LERF, these thresholds provide some significant margin before reaching a color threshold.

The approach used to select risk colors is an attempt to balance the need to identify heightened risk levels to plant staff without generating excessive entries into the "orange" risk metric. Various routine maintenance actions can result in entry to the "yellow" risk level. However, no single train maintenance action (as allowed by the plant's Technical Specifications) would trigger an “orange” risk level. “Orange” risk would only be experienced under configurations in which multiple risk-significant equipment trains were out of service, as well as during other unusual emergent conditions.

Cumulative risk of a maintenance configuration is not explicitly tracked on a routine basis. However, long-term equipment outages are monitored to ensure that their impact on ICDP and ILERP are properly controlled.

The utility does not track configuration risk as a performance indicator. The plant’s performance indicators are focused on issues such as individual system performance and maintenance backlog. However, there are several management constraints that do impact how maintenance is planned and executed, i.e., guidelines considering risk implications of equipment out of service.

The general plant philosophy is that “orange” risk levels should be avoided, which does constrain some planned maintenance activities. In addition, for planned maintenance purposes, it must be assumed that severe weather conditions are in effect at the time that the maintenance is to be performed. At one plant, for example, assuming a severe weather condition results in the expected risk level to always be “yellow” prior to taking any equipment out of service.

It was noted, however, that while work planning at that plant must assume that severe weather is always occurring, Operations maintains an actual risk level in the EOOS software based on current conditions. Both the daily “actual” risk color and the “planned maintenance” risk color are reported daily to plant staff. One concern that was noted is that with the planned maintenance risk color always at “yellow,” plant staff can’t easily determine what the risk impact of the day’s maintenance actions will be (i.e., small impact, or more significant). Hence, specific risk impacts would be masked as a result of the “yellow” risk color imposed by the severe weather assumption if the "actual" risk color based on actual weather conditions was not also communicated.

Plant staff noted that is it important to understand that periods of heightened risk are acceptable as long as appropriate contingencies are in place to address the risk contributors.

Risk Color Metrics Experience and Insights at Utility “B”

This multi-site utility previously relied on instantaneous CDF/LERF as the primary risk measures for CRM during at-power conditions; however, it recently switched to using Incremental Core Damage Probability and Incremental Large Early Release Probability as its primary risk measures of concern. Outage risk is managed using risk colors determined by qualitative Defense-in-Depth models.

It was noted that when instantaneous risk was being used as the primary risk measure, too much attention was being focused on plant activities that resulted in short periods of high risk. Equipment that resulted in only small increases in the instantaneous risk levels could be allowed to remain out of service for a long period of time. As a result, the aggregate risk of the “long term low risk” configuration could equal or even surpass the “short term high risk” configurations, but without an equal emphasis from station management.

Instantaneous risk (CDF/LERF) is still monitored as part of the overall CRM program, but only a simple binary “allowed” vs “not allowed/RED” differentiation is used. This is used only to indicate if the “red” limit on instantaneous CDF (1E-3/year) is being exceeded.

In the monitoring of ICDP and ILERP, plant personnel informally use the terminology of "yellow soon" to indicate plant conditions that would result in the ICDP/ILERP levels exceeding the NUMARC 93-01 threshold for RMAs within a few days. It was noted that using the ICDP/ILERP monitoring approach, it is possible to eliminate the concept of "risk colors" if desired. Risk could be categorized based on other measures, such as "Region 1" for operating below the NUMARC 93-01 threshold for RMAs, "Region 2" for operating in ICDP/ILERP region requiring RMAs, and "Region 3" for unacceptable risk conditions. However, risk colors are still in use at this utility.

For establishing effective risk color metrics for ICDP and ILERP, a "yellow" configuration is one with an ICDF/ILERF that results in exceeding the NUMARC 93-01 limits for RMA implementation within 90 days. The 90 day period was chosen because it represents the duration at which a temporary alteration needs to be screened or reviewed under 10CFR50.59.

Using risk metrics is not considered to be a Key Performance Indicator (KPI). The (a)(4) process is intended to be a risk "management" tool; it is not a risk "measurement" tool. Meaning, the program is used to assess and then manage planned/unplanned work occurring "now." The use of long term risk statistics (e.g., accrued risk over the past cycle) is primarily a "look back" at past risk and may not be a good indicator of how plant staff will respond to future events. Also, if the past risk results were not in the optimal range for the KPI, an unintended consequence would be a focus on delaying/ re-scheduling work so as to achieve a better KPI. The overall intent of Maintenance Rule is to balance unavailability and reliability; delaying planned work on important equipment might improve its availability, but could undercut long-term reliability.

It was noted that what is most important for effective risk management is ensuring that operations and work week management personnel truly understand what the plant's risk contributors are (components and systems, as well as any specific plant configurations during shutdown, etc.) and how risk accrues over time.

Risk Color Metrics Experience and Insights at Utility "C"

This utility has a fleet with both BWRs and PWRs. As noted for the other utilities, outage risk management is performed using qualitative Defense-in-Depth modeling to assign risk color levels. For at-power monitoring, the utility used a combination of quantitative PRA results and qualitative safety function evaluations to determine risk colors for many years. However, the process was recently changed to rely primarily on quantitative risk levels to determine risk colors for current plant conditions.

For planning of maintenance actions, the risk monitoring tool still provides access to the qualitative safety function logic. So, the safety function impacts can be considered by work week management staff during the development of maintenance plans.

Instantaneous CDF and LERF are the primary metrics in use. However, if external conditions are imminent that could impact risk (such as severe weather), control room operators can set a High Risk Evolution flag in the risk monitoring software that would invoke Defense-in-Depth logic models that would result in increasing the risk color appropriately.

The quantitative CDF/LERF risk color thresholds are set on the basis of multipliers of the "zero maintenance" risk. The transition from "green" to "yellow" is generally set at two times the baseline risk. The transition to "orange" is generally set at ten (minimum) to twenty-five times (maximum) the baseline risk. The transition to "red" is set to either a fixed limit (less than the NUMARC 93-01 value of 1E-3/year) or twenty times the baseline risk, depending on specific plant risk characteristics. The Orange and Red risk levels are based on each station's base "zero maintenance" CDF and LERF values.

Risk is not formally considered to be a KPI. However, management expectations concerning the risk impacts of maintenance play an important role in day-to-day plant operations. The risk management philosophy is generally conservative, which results in challenges to justify instances in which the plants plan or experience intervals of "yellow" or greater risk. Risk levels at similar plants in the fleet are often compared, and consistency between plants is emphasized. However, it was noted that some risk differences exist as a result of differing plant design features which makes achieving the desired level of consistency difficult to achieve. It is often the practice to perform "yellow" risk maintenance on an around-the-clock basis to minimize the time spent in the elevated risk condition.

As a result of management attention to elevated risk, there is a strong emphasis on maintaining "green" risk levels. This can result in some potential maintenance actions being deferred into the refueling outages. In other cases, additional compensatory measures are implemented that can result in some "yellow" risk actions being allowed to be categorized as "green" to permit them to be worked on-line, particularly without the need for around-the-clock maintenance scheduling.

It was noted that deferring some maintenance actions to the outage may reduce short term risk but could impact equipment performance if the maintenance deferral results in performance degradation of the equipment during the period prior to the outage.

Risk Color Metrics Experience and Insights at Utility "D"

Instantaneous CDF and LERF are the primary risk monitoring measures used at this single multi-unit site PWR utility for at-power conditions. Outage risk is managed using risk colors determined by qualitative defense-in-depth models.

The instantaneous risk color thresholds are set using a combination of inputs. This approach has been in use at the plant for a number of years. Among the factors considered include:

- The risk increase necessary to accrue 1E-6 of ICDP during 24-hour/three-day/seven-day work windows
- Multiples of the zero maintenance risk (e.g., 2x, 10x, etc.)
- Ensuring that outages of key plant equipment (in particular, the plant's turbine-driven AFW pump) result in a "high yellow" risk color.

Based on joint examination of these three factors, a set of risk thresholds are established for transitioning between the "green," "yellow," "orange," and "red" risk color regimes. Instantaneous LERF is tracked in a similar manner, but generally does not generate risk color levels greater than those seen for CDF.

A "high yellow" risk level requires plant management approval unless the action taken is needed to perform a required Technical Specifications surveillance. The risk color thresholds are set to ensure that appropriate management attention is obtained when performing those items that cause significant risk increases. It was noted that most planned maintenance actions do not result in reaching the "high yellow" risk level.

Adjustments to the risk levels are also made for severe weather conditions in the area or for work in the plant switchyard. Control room operators have the option of either qualitatively increasing the current risk color by one level when these conditions occur, or quantitatively evaluating the risk impacts in the EOOS risk monitor using pre-determined risk factors that are provided.

To ensure that NUMARC 93-01 cumulative risk limits are not exceeded, plant practices do not allow scheduling of online maintenance tasks that exceed one-half of the Technical Specifications allowed outage time without plant management approval. In general, long-term outages of low risk plant equipment are also constrained by Maintenance Rule unavailability criteria limitations.

Risk metrics are not considered a KPI; however, unplanned entries into "yellow" or "orange" risk levels, or entries in these risk regimes that extend beyond projected durations, are tracked as indicators. In addition, entry into a planned "orange" risk level require prior approval from the Chief Nuclear Officer. As a result, "orange" conditions are rarely planned. One KPI that is indirectly tied to risk is the tracking of instances where actual out of service times exceeded the planned out of service times by 10%.

Risk Color Metrics Experience and Insights at Utility "E"

This utility with a fleet of both BWRs and PWRs uses instantaneous CDF/LERF risk as its primary risk metrics for on-line risk assessments; however, ICDP and ILERP are also considered in setting the instantaneous risk thresholds. For shutdown risk management, this utility's plants use qualitative Defense-in-Depth logic trees, similar to those used at the other utilities that were surveyed.

For on-line risk assessments, the "yellow" risk threshold is set based on the risk increase needed to accrue 1E-6 of ICDP within 7 days. The risk level that results in the 1E-6 ICDP limit being exceeded within 36 hours (typically ½ of many Technical Specification allowed outage times) is set as the "orange" threshold. The "red" CDF threshold is set at the NUMARC 93-01 limit of 1E-3 per year. The LERF thresholds are set at one order of magnitude lower than the CDF values.

In addition to the instantaneous risk colors for at-power conditions, procedures direct plant personnel to contact the PRA group for additional evaluations if a "green" work task is planned to be performed for greater than 7 days in order to ensure that the cumulative ICDP/ILERP limits are not exceeded. PRA must similarly be contacted for any "yellow" activity that is planned for greater than 36 hours. For an "orange" activity that will exceed 72 hours, PRA must be contacted to ensure the NUMARC 93-01 upper ICDP/ILERP limits (1E-5/1E-6) are not exceeded.

The quantitative risk calculations can also assess the impact of external conditions that could impact plant risk, such as severe weather. Quantitative adjustments are made within the PRA model when those conditions are in effect. However, it was noted that no industry guidance exists as to how to treat these external influences and that there are several different approaches in use throughout the industry.

The plants at this utility previously considered a combination of Defense-in-Depth measures as well as the quantitative PRA results to determine the risk colors during at-power operation. The

DID logic is still available in the risk monitoring software for use during maintenance planning, however.

Consideration is being given to moving solely to a cumulative (e.g., ICDP/ILERP) risk monitoring approach in the future. This will be influenced by the fleet decision concerning implementing Risk Managed Technical Specifications (RMTS), which is also under consideration.

The utility used to track accrued risk as a KPI, but this is no longer done. Since the measure was a "look back" at past practices, it was not believed to be as useful as other indicators. While there are no risk-based KPIs, management does challenge instances in which elevated risk configurations are planned. The reluctance to enter elevated risk conditions has evolved over time, and it appears to have been driven somewhat by benchmarking comparisons within the industry.

While elevated risk colors are avoided as much as possible, it is recognized that some plant conditions result in higher risk. In some cases, refinements have been made to the PRA models to reduce conservatisms that have contributed to obtaining a higher risk level estimate for some maintenance actions.

Risk Color Metrics Experience and Insights at Utility "F"

This utility has several stations, consisting of both BWRs and PWRs. It is currently using ICDP and ILERP as its primary risk metrics for at-power configuration risk management. The time to reach various ICDP and ILERP thresholds are calculated for each configuration:

- The time to reach 1E-6 ICDP is the "yellow" threshold
- The time to reach 5E-6 ICDP is the "orange" threshold, and
- The time to reach 1E-5 ICDP is the "red" threshold

ILERP is evaluated in a similar manner, using thresholds that are one order of magnitude lower than the ICDP values. Quantitative adjustments are made in the risk calculations to reflect the existence of several environmental conditions (e.g., severe weather).

Shutdown risk is determined using qualitative Defense-in-Depth logic models to evaluate key safety functions. Having at least N+2 available success paths (where N is the minimum required number) is necessary to have a "green" risk level for each key safety function.

For at-power risk monitoring, the utility switched to the ICDP/ILERP approach in the 2012-2013 timeframe. The previous approach was to calculate instantaneous CDF and LERF and assign risk colors to the instantaneous risk levels based on whether ICDP and ILERP thresholds would be exceeded within an assumed time frame (e.g., 7 days). The adoption of ICDP and ILERP monitoring was made to acclimate the plant sites to eventual adoption of Risk Managed Technical Specifications, and to better accommodate the use of expanded PRA models that evaluated multiple hazards (e.g., fire and seismic risk, in addition to internal events risk).

The utility does not have any KPIs that are directly related to configuration risk levels. The plants do have an indicator that tracks instances in which unplanned risk color changes occur during shutdown conditions. These situations can occur if the risk impact of an outage configuration is missed due to a sudden schedule change.

Entry into a “red” risk level requires Site Vice President approval. Entry into an “orange” risk level requires the Plant Manager’s or Operations Director’s approval, and “yellow” risk levels require the Shift Manager’s approval. As a general practice, the plants do not plan maintenance actions that require entry into an “orange” ICDP/ILERP condition, and instances have occurred where the plant sites have deferred maintenance actions if an “orange” condition was predicted to occur. “Yellow” risk conditions can occur periodically, and it was noted that, at one site, “yellow” conditions now occur more frequently as a result of including the fire PRA model into the configuration risk calculations.

Risk Color Metrics Experience and Insights at Utility “G”

This single site multi-unit PWR utility uses ICDP and ILERP as its primary risk metrics. However, while risk colors are assigned to ICDP, colors are not utilized for the ILERP measure. The plant also has a plant trip model and a risk color is assigned to the incremental trip probability that is calculated from that model. The online risk colors that are used are consistent with those used by the Reactor Oversight Program (i.e. “green,” “white,” “yellow,” and “red”). The ICDP risk colors are similar to the ICDP thresholds provided in NUMARC 93-01, with slight differences to allow some margin for the station to act proactively.

Shutdown risk is evaluated using qualitative Defense-in-Depth models for the key safety functions. Risk colors are assigned based on the safety function status. Unlike the at-power risk colors, the plant uses “green,” “yellow,” “orange,” and “red” for these metrics.

Prior to 2010, the plant did not use risk colors to communicate risk for at-power conditions. Instead, accumulated risk was plotted for each work week and compared to risk targets. Based on recommendations from a self-assessment, the plant transitioned away from the accumulated risk plots to the four-color risk metrics in use today.

The plant has tracked accumulated CDP as a KPI for many years. It is actually a high-level indicator for Operations and they actively monitor the status of this indicator. The indicator is normalized based on a 1.0 value corresponding to the PRA-calculated average risk for the cycle (i.e., an indicator greater than 1.0 means that accumulated risk is greater than the PRA-estimated value). To account for shutdown periods, a surrogate risk value is included in the ICDP risk calculations for the shutdown period. This surrogate measure is based on the outage risk colors and CDF values.

Work weeks that result in “yellow” risk (which would be similar to “orange” risk in other plants, since the plant is using a “green,” “white,” “yellow,” “red” color scale) are occasionally planned throughout the cycle. However, spending too much time in a “yellow” condition can impact the ICDP indicator.

The plant never plans a “red” work week; however, it is possible that a “red” condition can result due to an emergent failure. The plant will perform maintenance around-the-clock for any “red” condition, as well as any unplanned “yellow” condition that has the potential to exceed the “red” ICDP threshold if work takes longer than planned.

It was noted that if the accumulated risk indicator approaches a high value, then it can result in modifications to maintenance practices. In most cases, the plant staff look more closely at possible Risk Management Actions that can be used to reduce the risk levels. Some of the pre-determined RMAs can be credited quantitatively, so these can be applied directly to reduce the risk level. For unusual configurations, the PRA group will be asked to identify specific actions that can be taken to reduce risk; in some cases, those situation-specific RMAs will also be credited in a quantitative manner.

4
INSIGHTS CONCERNING RISK COLOR METRICS ISSUES

The information gathered in Section 3 of this report, while not comprehensive, represents a sizeable fraction of the US nuclear fleet. So, it is reasonable to use this information to obtain insights and to identify industry trends. Based on this information, as well as that presented in the previous sections, the following insights and recommendations are noted.

Applicable Risk Metrics

As can be seen, there is considerable variation from utility to utility in the selection of risk metrics that are being utilized to monitor and control risk during day-today maintenance activities under at-power conditions. Some plants are using instantaneous CDF and LERF as the primary risk metrics, while others have adopted cumulative ICDP and ILERP metrics. Other plants use a hybrid approach (e.g., relying on instantaneous risk metrics, but setting risk color thresholds based on expected ICDP and ILERP accruals over a typical time period).

The guidance in NUMARC 93-01 allows for flexibility in the methods used to monitor risk. Each of the approaches that are described in Section 4 are compatible with the industry guidance. Several of the utilities noted that the methods used to monitor risk have changed in the recent past. One utility transitioned from the use of instantaneous risk measures to the use of cumulative measures. Two other utilities transitioned from an approach based on both qualitative and quantitative evaluations to ones using primarily a quantitative approach. The transition to RMTS also provides a rationale to adopt the ICDP approach to ensure that the (a)(4) program is closely aligned with RMTS.

While all of the plants continue to utilize the “risk color” approach for conveying relative risk status to plant staff, the criteria used to establish the threshold values that trigger risk color transition thresholds vary in methods and in quantitative values.

While there is no industry-standard guidance for risk metrics to use for at-power risk monitoring or guidance for establishing risk color thresholds, it appears that the lack of such guidance has not had a detrimental effect on the ability of plants to adequately monitor and manage risk on a daily basis. The variation that is exhibited across the industry reflects plant-specific preferences concerning how to best monitor and report risk conditions to plant staff.

During shutdown conditions, the approaches being used appear to be fairly standardized. Qualitative defense-in-depth logic models are widely used to assess the status of NUMARC 91-06 key safety functions. The degree of defense-in-depth determines the risk color status that is assigned to each safety function. Aggregation of the risk colors for each safety function into an overall “outage risk color” can vary. As noted in Section 2, EPRI has published possible approaches for standardizing the aggregation process in previous research [8].

Tracking Risk Colors as a Key Performance Indicator

Part of this research effort was to investigate the extent to which colors used as risk metrics might be considered as KPIs. Based on the information gathered from the sampling of utilities, it appears that configuration risk is not generally being tracked as a KPI. It appears that while some plants were including a risk metric performance indicator in the past, this practice may be diminishing. As noted in some of the utility discussions, tracking of measures such as accrued risk over time as a performance indicator may not be as effective in detecting performance issues as other types of measures. Elevated risk levels could have occurred for a number of reasons, including environmental conditions outside the plant's control, management-approved maintenance tasks that incurred elevated risk for short periods of time, and random failures of risk-significant equipment. So, having an accrued risk value that is above a planned target might not be an indicator of the need for performance improvement by plant staff.

However, one utility that was surveyed has a KPI to assess actual on-line maintenance risk assessment trends against the average PRA risk. This has a similar focus to KPIs that are used to evaluate maintenance effectiveness, with the added impact of integrating organizational awareness of risk into the conscious operation of the plant.

Another of the surveyed utilities noted that that unplanned entries into higher risk color regimes (i.e., "yellow" or "orange") were tracked as an indicator, as well as instances in which the time spent in these regimes exceeded the planned duration. Indicators that track elevated risk configurations that extend beyond planned intervals seem to be appropriate, as these measures indicate deviations from planned maintenance, with increased risk as a result. Unplanned entries into higher risk colors could occur both due to random failures of high risk-significant components as well as due to incomplete or incorrect maintenance risk assessments. Such measures may also be appropriate as they could be indications of equipment or human performance issues.

In summary, the use of KPIs that are risk-related but focused on specific characteristics as a means to evaluate maintenance effectiveness, such as those described above, may provide the benefit of identifying performance issues and thus are appropriate. However, KPIs linked only to the risk colors may result in acceptable, and possibly necessary, periods of somewhat elevated risk being viewed in a negative manner.

It should also be recognized that there is growing interest in crediting FLEX equipment in PRAs and in shutdown risk assessments. This is in the early stages of development and will not be treated in detail in this report. One US plant has incorporated the use of FLEX equipment during shutdown conditions to achieve "all green" outages based on the N+1 defense-in-depth approach in response to a management initiative. Outage conditions involve challenging and dynamic plant configurations. In this case, the use of FLEX equipment adds real redundancy during shutdown conditions. This approach adds real plant response capability and thus real safety benefits. In a case such as this, the CRM program needs to include the appropriate adjustments to include the FLEX features and ensure that the CRM program elements are maintained and effective. As FLEX features are further incorporated into risk models in the industry, the implications should be explored in future research.

5 CONCLUSIONS AND RECOMMENDATIONS

In examining the history of shutdown and at-power configuration risk management, it is clear that the intent has always been to establish colors that represent risk levels and correlate them to risk management actions. Software products were developed based on this principle.

Both the risk multiplier and ICDP methods are in widespread use for at-power risk assessment. For shutdown risk assessment, defense-in-depth methods are most commonly used in the US. The plant interviews indicate that the discipline of CRM is mature with well-established and effective practices. This conclusion is consistent with the 2011 CRM survey results [14].

Use of the ICDP method is not new, but the application of it continues to advance as more utilities have adopted monitoring of this metric on a more formal basis. Since it uses the same risk metric as RMTS, it provides consistency with RMTS for plants planning to adopt that application. The features of Phoenix Risk Monitor provide additional capabilities for this method that utilities have begun to adopt, such as the explicit display of, rather than inferred, ICDP results.

Examination of current plant practices did not reveal significant use of official KPIs to influence the development or use of CRM programs. However, discussions with the several utilities indicates that many plants have risk-limiting philosophies or management expectations. As noted in Section 4, these philosophies and expectations have caused some at-power maintenance actions to be re-structured, re-scheduled to lower risk periods, or deferred to outage periods. Actions that are taken to re-structure maintenance tasks to lower the risk impact, or re-scheduling a maintenance task to a time period where the risk impact will not be as significant are good examples of using risk insights to appropriately manage risk.

It should also be noted that the CRM guidance documents recognize that yellow and orange conditions represent acceptable risk increases, provided that actions are taken to assess non-quantifiable factors and establish risk management actions that are appropriate to the configuration. Therefore, such configurations should not be treated as unsafe conditions to be avoided in all circumstances.

When deciding to defer an on-line maintenance task to an outage, the question becomes one of a trade-off between risk and one or more other key plant performance attributes. Deferring a routine preventive maintenance task, as a minimum, may have an economic impact since outage labor costs (and possibly outage duration) may increase. Given that the industry has worked hard to limit maintenance during refueling outages to reduce outage costs, returning some maintenance tasks to the outage works against that effort. If the deferment is due to the imposition of overly conservative risk philosophies, then the additional outage costs may not be warranted.

Deferral of maintenance on equipment that is showing early signs of performance degradation can also have an impact on equipment reliability and, possibly, power generation. Correcting an equipment issue early can prevent a failure later in the operating cycle. Again, if the decision is made to defer the repair activity to an outage due to an overly conservative risk philosophy, it is possible that equipment failure could result. This would result in increased maintenance costs (to correct the failure), equipment reliability impacts, and could result in a power reduction or shutdown if the equipment impacts power generation or the equipment has a short Technical Specifications allowed outage time.

6
REFERENCES

1. U.S. Code of Federal Regulations, 10CFR50.65.
2. *EOOS Version 4.1: Software and Documentation*, EPRI, Palo Alto, CA: 2012, 1024818.
3. *Phoenix Risk Monitor Version 2.0a: Software and Documentation*, EPRI, Palo Alto, CA: 2017. 3002011626
4. *Guidelines for Industry Actions to Assess Shutdown Management,* Nuclear Energy Institute, NUMARC 91-06, Revision 0, 1991.
5. *ORAM-Sentinel^TM Version 3.4 User's Manual: All Modes Maintenance and Safety Function Advisor,* EPRI, Palo Alto, CA: 2001. 1006363.
6. *Outage Configuration Risk Management Consistency Study,* EPRI, Palo Alto, CA: 2003. 1008051.
7. *Qualitative Risk Assessment Methods for Shutdown Risk Management.* EPRI, Palo Alto, CA: 2006. 1013501.
8. *Shutdown Configuration Risk Management Guidelines: Color Aggregation and Treatment of Shared Equipment.* EPRI, Palo Alto, CA: 2015. 3002005277.
9. *EOOS Version 2.6 User Manual*, Science Applications International Corporation. Los Altos, CA. 1997.
10. *Configuration Risk Management Risk Transition Thresholds: EPRI Configuration Risk Management Forum –2012 Research Task*. EPRI, Palo Alto, CA: 2012. 1025292.
11. *Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants*, Nuclear Energy Institute, NUMARC 93-01, Revision 4B, 2015.
12. *Review of Current Practices for Establishing Configuration Risk Management Thresholds for Nuclear Power Plants: EPRI Configuration Risk Management Forum - 2003 Research Task*, EPRI, Palo Alto, CA: 2003. 1007972.
13. *Review of Current Practices for Configuration Risk Management at Nuclear Power Plants: EPRI Configuration Risk Management Forum - 2007 Research Task,* EPRI, Palo Alto, CA: 2007. 1015098.
14. *A Survey of Current Practices for Configuration Risk Management at Nuclear Power Plants: EPRI Configuration Risk Management Forum - 2011 Research Task,* EPRI, Palo Alto, CA: 2011. 1022999.
15. *PSA Applications Guide,* EPRI, Palo Alto, CA: 1995. TR-105396

Export Control Restrictions

Access to and use of this EPRI product is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or U.S. permanent resident is permitted access under applicable U.S. and foreign export laws and regulations.

In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI product, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case by case basis an informal assessment of the applicable U.S. export classification for specific EPRI products, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes.

Your obligations regarding U.S. export control requirements apply during and after you and your company's engagement with EPRI. To be clear, the obligations continue after your retirement or other departure from your company, and include any knowledge retained after gaining access to EPRI products.

You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of this EPRI product hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI members represent 90% of the electric utility revenue in the United States with international participation in 35 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together…Shaping the Future of Electricity

3002012995

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