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Assessing Nuclear Power Plant Risk Management Effectiveness

Technical Report

Assessing Nuclear Power Plant Risk Management Effectiveness

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REPORT SUMMARY

This report provides a description of a risk-management process as a fundamental component of maintaining safety at operating nuclear power plants. It provides a framework around which risk management can be used to effectively control nuclear plant safety risk. It is expected that this framework will evolve based on industry experience and expertise through its implementation at nuclear plants. It is intended that this structure provide a basis from which an efficient transition to a risk-informed, performance-based regulatory structure can be achieved.

Background

Because of changing economic and regulatory conditions, effective nuclear safety risk management will be a cornerstone for both the successful continued operation of existing nuclear power plants and the addition of new nuclear-fueled generating capacity. At the same time, efforts to create risk-informed regulations at existing plants have been slow and costly, in part because of an expectation that any change in risk resulting from the regulatory change must be completely and quantitatively identified, and uncertainties must be accommodated by additional defense-in-depth, performance monitoring, and other conservatisms. Existing risk-management activities can more effectively address these risk concerns. Evidence shows that the nuclear industry is prepared to accept this challenge. Probabilistic risk assessments (PRAs) are common at nearly all plants, configuration risk-management programs support the work management processes, and risk justifications are routine elements of operational and regulatory decisions. In short, there is an increasing risk-management culture at the plants, with many risk-management activities embedded in most plant processes. This report provides a means of describing and assessing this risk-management process.

Objectives

- To identify aspects of risk management that are necessary to adequately control plant safety risk during various operational configurations; support cost-effective transition to a risk-informed, performance-based regulatory environment; and support the licensing of next-generation nuclear generating stations
- To provide an assessment method from which a particular plant's success in implementing effective risk-management policies and developing a "risk culture" is measured
- To obtain insights into the applicability of the methods from limited application at a host nuclear plant site (the structure and methods described herein are intended to provide a starting point from which a risk-management framework can be used to effectively control plant risk and to transition to a risk-informed, performance-based regulatory framework)

Approach

The risk-management approach does not rely on development of new programs but builds upon a solid foundation developed over many years of successful plant operation. It integrates and leverages aspects of risk management currently embedded within existing plant programs and processes. As such, it is directly compatible with the Nuclear Energy Institute/Electric Utility Cost Group (NEI/EUCG) Standard Nuclear Plant Process Model. Using the Standard Nuclear Plant Process Model as a starting point, the risk-management approach described in this report identifies and maps risk-management activities and their critical attributes to existing plant processes. This mapping accounts for the importance of each attribute to plant safety, which then permits demonstration (in a qualitative manner) of the explicit nuclear safety benefits obtained from risk-management activities and development of a methodology to assess the performance of these activities at individual nuclear power plants. The mapping thus provides a mechanism to monitor the effectiveness of the risk-management activities.

Results

The approach described in this report provides a framework for the application of risk management to effectively control safety risk at nuclear power plants. This framework identifies processes and functions in place at commercial nuclear plants that significantly affect plant risk. The approach has also been used to develop an assessment methodology (including a detailed set of evaluation questions) to permit the evaluation of the effectiveness of risk management. The approach was demonstrated by a limited application at a host nuclear plant. This demonstration validated the approach and resulted in several enhancements. However, due to the limited nature of the validation, the completeness of the process and of the evaluation questions has not been fully validated. Thus, additional applications should be performed to validate the methodology to permit industry-wide application.

EPRI Perspective

EPRI has a strategic objective of supporting industry efforts to transition to risk-informed regulations. These efforts require an objective assessment of the safety risk resulting from any change. Of course, there is uncertainty associated with this change, and generally there is an expectation for performance monitoring to verify conditions after the change. Accommodating the uncertainty and verifying performance have proven to be costly and time-consuming. As a result, a risk-informed change often loses its value entirely. This report presents a demonstrated, effective risk-management process that addresses these barriers to risk-informed regulation. This same risk-management process optimizes safety and costs in general. Importantly, this risk-management process comprises activities and resources that already exist at well-run nuclear plants.

Keywords

Risk/safety management (41F)
Probabilistic risk assessment
Nuclear plant operations and maintenance
Risk-informed regulation

EXECUTIVE SUMMARY

The economic and regulatory landscapes of nuclear power generation are changing dramatically. This transition of the generation marketplace has forced nuclear plant operators to become more focused on plant performance and cost. The regulatory perspective is also transforming into a framework that is risk-informed and performance-based. Because of these changing economic and regulatory conditions, effective safety-risk management can be a cornerstone for both the successful continued operation of the existing nuclear power plant infrastructure and the addition of new nuclear-fueled generating capacity, including next-generation plants that use advanced technologies.

This report provides an overview of risk-management activities at nuclear power plants, which complement risk assessment to achieve the objectives of risk-informed, performance-based regulation in a cost-effective manner. The purpose of this approach is to utilize risk management in a manner that allows integration into existing plant programs to effectively support these objectives. The approach described in this report serves as a technical basis for assessing whether risk management effectively controls plant safety risk. To achieve this objective, the approach (1) provides the capability to monitor the effectiveness of risk management, (2) supports risk-based decision-making and regulatory initiatives at operating nuclear power plants, and (3) integrates risk management into future nuclear generating facilities.

Risk management builds upon a solid foundation developed over many years of successful plant operation. It integrates and leverages aspects currently embedded within existing plant programs and processes. As such, it is directly compatible with the Nuclear Energy Institute/Electric Utility Cost Group (NEI/EUCG) Standard Nuclear Plant Process Model (SNPM). Using the SNPM as a starting point, the approach described in this report identifies and maps risk-management activities and their critical attributes to existing plant processes. This mapping accounts for the importance of each attribute to plant safety, which then permits demonstration (in a qualitative manner) of the explicit nuclear safety benefits obtained from risk-management activities. It also facilitates development of a methodology to assess the performance of these activities at individual nuclear power plants, thus providing a mechanism to monitor the effectiveness of the risk-management activities.

This report describes development of the risk-management approach. It is expected that the processes and methods described will evolve as more information and data are gathered and input from plant operators and regulatory agencies is obtained. Thus, it is envisioned that this approach will evolve over time. The process developed during the conduct of this research provides a prioritized catalog of functions necessary for application of effective risk management. It also describes the interactions necessary to ensure that the activities are both effective and cost-efficient, thus providing plant operators the capability to ensure that the necessary programmatic elements are in place to effectively control plant nuclear safety risk and to monitor their effectiveness to ensure that they are achieving the desired outcomes.

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1
INTRODUCTION

The economic and regulatory landscapes of nuclear power generation have changed dramatically over the past decade. Transition to an open-access generation marketplace has forced nuclear plant operators to become much more cost-conscious and focused on plant performance. The regulatory perspective is also transforming to a framework that is risk-informed and performance-based. Because of these changing economic and regulatory conditions, effective safety-risk management can be a cornerstone for both the successful continued operation of the existing nuclear power plant infrastructure and the future addition of new nuclear-fueled generating capacity, including future plants utilizing advanced technologies.

Although increased application of risk-informed and performance-based regulation is an objective of nuclear regulators and nuclear plant owner/operators, plant improvements from risk-informed regulations have been disappointingly few, and license submittals have been complex and costly. This is primarily due to the difficulty in transforming from the current regulatory regime from one characterized by a prescriptive regulatory structure to one where the owner/operator has more freedom to select from a range of solutions that meet the regulatory objective. However, it should be noted that this transformation is not unique to the nuclear power industry but encompasses a wide range of public policy issues dealing with economic negative externalities (in the case of nuclear power plant operation, the risk assumed by the public for the potential health and environmental consequences of a core damage accident resulting in a large release of radioactive material) [1].

In the specific case of application of risk-informed, performance-based regulation of nuclear power plants, the process currently is stuck on the perceived need to use the best available probabilistic risk assessment (PRA) methods, models, and data to quantitatively evaluate the impact on risk before any change is permitted. These analyses are used to predict the future risk from a proposed change to a high level of precision. However, due to limitations in the input data, the complexity of the underlying models, and the cost associated with the analyses, this level of precision cannot be achieved. Furthermore, there is a strong impetus from the regulator to evaluate residual uncertainties in great detail. In the applications of a risk-informed, performance-based regulatory framework to date, this analysis has been required as an addition to the existing regulations, thus increasing costs and resulting in very little actual improvement in safety [2].

This report provides an overview of risk-management activities at nuclear power plants that complement risk assessment to achieve the objectives of risk-informed, performance-based regulation in a cost-effective manner. The purpose of this approach is to utilize risk management in a manner that permits integration into existing plant programs to effectively support cost-effective plant operation and the objective of implementing risk-informed, performance-based

regulatory initiatives. The approach described in this report will serve as a technical basis to verify the process for ensuring adequate nuclear safety throughout the plant life cycle. The intent is to foster a broad application of risk-management principles to ensure that plant safety is maintained at an economic cost that permits competitive operation. To achieve this objective, the approach must provide the following capabilities:

- Provide the capability to monitor the effectiveness of application of risk management
- Support risk-based decision-making and regulatory initiatives at operating nuclear power plants
- Integrate risk management into the next generation of advanced nuclear generating facilities

Achieving these objectives will permit a risk-management focus to support the desired transition to a risk-informed, performance-based regulatory environment. It should be noted that achieving these objectives would provide extensive benefits from both a public health and safety viewpoint (that is, reduced potential for accidents with significant off-site radioactive releases) and from an economic viewpoint (that is, efficient allocation of limited resources with commensurate competitive investment return).

The risk-management approach builds upon a solid foundation developed over many years of successful plant operation. It integrates and leverages aspects of risk management currently embedded within existing plant programs and processes. As such, it is directly compatible with the Nuclear Energy Institute/Electric Utility Cost Group (NEI/EUCG) Standard Nuclear Plant Process Model (SNPM) [3]. A simplified schematic of this model is shown in Figure 1-1. For clarity of this report, only the “level zero” processes are shown, and some process names have been simplified. This model provides a hierarchical mapping of plant functions required to support safe and cost-effective operation. The detailed expansion of the model provides linkage to industry-accepted standards from which effective performance can be achieved and metrics with which this performance can be measured. Use of this structure also has the following additional benefits. First, the structure of the SNPM has been accepted throughout the nuclear industry in the United States as a useful economic model for the purposes of providing cost and operational performance comparisons. Second, The SNPM provides a detailed structural breakdown of high-level activities performed at all plants and thus is generically applicable. Finally, the structure supports development of applicable metrics to monitor and compare performance.

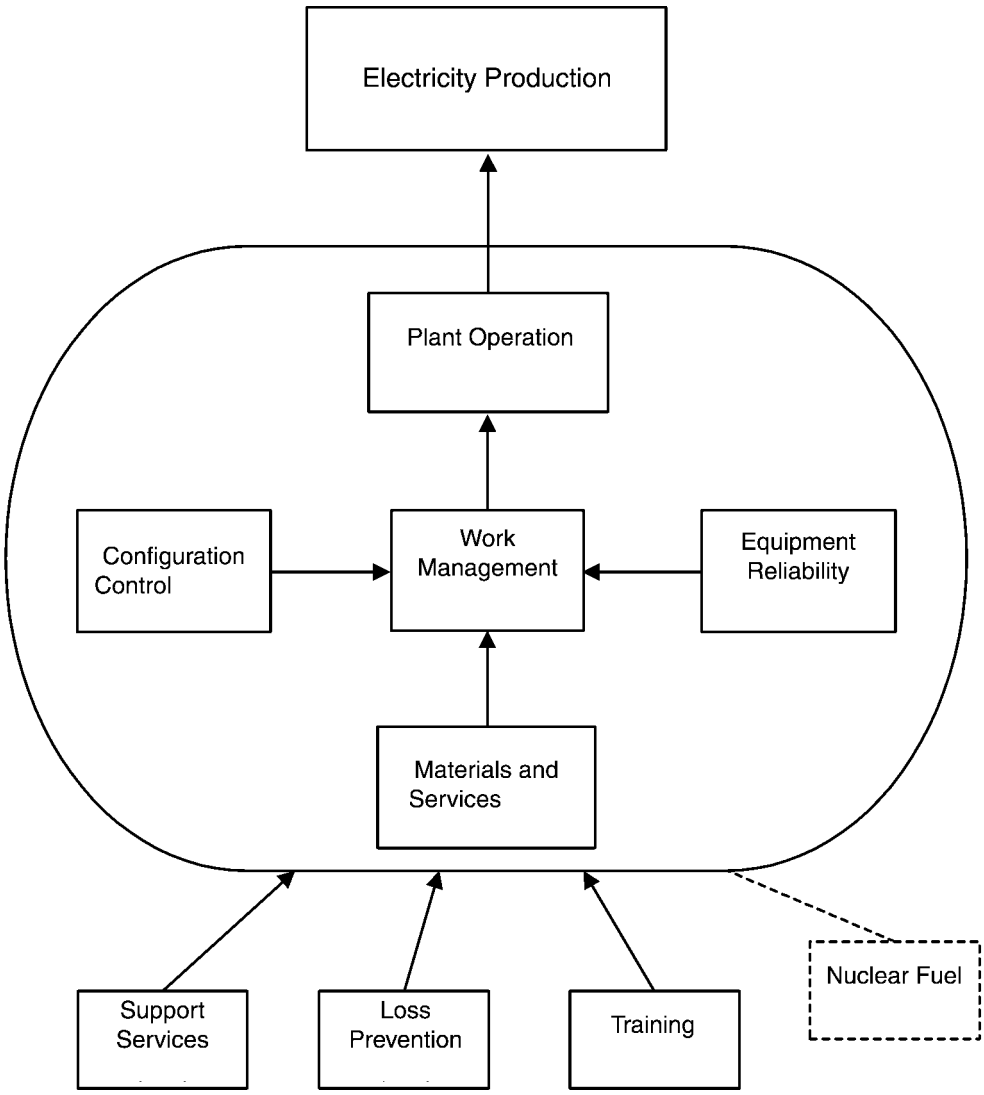

Figure 1-1
Standard Nuclear Plant Process

Using the SNPM as a starting point, the risk-management approach utilizes results from a case study at the Catawba Nuclear station ([2], reproduced here in Appendix A) to identify and map risk-management activities and their critical attributes to existing plant processes. This mapping accounts for the importance of each attribute to plant safety. This then permits (1) demonstration (in a qualitative manner) of the explicit nuclear safety benefits obtained from risk-management activities (benefits that currently are not accounted for in plant PRA analyses) and (2) development of a methodology to assess the performance of these activities at individual nuclear power plants, thus providing a mechanism to monitor the effectiveness of the risk-management activities.

This approach makes maximal use of those portions of risk management that currently are in place at operating nuclear plants. Thus, for most plants, application of risk management will not require the addition of new and expensive programs or technologies. Rather, it will predominantly require management and technical focus to support the new paradigm. To support this shift, the longer-term objective of this research is to develop a risk-management technical basis document that is intended to provide plant owners/operators with a roadmap with which to conduct risk-management activities. This roadmap provides a prioritized catalog of functions necessary for application of effective risk management. It also describes the interactions necessary to ensure that the activities are both effective and cost-efficient, thus providing plant operators the capability to ensure that the necessary programmatic elements are in place to effectively control plant risk and to monitor their effectiveness to ensure that they are achieving the desired outcomes.

2
RISK-MANAGEMENT APPROACH

An important objective of risk management is to provide a basis for supporting change from the current prescriptive regulatory regime to a future risk-informed, performance-based approach. To date, this transition has been slow to occur, has not been cost-effective, and has been limited by very conservative decision-making, usually manifest by the addition of new regulatory requirements onto the existing structure rather than replacement of inflexible prescriptive requirements with effective and flexible ones. This primarily has been due to the inability to account for the uncertainties in the plant PRA models, assumptions, and data. Thus, stakeholders are reluctant to transition to the new paradigm in an expeditious manner. The risk-management approach described in this report supports the desired transition by providing an approach that will ensure that nuclear safety risk is maintained at levels acceptable from a public-safety viewpoint. This approach can be viewed schematically in Figure 2-1.

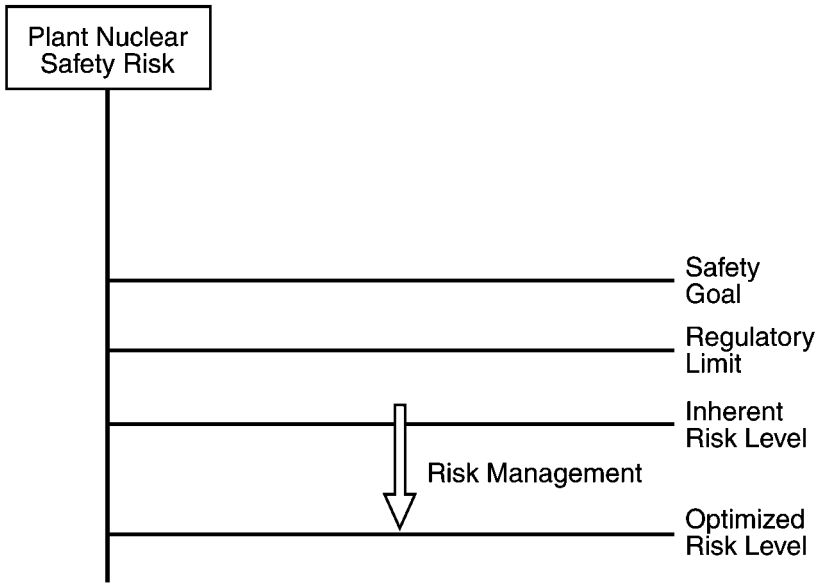

Figure 2-1
Nuclear Plant Risk Scale

Currently, the plant PRA estimates the level of "inherent" risk (risk due to plant design and equipment performance either from generic failure-rate data or generic data that has been updated with plant-specific failure history). However, the PRA does not explicitly model the effect of plant management and implementing processes on nuclear safety risk. Because experience across a wide range of industries indicates that management deficiencies (including programmatic and communication deficiencies) are a significant contributor to accidents [4], the uncertainty introduced by this lack of information in the PRA model has been one of the major

impediments to transitioning to a risk-informed, performance-based regulatory environment. However, the PRA also does not explicitly provide credit for the multitude of risk-management practices (and their effectiveness at reducing risk) employed at all operating nuclear power plants.

As a specific example, no credit is given for implementation of predictive-maintenance technologies to monitor the condition of plant equipment. Use of these technologies has a profound impact on knowledge of the condition of the equipment, such that the failure rates of equipment to which predictive monitoring technologies are applied may be much lower than the average values utilized in the PRA calculations, with commensurately lower overall safety risk than estimated by the model. It should be noted that even if data were collected and plant failure rates were updated to reflect application of these risk-management tools, the beneficial results obtained would not be evident for a significant period of time. This is due to the long lead times required to obtain sufficient data to provide a statistically significant result. Due to these long lead times, it also would be difficult to identify the precise cause of the improved performance. For the case of application of predictive maintenance technologies, this is particularly true due to the rapid advances in the state of the art for diagnostic and prognostic techniques. Because these technologies are typically applied to most (if not all) risk-significant equipment contained in modern nuclear power plants, the individual failure probabilities at any point in time for these components are most likely much less than the average failure rates used in the PRA calculations. Additionally, if monitored equipment is operating with identified degradation mechanisms (detected by the predictive-maintenance technologies), the degradations are identified and analyzed such that timely corrective actions may be scheduled and any other appropriate compensatory actions (such as more frequent application of the monitoring technology to track the progress of the degradation mechanism) are incorporated, thus ensuring that the possibility of unexpected failure is minimized. Application of other risk-management processes results in a similar beneficial effect on reducing overall plant risk.

This reduction in plant risk is counterbalanced by a potential increase due to any existing organizational and management inefficiencies. However, in the SNPM, the equipment-reliability and loss-prevention functions are specifically tasked with monitoring performance across the complete spectrum of the plant (the quality, performance, and health of individual plant components and subcomponents at the micro-scale and the quality, performance, and health of systems and the plant as an integrated entity at the macro-scale, including the effectiveness of management decision-support systems). Since the accident at Three Mile Island, the effective application of these processes has resulted in significant improvement in plant performance throughout the industry (as evidenced by the marked improvement in numerous industry performance measures), with a resultant improvement in nuclear plant safety levels. This has been especially true since the late 1980s, when use of risk-management tools (such as the widespread application of predictive-maintenance technologies, implementation of improved work planning and scheduling processes, and implementation of equipment/system-health monitoring programs) have been implemented throughout the industry. It should be noted that

these improvements have been quantifiably observed, to some extent, in PRA calculation results (primarily due to decreased event initiator frequencies) [5]. Thus, there is significant evidence that application of risk-management techniques has had a profound effect on improving plant safety while concurrently contributing to the improved operational and economic performance of operating plants.

To further advance the improvements obtained to date, and to support a risk-informed, performance-based regulatory framework, application of risk-management techniques will require a more structured approach than has been used to date. However, this should not be construed as requiring the addition of significant new programs and a large attendant overhead and bureaucracy. The required methods and processes can be effectively embedded within existing plant programs and processes. As will be discussed later in this report, there is significant evidence that many of these methods are currently applied at operating nuclear power plants with significant concurrent improvements in plant safety and economic efficiency.

Application of an effective risk-management process consists of the following four elements:

1. Identifying risks

2. Quantifying and prioritizing risk contributors

3. Responding to indicators of risks or adverse trends

4. Maintaining a risk-management culture

In application of risk management to proposed plant changes (including design, procedural, programmatic, and organizational changes), quantifying and prioritizing risks consists of much more than using the PRA to predict the future risk of the proposed change. It also includes the monitoring of risk rates as plant configurations are planned and implemented, monitoring leading indicators that foreshadow changes in risk, and calculating risk after implementation to document the actual risk levels that occurred as a result of the change. Timely response to indicators of increased risk or adverse trends not only controls risk at or below projected levels but also, through proactive improvements, continues to reduce future risk levels. Maintaining a risk-management culture ensures that the process is effective and that it evolves to address emerging issues and incorporates lessons from plant and industry operating experience.

Most nuclear plants do not have formal risk-management programs for public-safety risk. Rather, the application of risk-management activities is embedded as elements of other plant programs. The risk-management approach to nuclear plant safety identifies these activities and demonstrates that they are effective in managing public-safety risks. In effect, they represent a risk-management overlay upon the existing formal processes at the plant. A useful analogy is the process used by organizations to control business-related risks. Most industrial process facilities (including nuclear power plants) do not have formal, standalone programs to manage these business risks, although this is an essential function to ensure the success of the enterprise. These functions are distributed throughout the various line organizations and embedded within their respective programs and processes. The objective of business risk management is not to

eliminate all risk; it is simply to identify the risks associated with a set of potential alternatives, gather sufficient data to analyze the various tradeoffs, and to formulate an appropriate decision that controls the risks at levels that are deemed to be acceptable. These actions typically all must be completed subject to some time constraints. Note that the alternative with the lowest level of risk may or may not be the one chosen via this process. The approach to achieve this objective is to embed appropriate risk analysis tools (from qualitative methods using simple business principles to quantitative methods such as construction of decision trees and calculation of some standard metric such as expected monetary value for each of the possible alternatives) and management controls into the various plant processes. This ensures that appropriate analysis methods are applied, based on the economic significance of the decision, and that decisions are made at an appropriate level within the organization. This approach also ensures that decisions are made in a cost-effective manner with input and concurrence of the various stakeholders [6]. It is this approach that is also being used to control public-safety risk at nuclear power plants.

Because nuclear power plants have safely operated for many years, a large portion of risk management has already been embedded within the plant's processes and procedures. The application of risk management as a structured discipline, therefore, is more of a matter of emphasis and enhancement than one of implementing a new technical/management concept. This transition has provided tangible benefits in improved plant safety and performance throughout the industry. The greatly improved performance of the plants coupled with observations from the initial assessments of risk-management effectiveness conducted at commercial nuclear plants provides strong evidence for this conclusion.

Thus, the first step in implementing an effective risk-management approach at a nuclear power plant is to identify those aspects of the SNPM that have significant risk impact. A generic mapping of these functions is provided in Appendix B. In this appendix, each level-zero SNPM process and its associated first-order sub-processes are categorized based on their impact on nuclear plant safety. The processes are analyzed to the first level because this level (in the SNPM model) is common to all nuclear plants. In the risk-management approach described in this report, the first-level processes can be classified as having a direct, supporting, or inconsequential effect on nuclear safety. Some examples include (note that the process identifier corresponds to the SNPM process identification provided in reference [3]):

Direct Safety Impact:

- (OP001) Operate and monitor structures, systems, and components
- (WM003) Perform preventive maintenance
- (WM004) Perform corrective maintenance
- (ER001) Develop and maintain long-term maintenance plan (PM/PdM programs)

Supporting Safety Impact:

- (MS001) Provide inventory management
- (MS002) Provide materials and services
- (SS001) Provide information technology services
- (LP004) Perform emergency planning

Inconsequential Safety Impact

- (SS005) Maintain grounds, facilities, and vehicles
- (SS006) Support community and government services

See Appendix B for a complete discussion of the SNPM level-one processes. In the risk-management approach described herein, the level of management attention prescribed to the process would be commensurate with its identified safety impact. This can be seen, in a qualitative sense, by the number of evaluation questions developed to measure the effectiveness of each process (see Appendix C for a listing of the questions developed to support conduct of the risk-management assessment process).

Because these activities are typically distributed throughout various plant organizations, it is then necessary to identify which organizations are responsible for each activity. It should be noted that in many cases, these responsibilities overlap and require the interaction of several organizations within the plant. A common example of this is the interrelationship between the day-to-day responsibility for providing configuration control and the various activities required to support the work-planning process. Because of these distributed responsibilities, an important element of ensuring effective risk management is the interface between the various organizations responsible for decisions, with potential risk implications. Thus, an important element of risk management is to ensure that the various processes permit efficient dissemination of information and that the interfaces between organizations are effective at communicating this information and working in a collaborative manner to reach appropriate decisions.

Inclusion of the channels of communication and their effectiveness in a risk-management approach is crucial to ensuring its effectiveness. Analysis of safety statistics in industrial applications indicates that at least 50% (and in some studies up to 85%) of industrial accidents are attributable to human error [7]. For mature technologies (such as nuclear power production, commercial aviation, and petrochemical processing), these statistics are not surprising. For these industries, lessons learned from previous events have been firmly embedded into system designs and operational procedures. These corrective actions have effectively eliminated many of the potential causes of accidents for these technologies and thus reduced the occurrence of significant incidents to a low level. For this reason, when a significant event does occur, it is typically characterized by multiple causal factors, often with significant human-performance and management-related elements.

Analysis of accidents within the oil industry also indicates two recurrent themes that directly contributed to accidents: (1) an emphasis by management, either explicit or perceived, of speeding up the work process to achieve increased productivity and (2) failed communications, both within and among the various plant organizations. Similar conclusions have been drawn in studies conducted within the nuclear power industry [8, 9]. Therefore, inclusion of these decision processes and communications channels is a vital element in ensuring effective risk management.

As a specific simple example of the degree to which these functions are interrelated, consider the interfaces between the operations, engineering, and work-planning functions required to identify and successfully resolve degraded performance of a plant component. First, identification of degraded performance requires effective performance of equipment monitoring to detect the degraded performance or condition. Using the sub-processes identified by the SNPM (see Appendix B for a tabulation of these designations), this action requires successful performance of functions OP001, ER001, and ER002. Once degraded performance is identified, operations must determine if any changes to plant configuration are required (function CC001). Next, the cause of the degradation must be determined (functions ER003 and ER004), appropriate work instructions must be generated (function WM001) and integrated into the plant schedule (function WM002). Prior to performing the corrective actions, necessary parts must be procured, receipt-inspected, and stored (function MS001). When the work is scheduled to be performed, the equipment must be removed from service (operations perform function CC001), parts must be obtained from the warehouse (function MS001), maintenance must be performed, and the identified corrective actions must be carried out (function WM004). Once the work is completed, the equipment must be verified as acceptable for return to service via post-maintenance testing (function ER002) and returned to service (functions CC001 and OP001). The impact on system and plant performance must be evaluated (function LP002), and any changes to the long-term maintenance plan for the equipment identified (function ER001). Throughout this process, the work orders, clearances, and other required electronic work authorizations must be obtained (requiring function SS001) and, for performance of the work and post-maintenance testing, the necessary procedures obtained (function SS003).

Thus, as is illustrated by this example, even the performance of this simple activity (one that is performed repeatedly on a daily basis at all plants) is complex and requires numerous interactions between the different processes with multiple interfaces between different organizations. Thus, an important component of an effective risk-management program is that these interfaces be in place and function effectively.

One of the major benefits of the SNPM is that it provides a standard set of processes against which individual plants can compare their operation. At all domestic nuclear power plants, the elements of the SNPM have been demonstrated to be in place and functioning. From a risk-management perspective, there is direct evidence that these functions are effective at limiting risk for at least one operating plant, and there is some objective evidence that these functions are

effective at most operating plants [2, 5]. However, from a regulatory perspective, if the risk-management approach is to be successful at furthering the transformation to a risk-informed, performance-based regulatory environment, an objective method of evaluating the effectiveness of the approach is necessary. This verification requires assessment of the following six criteria:

1. Appropriate indicators of nuclear safety risk are monitored. These risk indicators must be capable of being linked to the results predicted from the plant PRA studies. To achieve this objective, indicators related to annual average risk (core damage frequency [CDF] and large early release frequency [LERF]) and risk rate (instantaneous core damage probability and large early release probability) are monitored and verified that they were maintained at an acceptable level for the duration of the monitoring period.

2. Functions are in place to prevent risk-important safety challenges and to prevent poor response of plant equipment and personnel for events that are risk-significant. These functions include monitoring of leading indicators of degradation. It should be noted that many of these indicators are identical to performance measures currently in place and are used to monitor performance over time to support other regulatory-required programs, such as maintenance rule monitoring.

3. Causes of risk-significant degradations and of actual risk-significant events are evaluated and corrected. The depth of these evaluations is commensurate with the potential risk impact of the event and its generic applications and is of sufficient depth to identify basic underlying causal factors, including those due to management and organizational issues.

4. The risk impact of risk-informed changes is verified by performance monitoring. The cumulative impact of risk-informed changes is verified to be within anticipated and acceptable levels.

5. Risk-management activities evolve in response to plant changes and plant and industry experience, and the effectiveness of the program itself is regularly evaluated.

6. The culture of the staff and the plant organization are structured to accomplish effective risk management.

Thus the risk-management approach described in this report encompasses (1) embedding the four elements of risk management into the appropriate functions in the SNPM, (2) ensuring that the organizational structure provides adequate interfaces between the responsible implementing organizations to effectively carry out these functions, and (3) providing a method and metrics to evaluate the effectiveness of the risk-management overlay. To achieve these objectives, the risk-management approach described in this report builds upon models and processes previously developed and successfully applied within the nuclear industry. It is intended to provide an initial framework from which a complete risk-management approach can evolve, thus providing improved operational safety performance and fostering transition to a risk-informed, performance-based regulatory structure.

3
ASSESSMENT ROADMAP

An important consideration in implementing the assessment process described in subsequent sections is performing both the management and technical activities necessary to ensure success. As will be seen, the assessment process is versatile and permits a variety of implementation strategies. For example, it can be used to evaluate the integrated effectiveness of a plant's risk-management program from a macroscopic "big picture" viewpoint, or it can be utilized to evaluate a specific identified element of the process (microscopic viewpoint). It also provides a variety of potential assessment methods from which to choose. Because the assessment process possesses this multiplicity of capabilities, this section provides a roadmap that describes items that should be considered in its application. This roadmap is provided schematically in Figure 3-1. A short description elaborating each process step follows:

1. Define assessment objective: Identify the purpose of the assessment to be conducted, which can be broad or narrow in scope. Examples of the latter include assessments to determine the extent to which the plant may be susceptible to repeating an event that recently occurred at a different plant, performance of a thorough review to address an issue identified by an external agency (Nuclear Regulatory Commission [NRC], Institute of Nuclear Power Operations [INPO], and so on) or proactive review to determine potential consequences of implementing a proposed process change. This step should also identify any constraints (schedule, budget, team member composition, and so on) that may exist and need to be addressed.
2. Define assessment method: Determine which individual or combination of assessment methods described in Section 5.2 is most appropriate to achieve the objectives and fit within any of the identified constraints.
3. Select assessment team: Identify and obtain resources necessary to conduct the assessment, including plant staff, sister plant staff, corporate support staff, industry peer, and external consultants.
4. Prescribe assessment logistics: The end result of this step is a schedule for performing the assessment that has incorporated actions necessary to conduct it in an efficient and effective manner. At this point, the proposed integrated process should be reviewed against the identified objectives to verify that the assessment will achieve them.
5. Determine what are risk-significant functions: Based on the assessment objectives, identify the risk-significant functions that contribute to these objectives. The descriptions of the SNPM first-level functions provided in Appendix B and the detailed assessment questions provided in Appendix C can be used to facilitate this task.

6. Determine who performs the functions: For each identified risk-significant function, identify the appropriate plant staff that is responsible for its performance. If multiple organizations are involved, identify the necessary interfaces and processes used to achieve its performance.
7. Evaluate assessment questions: This step uses the questions provided in Appendix C as a starting point to develop the detailed list of questions and issues to include in the assessment. It is important to recognize that this listing should be considered a minimum set, and the assessment team should develop additional specific questions that directly address the objectives. Also, the assessment team should review the question weightings and modify them as appropriate to reflect the assessment objectives. Finally, the entire assessment construction should again be reviewed to ensure compatibility with the identified objectives.
8. Conduct the assessment: This task obtains data by conducting surveys, targeted interviews and/or observational studies as specified in the assessment plan. Guidance on the conduct of the assessment is provided in Section 5.
9. Score and evaluate the responses: This task analyzes the data obtained in the previous step. At this point the assessment team determines if sufficient data have been obtained to develop conclusions and recommendations or if further data are required. If more information is necessary, the process returns to the question of who performs the functions to determine additional personnel from which to obtain the required information.
10. Develop conclusions and recommendations: This step develops the conclusions and recommendations based on the information obtained during the survey.
11. Reconcile results with objectives: Prior to presentation of the conclusions and recommendations to management, the assessment team should reconcile these with the original assessment objectives to ensure that all of the objectives were achieved.

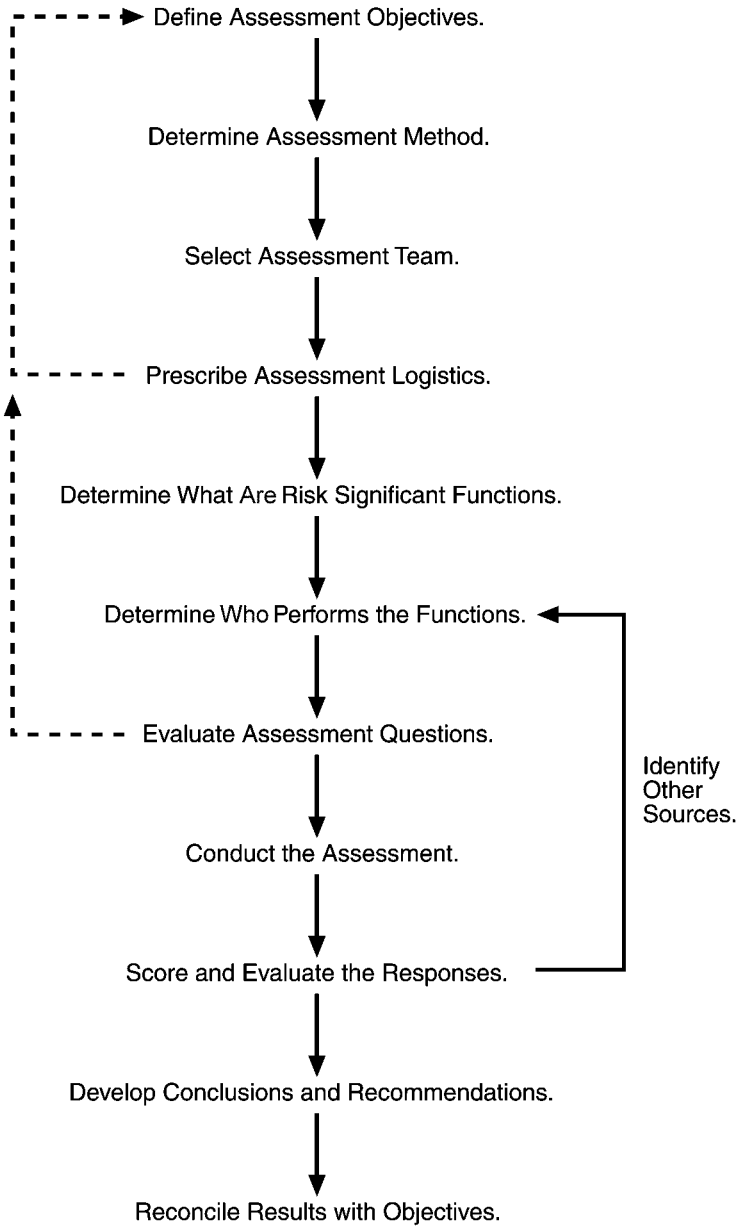

Figure 3-1
Assessment Process Roadmap

4
OVERLAY OF RISK MANAGEMENT ONTO PLANT PROCESSES

The first action to ensure an effective risk-management process is to embed the four elements of risk management into the appropriate functions in the Standard Nuclear Plant Process Model. Recall that these elements consist of the following:

1. Identifying risks
2. Quantifying and prioritizing risk contributors
3. Responding to indicators of risks or adverse trends
4. Maintaining a risk-management culture

To achieve an effective risk-management overlay, each organization (operations, maintenance, engineering, and so on) must possess a culture that is focused on identifying the risk implications of degraded equipment condition or performance and of scheduled plant activities. Plant personnel also must be vigilant in assessing these risks with their corresponding likelihood of occurrence and then aggressively follow up on the approved resolutions. In the following sections, specific actions are provided for each of the processes that compose the SNPM. Appendix B provides a discussion of the risk importance of the individual first-level sub-processes for each main level-zero process.

The result of the analysis provided in this section is an initial catalog of those functions, as defined in the SNPM, which provide a discernable impact on plant risk. It also identifies those risk-management activities and processes that have been applied at operating nuclear plants and have contributed to effective control of plant safety risk. As the process of risk management matures, it is expected that these processes will evolve to include new techniques to more effectively and efficiently manage risk. As such, the approach described in this report provides a point of departure for implementing risk management, developing an effective risk culture, and achieving a competitive, cost-effective plant operation.

Operations

From a nuclear-safety perspective, the plant operations process is the first line of defense in ensuring that risk remains at an acceptably low level. In addition to operating the plant, operations personnel also provide a significant interface to all of the other plant processes that, in a fundamental manner, directly support plant operations. From a risk perspective, operations

personnel have a unique integrated and intuitive understanding of the relationship of equipment reliability and availability to plant operations and safety. As the personnel who are specifically tasked with controlling plant evolutions and configuration, they provide a direct (and sometimes immediate) impact on plant risk. These key elements are each discussed in detail.

Integration of Operational Perspective into Other Plant-Decision Processes

A key contributor to effective risk management is the degree to which operations personnel are involved in decision making for the other processes identified in the SNPM. This is particularly true with respect to the model's core processes. Industry experience indicates that embedding operational experience into these decision-making processes provides for more effective communications, more robust prioritization of work activities, and more efficient utilization of resources. Additionally, involving operations in these decision processes provides a similar clarification in the perspective that operations has on different issues. Thus, this interaction has important reciprocal benefits and, from a nuclear-safety perspective, provides significantly improved decision-making capability for all of the processes involved. Also, because all of the other core processes impact the plant operations process, operations input into them will help limit the risk impact incurred from them. From a risk-management perspective, two areas of interface with the operations process are of particular importance: operations involvement in the work management and equipment reliability processes.

Integration of Operations in the Work-Management Process

Because of its unique role in controlling plant configuration and evolutions, operations is a vital contributor to developing effective integrated work schedules. This includes input on identification of degraded equipment, ensuring proper prioritization, ensuring compliance with plant technical specifications and other regulatory requirements, selection of applicable post-maintenance testing requirements, and determination of any transitional compensatory actions. All of these interfaces have significant consequences for managing risk. As a specific example, consider the case of a safety-significant component being removed from service for repair (for example, a high-pressure injection pump). Providing an appropriate interface from operations during the planning process will ensure appropriate operator resources required for necessary tasks such as clearance application and removal and performance of post-maintenance acceptance testing are identified. Providing communications mechanisms between operations and the organizations performing the work (maintenance crafts and planning and scheduling personnel) while the work is in progress will help ensure that the previously identified resources are available at the required times during the repair process, thus allowing an expeditious return to service of the equipment and effectively managing plant risk.

Because operations is directly charged with plant configuration control, it also has the most timely knowledge of the status of plant equipment and systems. If operations is also effectively integrated into the equipment-reliability process (see next item), it also will possess a detailed knowledge of the operational condition of alternate equipment, which may be required for use while the proposed scheduled activities are performed. Hence, effectively integrating the operations function into the work-management process will result in an improved capability to manage and control plant risk.

Integration of Operations in the Equipment-Reliability Process

Because operations personnel are continuously present at the plant, they provide a unique capability to identify any degraded conditions or performance in plant structures, systems, and components (SSCs) at an early stage. Thus, they serve a unique role in ensuring high equipment availability and reliability. To provide maximum safety benefit, this function requires a close working relationship with personnel tasked with monitoring the performance and condition of plant SSCs. As a fairly common example of effective risk management, operations personnel, upon noticing conditions outside normal expectations (such as warmer-than-expected temperature when placing one's hand on a bearing cap, unusual noise from rotating equipment, or installed instrumentation with indications near the upper or lower operating range as observed on plant rounds), inform responsible system engineering and predictive-maintenance personnel to investigate the potential anomaly. This information then can be used to specify appropriate actions (such as obtain additional predictive-maintenance data or analyze performance data for any previously unidentified trends or statistical deviations) to determine if degradation in performance or condition is occurring and, if so, determine the basic cause and specify any necessary corrective actions. Operational performance at this level has been proven to be effective at identifying incipient degraded conditions and thus is an important element in achieving effective risk management.

Maintaining Awareness of Current Risk Levels and Contingency Actions

In addition to the issue of operational interface with other processes, it is also important for operations personnel to be aware of the current risk status of the plant. Thus, it is important to provide an effective mechanism to convey this information to operations personnel. To be fully effective, this information consists of the current and planned near-term future state of the various plant safety functions, preferred systems for use to achieve these safety functions (if needed), any high-risk operational configurations to be avoided, and any required contingency actions that should be taken to mitigate plant risk. For effective risk management, processes will be in place to provide these functions. In addition to maintaining this awareness, operations personnel should have the capability to assess changing levels of risk due to unforeseen events. This should include the capability to make preliminary estimates of the impact of the event on plant risk and any required changes to the plant configuration or scheduled work.

As a specific example of this, several commercially available risk-management software packages provide the capability to assess emergent changes to equipment configuration "on-the-fly" using "what-if" analysis features. At many plants, these tools are available to plant control-

room personnel to perform these analyses in the event of an unforeseen change in plant equipment configuration (such as failure of a plant component that provides a high-level safety function). These assessments provide a rapid capability to assess the new status of high-level plant safety functions and provide a revised prioritized listing of equipment for use in the event of a significant initiating event (a protected equipment list). It should be noted that these assessments provide an additional level of protection beyond that provided in the actions required to meet the plant technical specifications.

Configuration Control

The configuration control process of the Standard Nuclear Plant Process Model includes activities that control the NRC licensing design basis of the plant. However, many of the same activities control the design and operational basis from an integrated-risk perspective—that is, considering cost, performance, environment, and safety. These activities include control of plant modifications, control of procedures and technical specifications, effectiveness assessments, and benchmarking activities.

Control of Plant Operational Configuration

Of primary importance, over the short term, is the function of controlling the plant operational configuration. Because this function is performed by plant operations, all of the discussion of the previous section applies. To ensure effective operational configuration management, nuclear plants utilize a structured control hierarchy. This hierarchy consists of three levels:

1. Regulatory controls
2. Procedural controls
3. Planning controls

At the highest level is a regulatory control layer, which consists of the plant operating license. Examples include the plant design basis (as specified in the final safety analysis report) and the plant technical specifications. These controls place explicit limits on permissible operational configurations and required actions to be taken (with associated time limits) if the permissible conditions cannot be met. At the next level, detailed procedural and process controls are in place. These controls provide detailed direction for ensuring that the license basis is met. They also provide explicit management controls with designated levels of review and approval authority. Finally, at all operating nuclear plants, detailed operational and maintenance plans are put in place. These plans provide detailed scheduling and sequencing of activities. For evolutions with the potential to significantly increase risk, these plans also specify explicit contingency actions to be taken.

To support operational configuration control, it is important that effective tools and processes that specify the current configuration of the plant are available to operations personnel. This is particularly important for maintaining the status of equipment for which control-room indication is not available. Note that this control is applicable in all operating modes (normal operations,

startup/shutdown, and outage [including refueling]), with specific requirements and controls for each mode. It also should be noted that the software tools mentioned in the operations section can provide both operations and planning personnel with a valuable resource to manage plant configuration. This is particularly true for the normal operating and outage regimes. Because plant startup and shutdown events are much shorter in duration (typically lasting only several hours), configuration control for these evolutions is typically limited to procedural controls for these regimes.

Response to Regulatory-Oversight Process

An important risk-management activity at the plant is the specific response to indicators, findings, and observations from the regulatory oversight process (ROP). The ROP is a risk-informed, performance-based process that calls for a graded plant response to indications of declining safety performance. The plant monitors prescribed performance indicators for seven cornerstones of plant safety. These trendable indicators provide a risk-management opportunity for the plant. The plant also responds to safety-significance determinations of events and inspection findings. These determinations, as part of the significance determination process (SDP), provide another opportunity for risk management.

Control of Plant Design Changes

The next necessary activity associated with configuration control is to incorporate information from nuclear risk assessments in the design change decision-making process. Results and insights gained from risk studies provide vital input in the design change process, including prioritization of different plant modifications and reliability analysis of different design alternatives. The extent to which these evaluations are performed should be commensurate with their potential safety impact. The methods used can range from quantitative analyses (using PRA fault tree/event tree analysis techniques) for design changes that are expected to provide significant safety impact, to qualitative methods such as a failure modes and effects analysis or a checklist of pre-identified plant- and system-level effects. The insights gained from these studies can then be used to optimize the design and specify any necessary actions to control risk and develop appropriate metrics to monitor performance once the design change is implemented.

However, it is important to note that inclusion of risk assessment results and insights should be one of several dimensions evaluated in the decision-making process. As previously stated, the objective of risk management is to provide the maximum reduction in plant risk for the lowest possible cost. However, to be feasible from a business perspective, the decision process must also account for all of the other constraints and external influences that impact the decision. It is important to recognize that attempting to reduce risk for each individual decision may result in a higher overall level of plant risk than could have been achieved if other criteria are accounted for in the decision-making process. This occurs because only a finite amount of resources can be made available for application to the plant; thus a minimization in plant risk over any time period can be accomplished if only all of the applicable issues (including both plant risk objectives and economic constraints) are included in the decision process.

Work Management

To date, the work-management process is the one that has found the most comprehensive application of risk-management techniques. This has occurred due to two factors. First, the economic imperative of transforming from a regulated monopoly to an open-access competitive market has required nuclear plant operators to significantly improve plant performance while controlling costs. Second, regulatory initiatives (including the maintenance rule) have intensified the imperative to focus on directing resources to areas that have a direct impact on plant risk. As a result, all domestic operating nuclear power plants have implemented risk-management considerations and practices into their work-management processes.

Configuration Risk Management Employing Maintenance Rule Paragraph (a)(4)

A structured configuration risk-management (CRM) process using results—and in most cases, models based on the plant PRA—are prevalent at U.S. nuclear power plants. 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 developed and demonstrated methods and models for CRM. The regulator encouraged the use of CRM and even required it for one aspect of the maintenance rule. Specifically, plants evaluate the risk significance of all equipment outage configurations in all modes of operation and take appropriate risk-management actions. 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.

Application of Production and Operations Management Techniques

Many of the work-management techniques applied at operating nuclear power plants that provide significant risk management benefit are business tools from standard production and operations management theory. Some of these tools used to manage risk in the work management process are:

- Application of schedule optimization/resource loading strategies (linear programming, queuing theory, and so on)
- Implementation of detailed long-range (operating cycle) maintenance schedules, including incorporation of rolling system outage schedules to conduct necessary maintenance activities during plant operation
- Development of functional equipment groups (FEGs), which facilitate schedule integration
- Development of standardized work practices
- Implementation of fix-it-now teams to handle minor maintenance problems
- Incorporation of dedicated work control centers and work-week managers (see below)

These concepts, taken from standard production and operations management techniques [6], have contributed to more efficient and productive use of highly skilled resources, reduced maintenance backlogs, and improved equipment, system, and plant performance. From a business perspective, they also have had significant benefits in containing costs and improving workforce productivity.

Assignment of Dedicated Work-Control Personnel

- Normal Operations – Work-Week Managers

An important improvement in the work-management process has been the implementation of dedicated personnel (known as work-week managers or work-week coordinators) whose primary responsibility is to coordinate activities for the work week. These individuals are assigned a work week at the initiation of the detailed planning and scheduling process (typically about six weeks prior to execution) and are involved with the detailed planning and scheduling of work activities for that week. During the execution week, these individuals track the work to ensure that it is progressing as planned, and if unforeseen issues arise, they are involved in ensuring that appropriate decisions are made and that senior management becomes involved when necessary. In the best functioning programs, these individuals provide a single point of accountability and management decision-making authority for all activities scheduled for that week. Also, in the most successful programs, these individuals have detailed knowledge of both integrated plant operations and risk-management techniques. They are also well versed in utilizing the risk-management software tools to support the decision-making process. In application of these processes, the key element is not the details of the processes (for example, number of weeks contained in the look-ahead or the particular organizational structure utilized) but rather the integration of all the elements and interactions associated with the planning and scheduling processes.

Typically, the work-week managers are well versed in the application of risk-assessment techniques and the specific results obtained for the plant (such as results from the plant PRA and interrelationships between plant equipment and high-level safety functions). They also are well trained in use of the risk-management software tools and analysis of the calculated results. Thus, these personnel provide a direct capability to assess and manage plant risk on an ongoing basis. As will be seen in Section 4, these personnel have been instrumental in providing a strong safety focus to the work-management process.

- Outage Conditions – Shift Outage Directors

The work-week manager concept also has been applied to management of refueling outage activities. This has included placing single-point accountable personnel on each shift (typically called shift outage directors) to monitor outage evolutions and ensure that appropriate decisions are made. Like the work-week managers described in the previous paragraph, these individuals provide a single point of contact for the various organizations performing individual work activities, thus greatly improving communications between plant organizations. Like the work-week managers described previously, these individuals also provide a single point of accountability for decisions. Additionally, at the plants that have been the most successful in implementing this approach, when planned activities with significantly increased levels of risk

occur (such as mid-loop operation), senior management personnel cover the work over all shifts in which the high-risk condition occurs. This level of involvement has contributed to a significant decrease in the number of industry events with potential safety impact during these configurations.

Metrics and Process Improvements

To be effective at controlling risk, the actual work conducted must be compared to the scheduled activities. Thus, effective and comprehensive metrics are necessary to assess the degree to which the work-planning process is successful. In addition to the use of metrics, an effective approach implemented at many plants has been to perform routine critiques after each scheduled block of work (such as at the completion of each work week or post-outage). These critiques, if conducted in an open environment, can result in identification of significant improvements, which may be incorporated in upcoming evolutions. During the preliminary plant evaluations used to ascertain the applicability of the risk-management approach (discussed in Section 4), the combination of applicable metrics and effective critiques was found to provide an important element of implanting a risk-management approach. These techniques foster an environment that is performance-based and facilitates continuous improvement.

Equipment Reliability

The equipment-reliability process of the SNPM is a major cornerstone in effectively controlling nuclear safety risk. This is because equipment reliability is directly related to the prevention and mitigation of plant challenges through the response of plant equipment and systems. Both plant operators and regulatory authorities have recognized this fact. As an example, many of the activities required by the maintenance rule directly impact the equipment-reliability function [10]. As such, significant industry resources (and regulatory attention) have been directed at addressing equipment-reliability issues. This has resulted in investments in technology and management systems to achieve these objectives. It has also provided a significant payback from improvements in terms of both plant safety and economic performance.

System-Health Monitoring

A major contributor to implementation of risk management is the concept of monitoring system health. This approach has been implemented successfully at a large number of plants. In the system-health approach, engineering personnel periodically evaluate the condition and performance of the systems for which they are responsible. Various aspects of performance and condition are assigned grades, typically via a red (unacceptable), yellow (degraded), white (marginal), and green (acceptable) color-coding. These “report cards” are presented to responsible plant managers for review and approval. Typically this review requires the responsible engineer to provide a justification/defense of the grade, thus ensuring that the assessment is an impartial evaluation of system health. This approach has proven to be a very useful and effective tool to monitor system performance, identify and prioritize performance issues, allocate resources, and ensure appropriate management involvement in the decision-making process. For plants that utilize a multidisciplinary review of the system-health

evaluations (those that include operations and maintenance managers as part of the management review team), the system-health grades also reflect the information obtained from these perspectives and provide of a more robust process than if review is conducted using only engineering personnel. Thus, monitoring system health helps to control risk by broadly disseminating system and equipment performance information to plant management. This supports the effective prioritization and application of resources, with concurrent benefits to plant performance and safety.

Specification of an Integrated Maintenance Strategy

A second important component of the equipment-reliability process is the specification of an appropriate maintenance program for plant equipment. This process includes specification of appropriate predictive-maintenance technologies to assess equipment performance and condition. Analytical tools have been developed and applied at numerous nuclear power plants, tools that provide systematic engineering approaches to specify appropriate proactive maintenance and performance monitoring. These tools have included technologies such as:

- Reliability-centered maintenance (both classical and streamlined versions) [11, 12]
- Generic maintenance plans (specific to different component types, commonly known as maintenance templates) [13]
- System monitoring process specification [14]

Additionally, increased application of predictive-maintenance technologies has resulted in improved capability to detect incipient degradation in significant plant equipment, resulting in a large reduction in unanticipated equipment failures and improved scheduling efficiency. In particular, from a safety standpoint, it should be noted that the application of predictive-maintenance technologies has had the effect of reducing plant failure rates below the average values typically assumed in plant-safety analyses using generic data. Thus, unless these failure rates are updated (such as via Bayesian updates) using plant-specific failure data, the results of the risk-assessment studies will overestimate the analyzed risk due to failures for those components on which comprehensive diagnostic and prognostic technologies are employed to assess equipment health and condition. (Note, however, that this may be compensated for in the analysis by underestimates of the risk due to issues such as human error probability, management and programmatic inefficiencies, and so on). It also should be noted that due to the long time lags required to obtain a statistically significant amount of performance data to provide these updates, the benefits of these technologies on plant safety might not be reflected in the model results until well after the effects are realized. Thus, application of predictive-maintenance diagnostics/prognostics provides a practical example of the benefits of implementing a risk-management approach without the need to perform a detailed quantitative evaluation of the potential risk benefits prior to implementation.

Performance Analysis and Improvement Programs

An additional risk-management technique in place at many plants is the implementation of a formal performance-improvement program. Although this program is part of the loss-prevention process, a large portion of the items relate directly to plant equipment reliability and performance. Because these programs address risk in the broadest sense, they provide an important element for the identification and prioritization of equipment performance issues.

Integration of Equipment Reliability in the Operations and Work-Management Processes

Similar to the plant-operations process, the success of the equipment-reliability process to effectively manage risk directly depends upon the capability to interface with the work-management and operations processes. This is true with respect to both interdepartmental and intradepartmental communications. As an example of the former, one aspect of robust decision making is the extent to which personnel involved with performance of different predictive maintenance technologies are effective in communicating with each other to obtain corroboration of results from data obtained from multiple technologies. These personnel must also communicate the results to the responsible system engineer. An example of the latter is the communications between these engineering personnel and shift operations and the planning and scheduling organizations to take appropriate actions to prioritize and schedule necessary corrective actions.

Materials and Services

The major portion of this process directly supports the work-management process; in particular, the majority of the sub-processes are necessary to support the efficient conduct of maintenance on plant equipment. Thus, the previous discussion for the work-management process applies to this process also.

Inventory-Management Technologies

Application of advanced inventory-management techniques (such as blanket purchase orders, use of commercial off-the-shelf (COTS) parts, and just-in-time delivery) has resulted in improved availability of necessary parts and more economical operation of this function at a large number of plants. An additional technique, which is applicable to utilities with operations at multiple plant sites, is the capability to share spare parts between these sites. On an industry-wide basis, membership in the Pooled Inventory Management System (PIMS) provides an economical method to maintain immediate access to equipment with high capital costs and long lead times.

From a risk-management perspective, these technologies provide a supporting impact on plant risk. They are necessary to ensure that appropriate spare parts are available to support plant maintenance activities. These activities, which identify appropriate on-site warehousing and procurement/delivery schedules, help ensure the capability to obtain necessary parts in a manner that does not significantly increase the unavailability of equipment important to plant safety.

Integration of Materials and Services in Work-Management and Equipment-Reliability Processes

From a risk viewpoint, there are two significant process interface issues that are important for the materials and services process to address. The first is the interface between the materials and services process and the equipment-reliability process. Effective interaction between these two processes is necessary to ensure that decisions about spare parts incorporate information on equipment functional importance and the specified maintenance plan for plant equipment for which the part is applicable. Effective interface between these two program elements ensures that spare parts necessary to support risk critical maintenance activities are either available on site or are obtainable within a very short time. The second is the interface between the materials and services and the configuration-control processes to address equipment obsolescence. As the existing fleet of operating plants ages, this issue is becoming increasingly critical in maintaining plant performance at a high level but in a manner that is economical and meets regulatory requirements.

Support Services

The support-services process provides direct support to the core processes. However, the associated sub-processes impact only plant safety through their impact on the core processes. Of particular importance are (1) the impact of information technology on the implementation of the core processes and (2) the impact of human-resources services to attract and retain a highly competent plant staff.

Information-Management Systems

Information-management systems at nuclear plants provide the enabling technologies for efficient implementation of the core processes. Thus, they are necessary to facilitate effective decision-making and support successful risk management. Previous studies [15] that analyzed the performance of maintenance decision making from an information-management perspective indicate the necessity of ensuring effective information flow to decision makers at key steps in the process. Advances in information technology, particularly the advent of the Internet, with online access to industry standards and information, and the implementation of corporate-wide intranet networks, have resulted in improved decision making by providing nearly instantaneous access to relevant information. As information technology evolves, risk-management timeliness and integration are expected to improve even more. As an example, all of the information

contained in the preventive-maintenance basis guidelines [13] mentioned in the equipment reliability process discussion is available to EPRI member nuclear utilities as an on-line database. In addition to the information in the written reports, the database contains a large amount of failure mechanism information with calculation tools to allow the user to analyze the changes in risk associated with the implementation of different maintenance strategies.

Human-Resource Services

As the average age of the fleet of operating plants increases, knowledgeable personnel, with many years of experience, leave plant employment (due to retirement, advancement within the company, or pursuit of other external opportunities). An important aspect of this process is to develop and implement strategies to ensure that the knowledge base inherent in the plant staff becomes embedded within the organization's processes and procedures. It also is important to ensure that incentives are in place to attract and retain highly qualified and knowledgeable personnel to maintain this expertise over time. This is especially important as the industry transitions to a deregulated structure in which the most qualified, best performing individuals will have an increasing variety of opportunities (both internal and external) from which to choose. Additionally, as technology (such as information technology and predictive-maintenance technologies) and management theory advance, it is important to provide mechanisms to obtain these skills and apply them throughout the plant.

Loss Prevention

Similar to the equipment-reliability process, the loss-prevention process is a major cornerstone in effectively controlling nuclear safety risk. This is because, like the equipment-reliability process, this process is directly related to the prevention and mitigation of plant challenges. Thus, the generic implications discussed for the equipment-reliability process are equally applicable to the loss-prevention process. Additionally, many of the activities necessary for effective risk management are performed as part of the loss-prevention process and its sub-processes and address risk in the broadest sense. Among the issues addressed are public safety, environmental impact, personnel safety, and asset protection. Activities associated with this process include licensing, safety assurance, severe accident management, emergency preparedness, probabilistic risk assessment, cost/benefit analysis, fire prevention, review of generic safety concerns, and plant security.

Use of Risk Oversight Management

An important aspect of loss prevention is the specification and use of organizations specifically tasked with managing risk. These organizations provide direct evaluation and assessment of risk and provide feedback to line management of the risk impact on various plant issues and decisions. Because of their primary safety focus, the two organizations described below are instrumental at monitoring plant safety and in fostering a safety culture throughout the plant:

- Nuclear Safety Review Board

At the highest level, plants have designated and utilize a nuclear safety review board for broad senior management review of plant safety and performance (including risk). These organizations, which typically include senior corporate managers, senior managers from utility-owned sister plants, and outside consultants with background in nuclear safety, are tasked with review of plant operations from a strictly nuclear-safety viewpoint. Included in these reviews are analyses of plant events that have occurred since the last meeting for possible safety impact. Additionally, plant-performance issues, including analysis of systems categorized as (a)(1) under the maintenance rule, are reviewed. Finally, at many plants, analysis of risk performance (including integrated risk curves, which compare the integrated effects from plant equipment failures and scheduled maintenance outages) is reviewed.

- Risk Assessment Organizations

The senior management oversight described above is typically supplemented on an ongoing basis via line organization personnel who are part of the plant or corporate support staff. These personnel provide review of plant operations, maintenance, and engineering from a nuclear-safety perspective. At many plants, these personnel analyze plant data (such as work schedules and equipment/system outage durations, equipment failure rates, and maintenance rule performance data) to assess the direct risk impact of plant events and performance and to update the results of the PRA analysis. These personnel also provide a primary feedback mechanism to senior plant and corporate managers on an ongoing basis for issues affecting nuclear safety.

Integration of Loss Prevention into Other Plant-Decision Processes

Many licensing activities ultimately support other plant processes such as maintenance-rule compliance (supporting the equipment-reliability function) and risk-informed technical specifications (supporting configuration control). These activities were discussed with those processes. However, the interfaces between these processes are important for effective risk management. Thus, an important component of an effective risk-management process is the effectiveness and efficiency with which loss prevention-related issues and concerns are incorporated within the other plant processes.

Training

The training organization provides services to the plant operations, engineering, and maintenance organizations. The training organization's mission is divided between two groups of customers. The first group is plant operations personnel, including the licensed operator corps. This includes initial training to support the attainment of reactor operator/senior reactor operator licenses. It also includes periodic re-qualification training of all licensed operations personnel (including plant staff license holders). All domestic nuclear plants licensed operator training programs are accredited by INPO and all licenses are granted by the NRC. This process ensures achievement of a basic minimum set of qualifications and knowledge of personnel who manipulate plant reactivity.

Training of Licensed Personnel on the Risk Impact of Significant Plant and Industry Events

One notable aspect of the operator training programs, from a risk-management perspective, is that industry and plant events with potential safety implications are reviewed periodically with licensed personnel as part of re-qualification training. This review has important implications in fostering a safety culture among the operations staff and increases their awareness of the need for a constant focus on safety. It also provides a useful reminder of the potential consequences of human error and the need for a constant focus on safety.

The second group of customers for the training organization is the remainder of the plant staff, including maintenance and engineering personnel. One of the important aspects of this function is the training of plant systems engineering personnel. Because these personnel perform the majority of the equipment-reliability and loss-prevention functions, the effectiveness of this training is important to ensure that personnel have a thorough understanding of the interactions between plant systems and their potential safety implications.

Plant Operations Training of Engineering Personnel

An important component of this training, in which the more senior members of the plant engineering staff are typically selected to participate, is providing training in the operational functions associated with the plant. This training, which includes training on use of routine and emergency operating procedures on plant simulators, provides a beneficial perspective to engineers and helps to foster a safety culture.

Risk-Technology Tools Training of Engineering Personnel

Another beneficial area, from a risk-management perspective, is training of engineering personnel in the fundamentals of risk assessment and management. This includes training in the various tools used by risk-assessment engineers. As the regulatory framework changes to one that is risk-informed and performance-based (such as the maintenance rule [10] as a first example), it is becoming increasingly important for line personnel to be familiar with these techniques to permit them to understand the bases for various decisions that affect them. As a

simple example, it is important for plant system engineering personnel to understand the basic reliability engineering and statistical principles used in calculating the probability for a particular number of failures of a plant component to permit setting of maintenance rule performance criteria for functional failures at a level that is technically justifiable. As another example, training on the use of reliability-engineering techniques applicable to maintenance task specification (such as failure modes and effects analysis, use of maintenance templates, and use of the EPRI PM Database) provides for more effective characterization of the safety impact of equipment failure and specification of applicable predictive and preventive activities to prevent the expected failure mechanisms.

5
EFFECTIVENESS EVALUATION

An important component of risk management is periodically evaluating the integrated effectiveness of the various processes at controlling plant risk. Because these processes are distributed throughout the organization, this entails an assessment that encompasses the entire plant. Fortunately, as described in previous sections, elements of this are performed on an ongoing basis by various organizations with overall safety oversight (at a senior management level) performed by the nuclear safety review board. Quality-assurance and regulatory-compliance audits also evaluate the effectiveness of the various plant organizations and processes. Finally, inspections conducted by the regulator (NRC) and industry peers (through INPO) provide an additional level of review.

However, each of these evaluation processes focuses on different objectives and is conducted independently. Currently, there is no process that evaluates performance from a uniquely risk-management viewpoint. Thus, it would be beneficial to have a single process by which the overall effectiveness of risk management can be evaluated. Development of such an evaluation process would provide a common assessment method that would permit monitoring the effectiveness of risk management at a plant over time. Additionally, designing the process to be generically applicable would permit support of benchmarking between different plants. Thus, this process would be useful for assessing the beneficial aspects of risk management on plant safety and could be used to disseminate best practices throughout the industry and also to foster the transition to a risk-informed, performance-based regulatory framework.

Prior to this research effort, this risk-management evaluation concept was investigated by way of a case study at an operating nuclear power plant. This case study was conducted on an ad-hoc basis via a one-week site visit using personnel from EPRI and the host utility's corporate office. This case study resulted in significant insights, which were reported in reference [2] and resulted in the initiative to perform this research. For convenience, the full report of this case study is provided in Appendix A. This case study was focused on documenting the use of risk-management techniques and demonstrating a risk-management culture at the plant. The approach used was very successful at achieving these objectives. However, because the case study was performed on an ad-hoc basis, it lacked a formal structure for its conduct. Thus it would be difficult to repeat using a different set of observers. Additionally, because it provided no formal criteria for evaluating the results obtained, results from subsequent assessments of the observed functions at the plant could only be compared qualitatively with previous results.

To achieve the previously described objectives, an evaluation process consisting of a targeted set of evaluation questions has been developed. These questions are intended to characterize the extent to which risk-management techniques are applied at a particular plant and their effectiveness at controlling plant safety risk. This set of questions (provided in Appendix C),

allows the evaluation to be conducted either in a questionnaire format, from which responses from appropriate plant personnel can be gathered and analyzed, as a set targeted interviews, or as a combination of the two. The questionnaire format allows for rapid and inexpensive assessment; the targeted-interview format permits a more detailed evaluation with the ability to conduct more thorough follow-up. For a first application of the method at a particular plant, use of a combination of questionnaires and targeted interviews is an appropriate option. Use of questionnaires will permit obtaining a significant amount of data (permitting statistical analysis of the results) from a broad cross-section of plant personnel. This can be followed by targeted interviews with additional personnel, including those not included in the questionnaire survey, to obtain more detailed information. Additional data also can be obtained, if desired, via field observational studies.

Whichever method is used, an important aspect of the evaluation process is that it is constructed such that the data can be quantified, statistically analyzed, and trended over time. Thus, results of follow-on evaluations can be compared to provide an assessment of changes in effectiveness of the application of risk management over time. Appendix D provides one method of quantifying the assessment results to support accomplishment of this objective.

In this section, the construction of the evaluation process is discussed. Methods for its conduct are then described with the respective advantages and disadvantages of the different methods discussed. In Section 5.3, results obtained from a limited application of the process using targeted interviews are provided. In Section 5.4, insights from a more complete assessment are provided.

It should be emphasized that this process is intended to provide a point of departure for assessing the application and effectiveness of risk management at commercial nuclear power plants. It is expected that the process will expand and evolve as the risk-management approach matures and its use becomes more widespread throughout the industry.

Assessment Construction

The risk-management assessment is intended to provide a structured method to evaluate the extent to which the aspects of risk management discussed in Section 3 are embedded within the various plant processes and are effective at achieving their objectives. As described there, each process of the SNPM accomplishes several objectives that are necessary for effective risk management. Additionally, many of these processes are interrelated with effective interfaces and communications necessary to achieve robust decisions. Finally, different organizational structures at different plants result in the need for different lines of communication to be effective. Thus, all of these aspects need to be evaluated.

The assessment approach described in this report was developed using the SNPM as a useful classification system for identifying plant processes important to risk management. However, because the SNPM was originally developed to serve as a business-cost model and data-classification scheme, the various identified functions are designed neither from a

risk-management nor a plant-organizational viewpoint. Thus, from a risk-management perspective, some of the identified processes are much more significant than others. In fact, several of the processes have no direct relationship to risk management and thus are not evaluated as part of this assessment process.

Second, the SNPM was designed from a functional viewpoint; therefore, identified functions may be interspersed across several different plant organizations. From a risk-management viewpoint, it is not critical which organizations are tasked to accomplish each function. However, it is critically important that effective intra- and inter-organizational communication paths exist to permit the accurate and timely exchange of information necessary for reaching an appropriate decision. Thus, in assessing these functions, it is important to identify the appropriate organizational interfaces for each process. Appendix B provides a discussion of which SNPM processes are important from a risk perspective and what organizations are typically responsible for accomplishing them.

The assessment process is designed to evaluate the effectiveness of both the processes important to risk management and the degree of interaction between different organizations tasked with achieving the objectives of the processes. This evaluation is conducted by using an extensive set of targeted questions to conduct the assessment. The set of questions is keyed to the first-level SNPM process that it addresses. Additionally, each question is weighted (using a high, medium, and low scale) to its importance to risk management. The complete set of assessment questions is provided in Appendix C.

Assessment Methods

In application of the assessment questions provided in Appendix C, there are several possible approaches that can be used. The application of each of these approaches is discussed, and their respective advantages and disadvantages are elucidated in this section. It should be emphasized that no single method is “best” and that to obtain a detailed picture of the effectiveness of risk management at a particular plant, a combination of the approaches discussed below may be required. This is especially valid during the initial assessment process.

Survey Approach

The most straightforward approach for use of the questions is to use them directly in a survey of plant personnel. This approach has the advantage that a significant amount of data can be obtained inexpensively in a short period of time. Also, because a large amount of data can be obtained, the data are amenable to characterization by statistical techniques (characterization of statistical moments, ANOVA, and so on), both as a whole and within individual processes/sub-processes. Finally, because the data can be quantified, they are also amenable to trending to determine changes in performance over time.

If this approach is used, it is highly recommended that a broad cross-section of plant personnel be included in the survey. Surveying a broad cross-section of personnel will ensure that a robust set of data is obtained. The survey should consist of a sampling of various plant organizations (operations, maintenance disciplines, engineering, planning, and scheduling) and various organizational levels (maintenance crafts across all disciplines, operators, technicians, professional, supervisory, and senior management personnel). This broad level of sampling will help to eliminate potential biases in the responses. Additionally, if the various classifications of respondents are recorded (while keeping the responders anonymous), a broad-based sample also has the benefit of being capable of identifying issues that are specific to individual work organizations. However, while effective in obtaining large amounts of data over a broad spectrum of plant personnel, the survey approach has the disadvantage of lacking specific details. Thus, if significant issues are identified, additional investigation will be required to identify the underlying causes and specify potential improvements.

Targeted-Interview Approach

The targeted-interview approach uses the questions in Appendix C as a starting point for interviewing selected plant personnel to assess the effectiveness of risk management. These questions are used to elicit discussion with the selected plant personnel. Compared with the use of surveys, this approach has the advantage of being able to collect detailed information on the subjects discussed during the interview process. It also has the advantage that explicit examples illustrating the viewpoint of the interviewee can be used to substantiate the responses. Because the interviews are not limited to a specific set of questions, the approach can provide much greater detail than the survey approach described above. These reasons were significant drivers in selecting the targeted-interview approach as the method used in both the original evaluation performed by EPRI at Catawba and in the limited assessment conducted to validate the approach described in this report. It should be noted that the questions provided in Appendix C can serve as an initial set around which the targeted interview can be structured. In the limited assessment conducted for this study, the predefined questions were validated as providing a useful basis upon which to conduct a fruitful targeted interview.

Although the targeted-interview approach is well suited for obtaining detailed information, it has several limitations that should be noted. First, due to the cost associated with performing the interviews (typically two interviewers are used on each interview and conduct of the interview requires making the interviewee unavailable to perform his or her normal job responsibilities), only a small sample of the plant population can be reasonably obtained. Typically, this requires limiting selection of interviewed personnel to management and technical positions. This limitation has the potential to introduce bias into the results. Additionally, because the sample population is very small, quantification of the results for the purposes of trending is problematic; thus evaluation of changes in performance over time becomes more uncertain. Finally, because the interviews can be time-consuming, it may not be possible to assess all of the processes during the time frame in which plant resources are available.

Observational Study

This approach provides a means of obtaining data on performance by use of impartial observers. Thus, it provides a mechanism to obtain data that are relatively free from bias. In this approach, evaluators observe various plant functions (such as planning and scheduling meetings, operational activities, and maintenance activities) and observe the various risk-management activities identified within the set of questions. However, the process has the significant limitation that only activities observed can be evaluated. Also, unless a large number of activities is observed over a relatively long time period, the approach will provide data on a limited subset of the processes. For these reasons, this approach should not be selected as the primary method of conducting the assessment. Its use is best structured to applications where additional unbiased information is necessary to reach a conclusion or to serve as a quality check on data obtained via the other methods. In these limited applications, this method can be easily integrated into other evaluations routinely conducted (such as quality assurance audits, self assessments, and peer reviews).

Conclusions

Given the discussion of the advantages of each method described above, one can see that use of the survey and targeted-interview approaches provide complementary results—each method has compensating strengths where the other is weak. Thus, if a detailed evaluation of the performance of risk management is desired, a combination of these methods may be employed. This would be particularly valid for performance of an initial assessment. If time or resource limitations preclude a detailed evaluation, or there is indication from other plant-assessment processes that specific areas should be targeted, the targeted-interview approach provides the most detailed information for the lowest relative cost. Application of observational studies should be reserved to obtain information to confirm results obtained via the other methods, particularly when there is evidence that these results may be skewed by biases.

Results of Limited Application of Evaluation Process

To validate the proof of concept for the risk-management assessment approach, a limited verification study was conducted at an operating nuclear plant. The purpose of the site visit was to provide a preliminary validation that the evaluation methodology was capable of effectively assessing the extent to which risk management was integrated throughout the plant and the corresponding benefits to plant safety obtained. The evaluation conducted was not comprehensive in scope nor intended to provide extensive recommendations to the plant. However, the validity of the approach was verified; thus it warrants further application to permit further development and in-depth testing to ensure completeness of the approach.

Because only a limited time and budget were available for the validation effort, the assessment utilized the targeted-interview approach. The assessment was, by design, limited in scope to several sub-processes from the SNPM, which were identified to be of primary importance to risk management. These selected focus areas were as follows:

- Plant configuration control: This evaluation was limited to that part of the work planning/scheduling process that addresses this function. In particular, although important from a risk-management perspective, the assessment team did not look at activities performed by plant operations.
- Work-week scheduling, including the function of reviewing/minimizing risk impact, both during the planning phase and the execution phase: During the site visit, only on-line maintenance activities were evaluated.
- System performance monitoring and analysis (including maintenance rule monitoring).
- Proactive maintenance program specification (both preventive and predictive).
- Plant corrective action program, with emphasis on identification of risk significance in prioritization of items.
- Plant risk monitoring and analysis (PRA), with particular attention to evaluating overall impact on plant risk over time and updating of PRA information.

To obtain the desired information, plant and corporate personnel directly responsible for the functions listed above were interviewed. Each interview required approximately one hour to complete. The interviews were conducted over a period of one and one-half days. Corporate risk assessment personnel were interviewed at the company's main office (one-half day), and plant personnel with line responsibilities were interviewed at the plant site (one day). During the process, the following personnel were interviewed:

- Corporate risk assessment engineer (responsible for interface with the host plant)
- Corporate director of risk management
- Site programs engineering systems manager
- Site residual heat removal system manager
- Site maintenance rule coordinator
- Site engineering corrective action program coordinator
- Site preventive maintenance coordinator
- Site unit cycle manager
- Site risk-management engineer

Plant Configuration Control/Work-Week Scheduling

For these plant processes, the assessment concentrated on the mechanisms used to assess and control risk for maintenance activities conducted during plant power operating conditions. Operations conduct of configuration control was explicitly excluded from this assessment. Because the portions of the configuration control and work scheduling processes evaluated are intimately interrelated, the results obtained for these two processes will be discussed together.

The plant has formal mechanisms that incorporate risk assessment into the planning and scheduling process. Additionally, this process is highly developed with extensive interaction between the various responsible organizations. For example, all new identified corrective actions are reviewed by a multi-disciplined team consisting of personnel from:

- Operations
- Work Control
- Fix-It-Now (FIN) Team
- Maintenance Planning
- Maintenance Crafts
- Design Engineering
- Radiation Protection
- Chemistry

Detailed procedural guidance is provided to ensure that appropriate prioritization is assigned to emergent work.

At the evaluated plant, both long-range planning (cycle schedule managed by the unit cycle manager) and short-range planning (five-week schedules managed by individual work-week managers) are conducted. Preliminary risk assessments using the EPRI ORAM/SENTINEL software package are performed at this time. Detailed risk assessments for core damage frequency are performed starting at four weeks prior to the scheduled work week. During the cycle planning process, responsible system managers are involved to ensure that all necessary maintenance (including preventive maintenance activities) is included in the schedule. Use of functional equipment groups and standard clearance sequences has contributed both to greater efficiency and minimization of the amount of equipment removed from service. An additional valuable component of the work-control process is that three weeks prior to the scheduled work execution, the planned activities are walked-down in the field to verify that all elements required for execution are in place. Additionally, the effectiveness of these walk-downs at adequately planning the work activities is measured.

Finally, a comprehensive set of metrics monitoring the work-management process is in place and monitored. Continuous improvement also is obtained by conducting formal review sessions after the completion of each work week. These reviews are focused on identification of any problem areas encountered and development of potential solutions. Additionally, other opportunities for improvement are sought during the meeting.

In conclusion, the interactions associated with the planning and scheduling process were found to have a high degree of safety focus with extensive application of risk-management techniques. A significant strength identified was the multidisciplinary nature of the decision-making process. This feature ensures that a broad perspective is applied to the process, helping to ensure that decisions are robust with minimal potential to have unanticipated consequences.

Corrective Action Program

The corrective action program (CAP) (as applied to plant engineering) is currently transitioning from a focus on equipment-performance issues to one focusing on human performance. From a risk-management perspective, this shift is perceived as beneficial. Because significant research (encompassing numerous industries [4]) indicates that a large proportion of significant events are caused or exacerbated by human error, this focus is expected to provide significant safety benefits and further contribute to effective control of plant safety risk. This shift in focus of the corrective action program also should not result in any detraction of the evaluation and addressing of equipment performance issues because these are already addressed in other programs (such as maintenance rule and equipment health monitoring—see discussion below). The site has an extensive system of management oversight to review plant performance and issues with safety significance. This review consists of three levels:

- Management review committee consisting of site line managers
- Management review meeting consisting of senior site managers and managers from the company's other nuclear plants and corporate staff
- Nuclear safety review board consisting of senior corporate nuclear executives and external industry consultants

As a stand-alone process, CAP is reactionary in nature. However, it provides an effective method of addressing issues requiring significant improvement. Because the self-assessment process provides a useful proactive method to identify areas for improvement, the combination of the two programs provides an effective method of addressing plant-performance issues that have significant structural and organizational components.

System-Performance Monitoring and Analysis

The plant (like most other domestic plants) has a complete set of performance indicators to assess performance of structures, systems, and components that can affect plant safety. Many of these processes are driven by regulations, with industry guidance specifying what is to be monitored (such as INPO indicators) or specifying an acceptable process to determine them

(such as maintenance rule indicators). One aspect of this monitoring is that it is highly matrixed throughout the organization. However, as discussed for the corrective-action program, the plant has an extensive system of management oversight to review performance of SSCs and their impact on plant risk over time. However, there is an additional level of oversight (plant health committee) tasked specifically with reviewing system and equipment performance, which typically is accomplished through formal system-health reports.

One possibly significant insight with generic implications was obtained as a result of the interview with one of the plant system managers. Because this individual had a long tenure of experience at the plant, this opinion should be considered by plant management when designing performance-monitoring programs. Similar to most domestic nuclear plants, system-health reports, which summarize system performance, are routinely presented to plant management. The interviewed system manager believed that the primary benefit of these reports was to provide a conduit to plant management to inform them of significant issues from which they could prioritize the use of plant resources. However, in this system manager's opinion, these reports, because they are predominantly retrospective, do not provide significant benefit in identifying incipient issues. However, what the interviewed system engineer has found to be beneficial is the SYSMON process developed by EPRI to identify appropriate system parameters to monitor and analysis techniques to apply [14]. Application of this process has resulted in a comprehensive set of metrics for each system with a detailed level of technical justification for their use. Additionally, these metrics are designed, to the greatest extent practicable, to be anticipatory in nature and thus beneficial for the proactive identification and disposition of potential performance issues.

Integrated Maintenance Strategy Specification

The plant has a comprehensive proactive (that is, combination of preventive and predictive) maintenance program in place utilizing the typical suite of predictive technologies. Additionally, in addition to individual system mangers, the plant also has a staff of component engineers responsible for monitoring performance and addressing issues related to assigned component types. This arrangement has provided a comprehensive capability to monitor and assess plant performance from multiple vantage points.

However, in evaluating the proactive maintenance program from a risk-management viewpoint, there were several issues identified by the evaluation team. First, all maintenance activities were assigned using corporate-developed templates, which address the major component types. Because these templates were developed using the EPRI PM Basis Guidelines [13], they provide an excellent maintenance basis for these components. However, two issues are noteworthy. First, although the major characteristics necessary to appropriately identify the combination of operational features necessary to characterize the equipment (functional importance, duty cycle, and operating environment) were used in the specification of the maintenance program, these characteristics were never documented. Because this decision basis is not available, when issues arise, they must be recreated by the responsible system manager. This has not been an issue to date because of the high level of experience of the plant staff (many personnel interviewed had more than a decade of experience at the plant). However, this could become a concern in the future if this experience level should decrease. Additionally, this condition also places an added

burden on the plant engineering staff when investigating emergent issues. Second, application of the templates was "direct and blind." Because the templates were developed using a multidiscipline approach and included input from numerous plants and equipment manufacturers, they are quite robust. Thus, this has not resulted in any significant issues to date. However, because there is no available documented maintenance basis, there is a larger-than-normal level of uncertainty in the degree to which the maintenance program addresses the credible failure mechanisms of significant plant equipment.

Risk Monitoring and Analysis

For the plant surveyed in the limited validation effort, responsibility for risk monitoring and analysis is shared between site and corporate resources. Personnel from the corporate staff are responsible for maintenance of the PRA. Additionally, individuals from corporate staff are assigned as lead risk engineers responsible for one (or more) of the company's nuclear plants and provide the lead role in interface with the site. In discussions with both the corporate engineer and site staff, the corporate risk engineer spends a significant portion of time at the plant site. In addition to the assigned corporate risk engineer, there is a dedicated risk-management engineer assigned to the station engineering staff. This individual has line responsibility for evaluation of risk-related activities. This includes interface with the integration and development of work schedules, evaluation of plant events (as part of a causal factors investigation team), maintenance rule compliance support, and evaluation of emerging regulatory issues.

The assessment found that the plant has a fairly comprehensive risk-management focus for application to control of on-line maintenance activities. However, because the review was limited to impact on core damage frequency (large early release frequency was not evaluated), the risk focus is not complete. A more significant issue identified during the interview process was the observation that the site risk-management engineer spends a large portion of his or her time responding to emergent issues. Many of these are driven by regulations (addressing issues by analyzing them through the significant determination process or conducting notices of enforcement discretion [NOED] evaluations). In recent months, this has consumed a large fraction of the site risk-management engineer's time, with minimal discernable benefit to plant safety.

Conclusions

As discussed previously, the primary purpose of this limited assessment was to validate the approach developed to assess the effectiveness of risk management at a plant and the degree to which a risk culture was in place. Because the assessment was very limited in scope, any conclusions drawn from this assessment should be considered preliminary. This is especially true of conclusions about the effectives of the implementation of risk management at the plant. However, several of these preliminary conclusions are of sufficient interest to warrant discussion here.

First, the assessment process and survey questions were found to provide a good basis for assessing both the effectiveness of risk management and the degree to which a risk culture has been embedded in a plant. The questions served as useful staring points for discussions in a targeted-interview format. However, conduct of the assessment indicated the need to develop additional questions that focused specifically on risk-management techniques, tools, and their application. These questions have been developed and are incorporated in the list of questions provided in Appendix C. Additionally, the process was verified only for application of the targeted-interview approach and only over a limited number of processes. Application of the other evaluation techniques and full-scale application to the entire spectrum of risk-management processes require further research testing and validation.

One potential deficiency of exclusive use of the targeted-interview approach is that only a limited number of personnel can be interviewed. This provides a limited data set from which inferences can be drawn. As an example, the system manager who was interviewed collected operational data of equipment demands and run-hours, which are necessary to provide reliability estimates and direct comparison with assumptions contained in the PRA and maintenance rule performance criteria. However, he noted that this was neither a requirement nor a universal practice among the other system managers. Due to the time limitations for the interview process, it was not possible to pursue follow-up of this topic and ascertain to what extent these data are obtained and analyzed at the station. From a risk-management perspective, in the initial stages of conducting the evaluation, a combination of techniques may be appropriate to provide a comprehensive picture of the extent to which a risk-management approach has been integrated into the plant's decision-making processes. It should be noted, however, that the targeted-interview approach used in the limited validation study provided a significant amount of detailed information in a very short period of time.

At the host site, the work-management process was found to be both efficient and well managed. This process also has a strong risk-management component with nuclear safety risks (from a core damage frequency standpoint) identified, characterized, and managed. Communication paths between various work groups were found to be well established and effective. This process presents a good example of effective risk management and was the most mature instance of it identified at the plant.

One significant observation obtained during the plant evaluation was the degree to which highly skilled personnel were occupied with addressing either ongoing or emergent regulatory issues. In discussions with these personnel, it was clear that the prescriptive nature of the regulatory process required these activities to consume significant resources for their resolution. They also provided minimal benefits in terms of impact on plant safety or operational performance. By consuming highly valued resources that could be employed in more productive activities, addressing these issues in the required prescriptive manner reduces the effectiveness of these resources and, to some degree, reduces the levels of safety and operational performance that could be achieved. This condition provides an example of prescriptive regulation resulting in inefficient use of resources and compromising desired outcomes. In these instances, a more flexible risk-management approach could result in both better resource utilization and lower overall plant risk.

Finally, during interviews with line personnel other than those directly involved with risk management or work-scheduling activities, the primary focus was on the specific functions to which these individuals were assigned. Although the individuals interviewed provided a strong focus on plant safety, there was little evidence that an approach focusing on risk management was embedded throughout the organization. This is in contrast to the results of the initial studies conducted at Catawba, where a risk-management focus was evident at all levels of the organization and in all assessed plant processes. At the site that participated in this assessment, there was a great reliance on the dedicated risk-management professionals. Thus, the evidence indicates that the infusion of a risk-management culture is in the early stages of development at this station.

Insights from Full Plant Pilot Application

As part of this research and development effort, a full plant pilot implementation of the assessment was conducted. This assessment was performed as a self-assessment over a one-week period at the host plant site. The assessment consisted of two evaluation teams of two persons. Each team consisted of one member from the utility's plant or headquarters staff and one EPRI representative. The assessment was constructed using the approach described in Section 3, with the targeted-interview approach used to obtain assessment data. Because the assessment was conducted as part of the utility's self-assessment process, the plant-specific results obtained are proprietary to the utility and thus are not reported here. This section provides a discussion of the insights gained into the assessment process from this pilot application.

To prepare for the assessment, information on recent plant performance and operational events were provided to the EPRI team representatives approximately two weeks prior to arriving on-site. This documentation included the following:

- Most recent classification of cornerstone performance as specified by the regulatory oversight process
- Most recent system-health reports for several systems (including systems classified as Maintenance Rule (a)(1))
- Recent licensee event reports

(Note that because the assessment is performance-based, this preliminary review concentrated on information that provided indication of recent plant performance and any identifiable trends.)

From this review of plant performance, the assessment strategy was developed. To achieve this, the set of potential assessment questions was thoroughly reviewed to select a set of "core questions" that would constitute the primary focus of the assessment and would serve as the categories against which findings and observations would be identified. Of the set of questions presented in Appendix C, 100 were selected as core questions. From this set of core questions,

appropriate plant personnel were selected to participate in the targeted-interview process. The logistics associated with arranging the interviews were provided by the utility team members. An important insight obtained from performing these pre-assessment tasks was that they confirmed their importance of ensuring that the assessment was conducted efficiently and that it was effective in identifying both good practices (to ensure their continued effectiveness) and areas where improvement is needed.

To begin the assessment, a pre-job briefing was performed by the assessment team members on Monday afternoon. Because the assessment team consisted of both utility and external consultant members, the pre-job briefing was important to clarify objectives and expectations and to foster teamwork. On Tuesday morning, an entrance meeting was conducted with plant management by the assessment team. This meeting discussed the purpose of the assessment and the methods chosen for employment. The meeting also served to ensure that the objectives of the assessment team and plant management were aligned.

Targeted interviews with selected plant staff were conducted over three days (Tuesday, Wednesday, and Thursday). Interviews were conducted with the following personnel:

- System engineering
- Component engineering
- Preventive maintenance
- Work-week management
- Outage planning
- Plant operations
- Operations work control
- Maintenance Rule coordinator
- Maintenance crafts
- Instrumentation and controls technicians
- Configuration control
- Modifications
- Probabilistic risk assessment
- Regulatory affairs

These interviews were conducted in parallel and lasted approximately 90 minutes each. There were two important aspects of these interviews that contributed to the capability of the assessment to evaluate the effectiveness of risk management and identify relevant issues. The first is that a large cross-section of plant disciplines was interviewed. This provided a wide variety of viewpoints to be presented and enabled the assessment team to identify recurrent themes and develop a prioritization for items identified for improvement. The second aspect of importance that supported accomplishment of an effective assessment was that personnel from

various levels within the plant organization were interviewed. These interviews included craftsmen, technical personnel, and management up to second-level supervision. Finally, although not originally planned as part of the assessment, the assessment team observed several plant activities (such as a plant design review meeting and a senior management presentation at a plant "all hands update") during time periods when no interviews were scheduled. These observational activities provided confirmatory evidence to several of the findings and observations that were identified as part of the interview process.

At the conclusion of the interviews, the assessment team developed preliminary conclusions. These were presented to senior plant management in an exit meeting on Friday morning. After completion of the assessment, the team formally developed and documented the assessment results in an assessment report.

From the targeted interviews, presented information was synthesized by the assessment team members. Issues identified were classified into one of three categories:

- Finding: Identification of an area where risk management was not effective. These items were identified to require development of corrective actions and were entered into the plant's corrective-action program database for resolution by the utility assessment team members after the assessment was completed.
- Primary positive observation: This category includes areas where risk management was identified to be particularly effective. Their application should be continued and expanded where applicable.
- Primary negative observation: This category includes areas where risk management was identified to be less than optimally effective or could be subject to risk of performance degradation. These items were not considered to be of a nature that warranted immediate corrective actions; however, they constitute an area for management attention.

Each of the items identified as "finding" or "primary negative observation" was supported by at least one (and in the case of "finding" several) supporting observations to support the conclusion of the assessment team.

In addition to a detailed discussion of the assessment results, all findings and observations were mapped to the corresponding SNPM process and the associated core question to which the issue was applicable. This mapping is intended to permit use of the assessment results to provide a benchmark for future assessment and to support continual improvement. An example of a portion of this mapping is provided in Table 5-1.

Table 5-1
Example Mapping of Findings and Observations

Process: Configuration Control		**CC002: Provide Design Changes**		
QID	**Questions**	**Finding/ Observation**	**Supporting Evidence**	**Comments**
1	Responsible system managers participate in the engineering of all risk-significant design changes.	9, 18		
2	Needs for commercial-grade parts are identified, and information limitations are provided to system managers.		3.4	
3	Design-change process includes analysis of the potential impact on nuclear safety risk.	9, 10	9.1, 9.2, 9.3, 9.4	

An additional important conclusion, which was included in the report recommendations, was to utilize the results of the assessment as a baseline and to conduct follow-up assessment to evaluate the effectiveness of actions taken to address the identified issues. To further the development of the process and support use of assessment results as a metric that can be monitored and trended, the EPRI members of the assessment team used the methods discussed in Appendix D to quantify the assessment results. Application of this process resulted in the following observations:

- Use of the mapping of findings and observations made the scoring very straightforward.
- The obtained results were found to be useful in the evaluation of the effectiveness of risk management.
- The results were consistent with the qualitative judgments made by the assessment team.
- The quantitative results are in a form that would permit use for monitoring and trending.

These conclusions obtained from this pilot application indicate that the assessment approach described in this report is an applicable method to evaluate the effectiveness of risk management. It also is effective at identifying significant issues that require management attention and providing sufficient supporting evidence to support the results. Finally, the process of mapping assessment findings and observations to the corresponding SNPM process and associated assessment questions supports the use of the assessment results to provide a benchmark for future assessment and to support continual improvement. Additionally, quantification of the results via the scoring system described in Appendix D is simple to perform and will support development of metrics to monitor and trend the effectiveness of risk management.

The pilot assessment was performed to demonstrate the methodology and to provide the host plant with results and supporting information sufficient to permit development and implementation of action plans to obtain improved performance. Due to these objectives, a level

of effort (personnel, time, and so on) was provided that was sufficient to meet these objectives. The assessment process required approximately 10 work weeks for the assessment team to prepare for and conduct the assessment, develop the findings and observations, and prepare the final report. In particular, this effort was capable of identifying findings and observations (as defined above) with sufficient supporting evidence for management to develop and prioritize appropriate action plans. The assessment team believes that this provided a sufficient minimal effort to achieve a quality result. In particular, the assessment effort level expended in the pilot application should be considered a minimal one for the following reasons:

- The assessment did not cover all of the questions identified in Appendix C, including several core questions that were peripheral to the objectives of the assessment.
- This level of effort did not provide time for follow-up interviews to thoroughly investigate identified issues. Thus, the level of effort applied in the pilot application did not permit investigation at a level sufficient to provide detailed justifications of the conclusions nor to identify their underlying causal factors.

Notwithstanding these limitations, the assessment method was effectively demonstrated in the pilot application. Based on the results obtained, it can be concluded that the approach described in this report is an effective and efficient method of evaluating the effectiveness of nuclear plant risk management. Additionally, application of the quantitative scoring approach described in Appendix D was found to support development of a useful metric against which risk-management effectiveness can be trended.

6
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A
CATAWBA CASE STUDY PAPER

Nuclear Plant Safety Risk Management: A Case Study

April 2002

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A.1 Abstract

More risk-informed and performance-based regulation is an objective of nuclear regulators and nuclear plant owner/operators. However, plant improvements from risk-informed regulations have been disappointingly few, and license submittals have been complex and costly. This appendix proposes increased reliance on risk-management activities and less on predictive risk quantification as an optimal method to control risk and expedite risk-informed regulatory change.

This appendix provides a case study of the risk-management activities at Catawba Nuclear Station. Activities identified through plant interviews are described in the context of the Nuclear Energy Institute/Electric Utility Cost Group Standard Nuclear Plant Process Model. Processes include work control, equipment reliability, configuration control, loss prevention, support services, training, and operations.

Using these results and follow-up investigations as evidence, this appendix documents that six criteria for effective safety-risk management are satisfied at Catawba Station. These activities, considered as an integrated process, constitute a risk-management overlay that can effectively support risk-informed, performance-based regulations and operation of nuclear power plants.

A.2 Problem to Be Solved

More risk-informed and performance-based regulation is an objective of nuclear regulators and nuclear plant owner/operators. However, plant improvements from risk-informed regulations have been disappointingly few, and license submittals have been complex and costly.

Why? In almost all cases, the process is hung up on the perceived need to use best available probabilistic risk assessment (PRA) methods, models, and data. These analyses are used to predict the future risk from a proposed change to a high level of precision. This level of precision cannot reasonably be achieved. Furthermore, residual uncertainties are evaluated in great detail. Quantification of uncertainty is desired, and defense-in-depth or conservatism is heaped onto the resulting regulation change to achieve higher likelihood that the risk will be low. It is easy to see why this process leads to high analysis costs, open-ended schedules, and very conservative results.

This appendix argues that the high level of analysis precision is often unnecessary whenever the whole risk-management process is fully utilized. This risk-management process consists of four elements:

1. Identifying risks
2. Quantifying and prioritizing risk contributors
3. Responding to indicators of risks or adverse trends
4. Maintaining a risk-management culture

Figure A-1 graphically illustrates this risk-management process.

Figure A-1
Risk-Management Process Flow Chart

The detailed PRA analysis, described above as the snag in the process, is just one part of element 2 in Figure A-1. Quantifying and prioritizing risks consist of much more than using PRA to predict the future risk of a proposed regulatory change. It also includes monitoring of risk rates as plant configurations are planned and implemented, monitoring leading indicators that foreshadow risk changes, and calculating risk after-the-fact to document actual risk levels. Timely response to indicators of risks or adverse trends not only control risk at or below projected levels but also continue to drive future risk levels down through proactive improvements. Maintaining the risk-management culture ensures that the process is effective and that it evolves to address plant changes and operating experience.

So, overemphasis of precise PRA predictive calculations is one source of the logjam, and it can be remedied by more effective use of other elements of risk management. In fact, this appendix argues that such a process is safer than prescriptive regulation based on PRA predictions alone, even when these predictions are of high technical quality.

A.3 Approach

A first step in establishing this thesis is to describe and document an effective risk-management process. Fortunately, effective risk management already exists at numerous U.S. nuclear plants. This appendix describes the process at Catawba Nuclear Station as a case study. Catawba Station is a two-unit Westinghouse pressurized water reactor plant operated in South Carolina by Duke Energy. The plant first generated commercial power in 1982.

Risk management in this appendix is limited to the risks addressed by NRC regulations; that is, public-safety risk. Core damage frequency (CDF) and large early release frequency (LERF) are the public risk figures-of-merit that are used in this paper. These measures are generally considered to be effective surrogates for significant public-safety risks posed by nuclear plants.

It is important to note that most nuclear plants do not have formal risk-management programs for public-safety risk. The risk-management activities are elements of other plant programs. It is an objective of this appendix to identify these activities and to show that they are very effective in managing public-safety risks. In effect, they represent an informal risk-management overlay upon the formal processes at the plant.

The case study approach includes the following steps:

- Identify staff functions and recent issues at Catawba Station that demonstrate risk management.
- Interview key Duke personnel at Catawba Station and at Duke Energy headquarters who are responsible for these functions and issues.
- Map observed risk-management activities onto the INPO/NEI Standard Nuclear Plant Process Model.
- Using the interview results and follow-up investigations as evidence, demonstrate that six criteria for effective safety risk management are satisfied at Catawba Station.
- Discuss the implications of this effective risk-management overlay for risk-informed, performance-based regulations and operation of nuclear power plants.

Plant staff members at Catawba Station and key corporate office staff were interviewed to determine the extent of relevant risk-management activities at Catawba Station. The interviews probed into (1) routine staff activities that provide risk-management functions and (2) key events or issues that provided risk-management opportunities.

The routine activities were then "mapped" onto a standard process model for a nuclear plant. This standard model is widely used in the industry for benchmarking and generic process guidelines, although individual plant organizations vary to perform these processes. Figure A-2 depicts the high-level processes of the standard model. Risk-management activities were found in most process areas, and each is discussed in Section A-4. The events and issues were not specifically "mapped" to processes, but they are discussed at appropriate points to illustrate the workings of these processes.

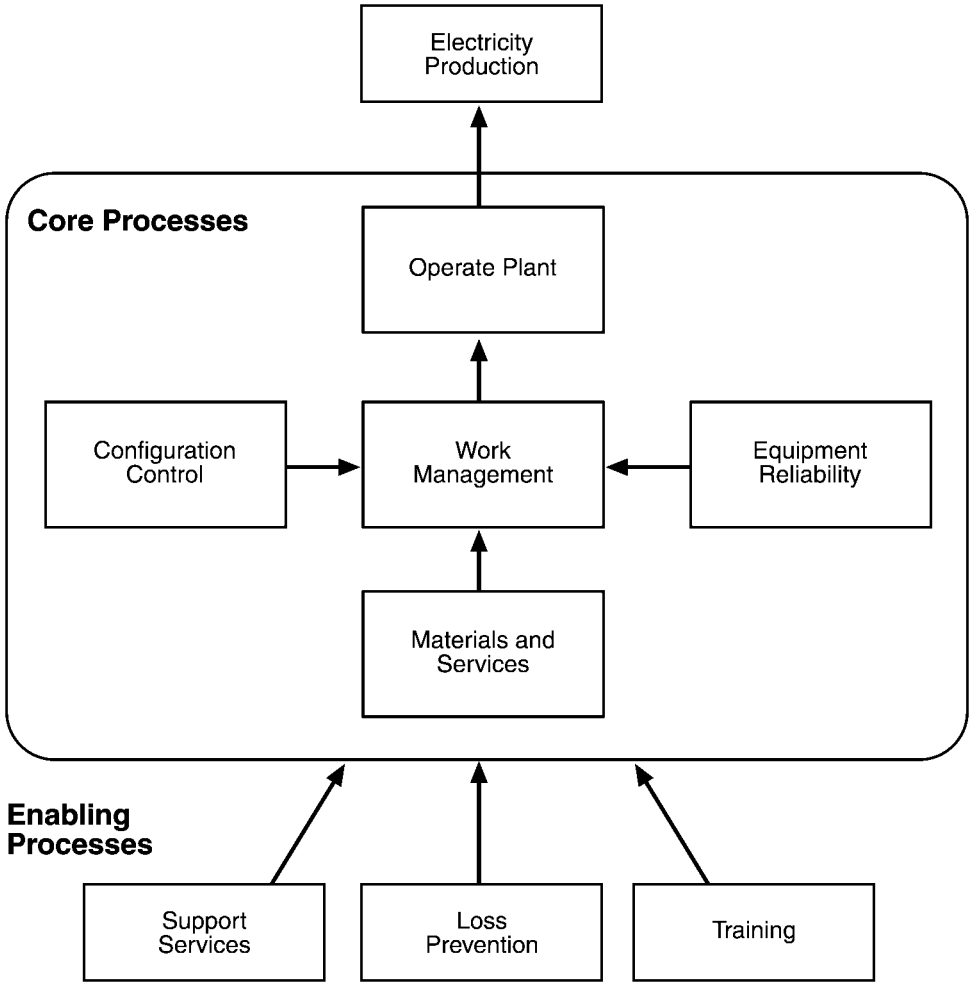


Figure A-2
Standard Nuclear Plant Process Model

The process mapping illustrates the ubiquity of risk-management activities, and the discussion explains the communication of risk-management information among the processes. Likewise, the discussion of events and issues illustrates the effectiveness of these activities in actual practice.

Confidence in these activities to comprehensively manage risk, however, requires a more critical review of risk-management capability and effectiveness. This critical review is provided in Section A.5 below by considering the effectiveness of the activities to address the following six criteria, which the authors contend encompass the objectives of risk management:

- Annual-average risk (CDF and LERF) and risk rate (core damage instantaneous probability and large early release probability) are maintained and monitored at the station.
- Functions are in place to prevent risk-important safety challenges and to prevent poor response of the plant equipment and personnel for events that are risk significant. These functions include monitoring of leading indicators of degradation.
- Causes of risk-significant degradations and of actual risk-significant events are evaluated and corrected.
- Risk-impact of risk-informed changes is verified by performance monitoring. The cumulative impact of risk-informed changes is verified to be within anticipated and acceptable levels.
- Risk-management activities evolve in response to plant changes and plant experience, and the effectiveness of the program itself is regularly evaluated.
- The culture of the staff and the plant organization are structured to accomplish effective risk management.

A.4 Overview of Catawba Station Risk-Management Activities

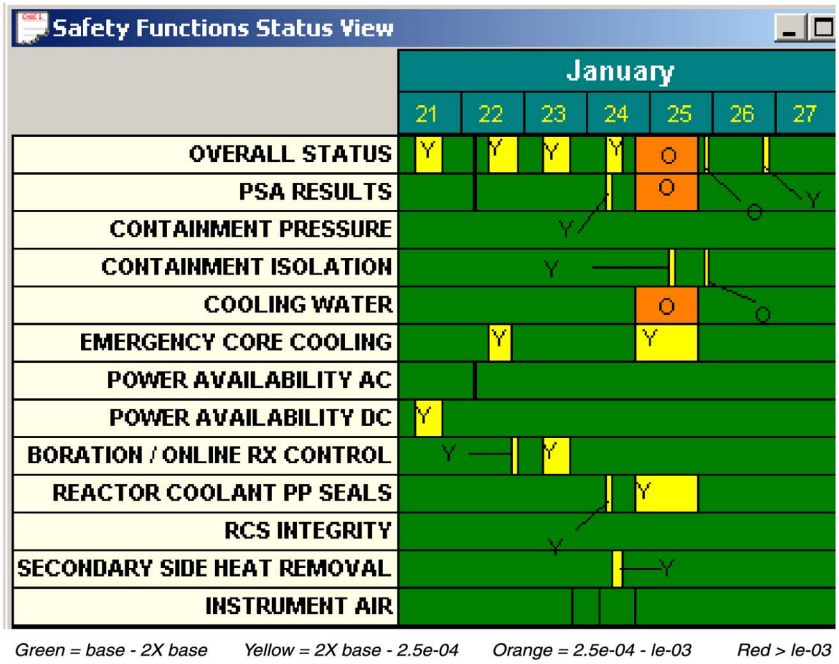
Using the structure of the standard process model, the findings of the interviews to identify risk-management activities are described below.

A.4.1 Work Management Process

We start the discussion of risk management with activities in support of the core process of work management. The standard process model defines the process of work management to include planning, scheduling, conduct of maintenance, and control of factors such as radiation and contamination. It will be evident that control of risk is a by-product of this process.

A.4.1.1 Online Maintenance Planning and Control

Catawba Station explicitly manages risk throughout the planning process for an upcoming workweek. The 13-week rolling schedule of planned system maintenance windows is designed to preclude simultaneous planned activities of high risk. Throughout the 8-week detailed workweek planning, the EPRI SENTINEL configuration risk modeling software is used. SENTINEL calculates risk and defense-in-depth resulting from the aggregate of all planned activities. Figure A-3 presents a SENTINEL analysis output for an example workweek. Heightened awareness or a risk-management plan is required for a “yellow” or “orange” risk configuration, respectively. A “red” configuration is never planned. Colors are correlated with PRA risk calculations.



Window Description (examples)

- YELLOW on 1/21 from 0700 to 1700 on "Power Availability DC" due to Replacing Choke in Inverter 2EIA.
- ORANGE on 1/24 1900 to 1/25 1900 on "Cooling Water" due to 1A KC HX Cleaning and Work on "A" Train KC Pumps.
- YELLOW on 1/24 1900 to 1/25 1900 on "Emergency Core Cooling" and "Reactor Coolant PP Seals" due to 1A KC HX Cleaning and Work on "A" Train KC Pumps.

Figure A-3
Example SENTINEL Online Workweek Report

In addition, SENTINEL communicates "special emphasis codes" to plant staff, indicating increased vulnerability to specific initiating events or other higher-risk conditions. During the actual work week, emergent conditions continue to be managed using SENTINEL. Any color change from such emergent work is reviewed by the work-window manager or shift-work manager for appropriate action.

The plant has defined a "Complex and Critical Maintenance" (CCM) category for infrequent activities that pose some risk potential and call for a detailed plan and increased technical and management attention. Typically, there is one or more CCM in a work week.

Several risk-management decisions are enabled by the use of SENTINEL and by the plant staff's thorough understanding of plant risk. These include:

- An activity can be routinely added to the work week plan as late as four weeks before it is to be performed. This practice enhances the safety value of predictive maintenance and condition monitoring activity in the plant.
- Needed activities can be added to a work week even if there is no corresponding system window.
- If there is no risk impact, an activity can be assigned to a single-point-of-contact (SPOC) team, commonly known as a fix-it-now team, for quick resolution.

A.4.1.2 Work Management: Outage Planning and Control

Many of the explicit planning and work-control risk-management practices used online have counterparts for outage work. A refueling outage template with 21 high-risk significant system windows and other critical evolutions precludes simultaneously planned activities of high risk. Throughout the 18-month planning cycle, the EPRI ORAM configuration risk monitoring software is used. Similar to the use of SENTINEL online, ORAM uses colors to grade preparation and oversight and assigns "special emphasis codes." During the actual outage, emergent issues are managed using defense-in-depth sheets. Any color change is subject to formal independent review team (IRT) approval. The IRT begins review of the schedule two months prior to the outage.

CCM detailed plans are used in outages as described for online maintenance. Typically, about 20 CCM plans are prepared for a refueling outage. Several risk-management decisions are enabled by the use of ORAM and by the staff's thorough understanding of plant risk. These include:

- The criteria for defense-in-depth colors are being critically reviewed corporate-wide, so they are well correlated with ORAM risk levels and are consistent among Duke Energy's nuclear plants.
- Risk management is a priority when choosing refueling outage duration—successive outages are becoming shorter but only as prudent risk management permits. Considerations include deciding if an activity should be done on-line or at shutdown according to the risk impact.
- The schedule is frozen for discretionary work four months before the outage—a short lead time compared to previous outages. This flexibility enables the best use of predictive maintenance and condition monitoring.

A.4.2 Equipment Reliability

The equipment-reliability process of the standard process model is key to effective risk management because equipment reliability is directly related to prevention and mitigation of plant challenges through response of equipment and systems. This process includes defining an effective preventive maintenance plan; surveillance and performance testing; equipment monitoring; and analyzing condition, reliability, and availability.

The cornerstone of equipment reliability is the system-health program. At Catawba, each important system and component group is the subject of a quarterly health report. The program is undergoing an important risk-informed revision: Systems will be categorized according to the risk-importance of their system functions. High risk-significant safety functions, consistent with the Maintenance Rule, as well as systems with high-risk generation functions, define Category A systems. Systems with lower risk-significant safety functions but that have regulatory significance are Category B. Remaining systems are in Category C. Comprehensive performance and condition monitoring is enhanced for Category A and B systems, with action levels set to avoid significant degradation. Preventive maintenance tasks and intervals are conservatively set to prevent failures and optimize unavailability. Less important functions and Category C systems use more predictive maintenance tasks and less conservative maintenance intervals. Table A-1 illustrates the monitoring activity for the high head injection and charging system.

Table A-1
Excerpt from System-Health Monitoring Report

UNIT	**Unit Rating** **Overall Health Rating**	
Common Parameters	1*	2
*Availability	G	G
*System reliability	G	G
*Maintenance rule status	G	G
Major component reliability (NV pumps)	Y	Y
TEPR items (top equipment problem resolution)	G	G
Functional material condition/walkdowns	G	G
Significant issues	Y	Y
Significant PIPs (corrective-active program)	G	G
Significant work orders	G	G
Primary system filter usage	Y	Y

* Systems shared between units will default to Unit 1.

Examples

Major Problems	Resolution
BAT pumps subject to strong/weak pump interaction on both units (PIP C99-2627).	NSM CNCE-61659 and CNCE-61660 to be implemented in 1EOC13 and 2EOC12, respectively, to resolve this problem.
Frequent Unit 1 VCT auto mak-ups due to 1NV-172A seat leakage (PIP C00-5718).	Modify 1NV-172A valve internals with low-leaking trim during the next applicable unit shutdown (Ref.: CNCE-70664).
Low reliability of the seal water injection filter isolation double disc gate valves on both units (PIP C00-3735).	Replace damaged valves with high-performance globe valves as they fail.

Another key risk-management activity of the equipment-reliability process is the corporate-wide corrective-action program, known as a performance improvement program (PIP). PIP dispositions every improvement opportunity at the plant, but it is discussed as part of this process because of its integral role identifying and resolving all equipment-performance degradations. The PIP process ensures that every risk-significant degradation receives the appropriate and timely evaluation, that corrective actions are implemented, and that the information is fed back into the plant risk tools.

At least monthly, system engineers examine cumulative out-of-service times for risk-significant trains of equipment against criteria that exist for the system-health program, maintenance rule, and other performance programs. The source of the information is the operations' out-of-service tracking system. Adverse trends result in generated PIPs.

The selection of effective preventive and predictive maintenance tasks and intervals for risk-significant equipment is also part of the equipment-reliability process. The system-health program and PIP both work to ensure effective maintenance. The system-health program confirms that important functional failures are addressed and monitors early indicators of degradation. PIP identifies corrective actions for any other actual or potential degradation detected during operation. In addition, the Maintenance Rule (a)(1) program mandates corrective action if any of its performance indicators are exceeded due to maintenance-related problems.

Major equipment reliability issues can involve consideration of capital improvements, major refurbishment, or programmatic changes in the way equipment is operated, tested, and maintained. These issues often arise because of risk concerns, and their resolution considers risk management as a decision criterion. The two examples below illustrate how risk was effectively considered in recent Catawba Station issues.

According to the PRA, turbine building flooding is a higher risk concern at Catawba Station. Inspection, repair, and possible replacement of expansion joints in the condenser circulating water system were considered in light of this risk information. After detailed consideration of failure modes, rupture mechanisms, aging of materials, and repair options, it was decided to repair a leaking expansion joint using a seal design from successful fossil plant experience and to monitor all other expansion joints for that failure mechanism. New expansion joints were ordered and warehoused in the event of any indication of serious degradation.

In response to the same flooding concern, Catawba is evaluating the installation of flood barriers around transformers in the basement of the turbine building. Careful consideration of all implications of the change resulted in the decision to evaluate modifying both Catawba units, even though modifying only one unit provides adequate equipment for accident response. The other unit will be modified to maintain symmetry at both units, thus improving the operator understanding and response to such an event.

Another example of a major equipment-reliability issue was the cleaning of service water system piping. Because of dependencies between units, unavailability of Unit 1 nuclear service water during that unit's outage was very risk-important to the other unit. The cleaning schedule and procedures were carefully developed, implemented, and monitored to manage risk for the operating unit.

A.4.3 Configuration Control

The configuration-control process of the standard process model includes activities that control the NRC licensing design basis of the plant. However, many of the same activities control the design and operational basis from an integrated risk perspective—that is, considering cost, performance, environment, and safety. These activities include control of plant modifications, control of procedures and technical specifications (Tech Specs), effectiveness assessment, and benchmarking.

Engineering evaluation of plant modifications was previously discussed. These risk considerations continue during the preparation and implementation of the modifications, and they are not discussed further here.

Control of Tech Specs plays a significant role in configuration control. Of course, compliance with Tech Specs is an explicit responsibility of Catawba Station operators. However, two other risk-management activities related to Tech Specs are worthy of note. First, Catawba uses either the Exigent Tech Spec Change process or the Notice of Enforcement Discretion (NOED) process, as appropriate, to justify startup or continued operations under conditions not allowed by conservative application of Tech Specs. After a thorough consideration of risk, continued operation is often safer than a disrupting mode or power change. Similarly, a startup or continued power escalation with some Tech Spec deviation can be shown to be preferable to a "quick fix" to satisfy a technical requirement that has little risk significance. Secondly, Catawba Station is

actively participating on the industry Risk-Informed Tech Spec Task Force, currently pursuing seven initiatives to allow risk-informed surveillance intervals, out-of-service-times, and required mode changes. These initiatives are based on generic determination of risk impacts and plant-specific risk-management activities, including a case-by-case consideration of equipment configuration risk.

Effectiveness assessment is a prominent risk-management activity at Catawba Station. Sixteen full-time corporate quality-assurance auditors routinely assess functional areas, including operations, maintenance, work control, engineering, radiation protection, emergency preparedness, and some corporate support functions. In addition to identifying opportunities for improvement, these assessments verify that functions evolve in response to changes in the physical plant, operations, and performance. Additionally, special request audits are performed each year, selected from issues identified by the system-health program, PIP events, INPO and NRC inspections, or other sources. Recent audit examples include material control, code safety valve reliability, in-service testing, and CRD control card failures. Also, one safety-system functional assessment is performed each year for a system identified to have potential functional issues.

Catawba also benefits from active participation in industry and Catawba-initiated benchmarking activities. The ongoing risk-informed system-health program update is the product of a recent benchmarking study.

A.4.4 Loss Prevention

Many of the risk-management activities at Catawba fall into the loss prevention process of the standard process model. This is an interesting generic process because its activities address risk in the broadest sense: public safety, environment, personnel safety, and asset protection. Activities include licensing, safety assurance, severe accident management, probabilistic risk assessment, cost/benefit, fire prevention, review of generic safety concerns, and security.

Many licensing activities ultimately support other plant processes—such as maintenance rule supporting equipment reliability and risk-informed Tech Specs supporting configuration control—and these activities are discussed with those processes. One additional licensing activity with risk-management value is the Regulatory Oversight Program (ROP). Clearly, monitoring of seven “safety cornerstones” provides both a risk-informed and a performance-based foundation for regulatory scrutiny. Therefore, Catawba proactively manages these indicators. For example, five front-line systems, which are monitored for availability within the ROP, are each reviewed by an IRT every five weeks on a rolling basis. Furthermore, the ROP significance determination process to disposition inspection findings is also both risk-informed and performance-based.

Review of generic safety concerns by the Catawba staff is a powerful risk-management activity within the loss-prevention process. Industry operating experience is reviewed and documented from numerous industry sources. This case study reviewed the Catawba Station consideration of one generic safety issue: the potential for containment sump blockage during reactor coolant recirculation following a LOCA. This issue is under review at Catawba in light of design-basis requirements as well as risk insights from the PRA.

Catawba safety-assurance activities are integral to risk-management effectiveness. The full-time independent nuclear oversight team (INOT) staff observes and assesses safety at power and throughout outages. Other safety review group staff screen and monitor PIPs for safety significant issues, facilitate root cause analysis, and monitor corrective actions.

The activities of the Nuclear Safety Review Board, comprised of nuclear plant site vice presidents from all Duke Energy nuclear plants and corporate managers, is worthy of particular note. This group reviews risk-management performance of the Catawba Station quarterly. A valuable monitoring tool, an annual running average CDF using actual plant conditions, is evaluated as part of this review to identify high-risk contributors during the review period. This monitoring tool clearly identifies intervals of high risk relative to average risk values calculated by the PRA. An example output from this monitoring tool is shown as Figure A-4. Contributing events are identified and explained in advance by the PRA Section at Duke Energy headquarters and by the Catawba Station staff.

Unit Common Parameters	Unit Rating Overall Health Rating 1*	 2
*Availability	G	G
*System Reliability	G	G
*Maintenance Rule Status	G	G
Major Component Reliability (NV Pumps)	Y	Y
TEPR Items (Top Equipment Problem Resolution)	G	G
Function Material Condition/Walkdowns	G	G
Significant Issues	Y	Y
Significant PIPs (PIP = Corrective Active Program)	G	G
Significant Work Orders	G	G
Primary System Filter Usage	Y	Y

*Systems shared between units will default to Unit 1.

Examples

Major Problems	Resolutions
BAT Pumps subject to strong/weak pump interaction on both units. (PIP C99-2627)	NSM CNCE-61659 and CNCE-61660 to be implemented in 1EOC13 and 2EOC12 respectively to resolve this problem.
Frequent Unit 1 VCT auto make ups due to 1NV-172A Seat Leakage. (PIP C00-5718)	Modify 1NV-172A valve internals with low-leaking trim during the next available unit shutdown. (Ref.: CNCE-70664)
Low reliability of the seal water injection filter isolation double disc gate valves on both units. (PIP C00-3735)	Replace damaged valves with high performance globe valves as they fail.

Figure A-4
Quarterly Report of Annual Average CDF Monitoring

Physical security is an important area of the loss-prevention process, and risk-management activities at Catawba address control of risks from threats such as terrorism—especially during recent periods of heightened national alert. Effectiveness of response against a threat is measured ultimately by preventing irreversible fuel damage that could result in a significant radionuclide release. Since the mid-1980s, Catawba has used "target sets" derived from PRA results to determine critical combinations of equipment needed to prevent the above end state. Response strategies are designed to protect these target sets. As the likelihood of threats evolves with technology and world events, both the response strategies and day-to-day risk-management actions change. Risk-management actions within the past several months include:

- Inclusion of additional structures within the fenced and monitored protected area
- Procedures to enhance the reliability and timeliness of backup safety systems
- Deferred out-of-service time for a critical safety train of equipment

Another risk-management function within the loss-prevention process is fire protection. The fire-protection engineers have developed a close working relationship with the PRA group. Both groups are participating in industry/NRC efforts on the development of a new fire protection rule, which intends to incorporate risk and performance-based concepts. However, the cost-benefit of the rule will be a key consideration in its eventual development. Because the existing risk model for fire, developed as part of the NRC request for an individual plant examination of external events (IPEEE), is not optimal for real-time assessments of fire risk, work control has been provided a list of critical areas based upon existing fire-risk knowledge. In addition, the PRA Group developed a matrix of important areas and required redundant equipment for outage and low power conditions to operations and work control to address fire risk.

Catawba Station staff maintain cognizance and participation in a number of plant-specific and industry issues related to fire risk, including a fire-risk standard, NFPA 805; EPRI Fire PRA methodology updates; risk-informed nuclear insurance standards development; the risk-importance of Hemick insulation as a fire barrier; and multiple fire-induced circuit failures.

Activities of the PRA Group is an element of the loss-prevention process and is the lynchpin of risk-management activities at Catawba Station; that is, it enables risk to be identified, quantified when necessary, and prioritized in a structured way. It is evident at Catawba that the PRA tools and the PRA staff engineers are an integral part of all risk-management processes. This integration is key to their success.

Cost/benefit analyses are important activities in the loss-prevention process at any nuclear plant. However, the way in which cost/benefit analyses and cost/benefit decisions incorporate safety risk determines whether they contribute to safety-risk management. There is considerable evidence at Catawba Station that safety risks are monitored and evaluated, to a large extent, independently of cost considerations. After the risk issues are completely identified and evaluated and appropriate near-term actions have been taken consistent with good risk management, then cost/benefit considerations are incorporated into the decisions for final disposition of the issue.

For example, the Catawba Station Maintenance Rule Expert Panel, which determines the scope of systems and activities within the program, make its risk-informed determinations without regard to cost/benefit. Similarly, the CCW process for the service water system cleaning was also determined to manage risk, with cost a secondary consideration. Finally, resolution of the condenser expansion joint repair and replacement program was primarily driven by risk-management considerations. In this case, cost/benefit was a strong determinant in the selection from among risk-acceptable solutions.

Sometimes the potential for a significant cost benefit is the motivation for the risk-management activity. Such is the case for an aggressive effort by Catawba and many other stations to implement a risk-informed steam generator testing program. The program would establish eddy

current test intervals based on observed condition of the tubes and on knowledge of failure mechanisms and degradation rates from years of accumulated experience with similar steam generator designs and materials. These programs would actively manage the public-safety risk from a steam generator tube rupture accident while allowing significant savings of test costs and plant-outage time.

A.4.5 Training

The training department services a number of plant departments, including operations, engineering, and maintenance. The training department's mission is divided between two sets of customers. The first group is licensed operators that require training that has been accredited or approved by outside agencies. Specifically, INPO and NRC provide accreditation and approval of the licensed reactor operators training program at Catawba Station. The second set of customers is the remainder of plant staff, which receives training on many subjects and for a variety of purposes. The major difference between the two groups is that training requirements (such as subject matter, periodicity, and testing) are predetermined by outside agencies for the first group, while requirements are much more licensee controlled and administered for the second group. In the current regulatory climate, training for the second group has a much greater potential for utilizing risk-informed insights.

The NRC has identified a listing of approximately 4000 "knowledge and ability attributes," which constitutes a good operator. These attributes are founded in design-basis philosophy (such as FSAR Accident Analysis and Tech Specs). In addition, the program is periodically audited by NRC staff. These auditors are training program specialists founded in the design basis philosophy used to develop these programs.

INPO also accredits the Catawba training program. Accreditation of the training program is a requirement of every licensee. The INPO process has defined eight objectives that each training program must meet in order to attain INPO accreditation. Although this objective could be risk-informed, this would require a coordinated industry approach because a single licensee cannot deviate from the above without risking loss of INPO accreditation.

Nonetheless, there are some risk-management attributes to the Catawba Station training program for operators. Initial ORAM/SENTINEL training was provided to operators. Trainers review system-health reports, PIPs, and defense-in-depth (DID) sheets, and they incorporate insights into a risk-management training module as part of annual re-qualification training. Just-in-time training is provided on a number of important and infrequent evolutions, including pre-outage sessions. So operator training does benefit somewhat from the risk-informed safety culture, but it is limited by many external requirements.

Other than plant operators, staff training includes risk elements as necessary. For example, the maintenance staff is taught the meaning and importance of configuration risk management performed with ORAM/SENTINEL, and they are required to perform an activity within 30 minutes of the prescribed outage window. Also, a committee including engineering, maintenance, and operations staff identifies changes in training needs of plant staff. On an *ad hoc* basis, this committee makes recommendations based upon PRA importance, recent plant operating experience, and industry events.

A.4.6 Support Services

Recent advances in information management at nuclear plants arguably provide the enabling technology for risk management. This thesis is supported by the wide availability of monitoring information on the corporate intranet. Examples of such information include system-health reports and summaries, ORAM and SENTINEL configuration risk profiles, lists of equipment in the maintenance rule goal-setting program, operators' lists of troubled equipment, and predictive maintenance results for a broad spectrum of equipment. As information technology evolves, risk-management timeliness and integration can improve even more.

A.4.7 Operations

The station's operation process, as noted in Figure A-2, integrates information from all the other processes discussed so far. As such, operations staff participate in many of the risk-management activities already identified. There are, however, several other operations activities of particular note, which have not been discussed previously.

Operations is responsible for required testing, operator-rounds monitoring, Tech Spec compliance, and release of equipment for maintenance and testing. Operators have a unique integrated and intuitive understanding of the relationship of equipment reliability and availability to plant operations and safety. They use this understanding together with the objective risk-management tools discussed above to manage risk.

Specifically regarding equipment reliability, operations identifies items on the equipment problem resolution (TEPR) list, which is a prioritization of equipment of particular risk concern. Of course, this equipment is the subject of other risk-management attention in other processes, but this list provides an integrating perspective to the issues with equipment.

Regarding release of equipment for maintenance, operations continually receives, from work management, lists of high-risk equipment configurations to avoid based on planned and actual equipment status. Operations also holds the release of any new work, until an evaluation is performed, whenever an emergent unavailability or work-carryover condition arises.

A.5 Support of Six Risk-Management Objectives

1. Annual average risk (CDF and LERF) and risk rate (core damage instantaneous probability and large early release probability) are maintained and monitored at the station. Catawba Station has three tools that are used regularly to achieve this objective:

- ORAM/SENTINEL, which calculates approximate core damage probability and, for SENTINEL, large early release probability for all planned plant configurations
- The core damage probability and CDF risk monitor that is reviewed quarterly by the Safety Review Board and is used to monitor against Catawba's annual CDF goals
- The full-scope PRA that is periodically updated to calculate average CDF and LERF for the Catawba Station

2. Functions are in place to prevent safety challenges and to prevent poor response of the plant equipment and personnel for events that are risk-significant. These functions include monitoring of leading indicators of degradation.

   The system-health program is the cornerstone of this function. The risk-informed maintenance task selection and frequency for high-risk significant equipment prevents challenges. Monitoring for the INPO Performance Indicator Program and the maintenance rule performance criteria are backstops for equipment issues. Aggressive, proactive use of the PIP program provides leading indicators of equipment degradation, human performance issues, and programmatic weaknesses.

3. Causes of risk-significant degradations and of actual risk-significant events are evaluated and corrected.

   The corrective action program, PIP, is the foundation of this capability. Structured review of all PIP entries ensures that appropriate cause evaluations are performed and that actions are done effectively and on time. The Safety Assurance Group has explicit responsibility for root cause evaluations. Maintenance Rule (a)(1) goals require evaluation and correction of any maintenance-related issue that results in exceeding a performance criterion.

4. Risk impact of risk-informed changes is verified by performance monitoring. The cumulative impact of risk-informed changes is verified to be within anticipated and acceptable levels.

   Demonstration of this criterion is the nexus for more efficient implementation of risk-informed regulations. Clearly at Catawba, any risk increase would be detected by the CDF and LERF monitoring described for criterion 1 above. This monitoring does not tie any risk change to a specific risk-informed change, but this monitoring does show that the cumulative impact of risk changes achieves the risk objectives.

Risk-impacts of specific risk-informed changes and verification of specific assumptions related to those risk-informed changes can be inferred from the detailed investigation of events and equipment monitoring that is done as part of activities described for criterion 3 above.

5. Risk-management activities evolve in response to plant changes and plant experience, and the effectiveness of the program itself is regularly evaluated.

   This criterion is the strongest justification for preferring risk-management activities in favor of prescriptive requirements, or predictive risk analysis, as the basis for a risk-informed operational or regulatory change. There are three reasons that this criterion will likely continue to be met at Catawba Station: (1) All important plant processes are formally periodically assessed; (2) the risk-management activities described above are all risk-informed, and the risk assessment is continually updated and communicated to plant staff; and (3) the risk-management activities described above are all performance-based, so risk-important changes will be reflected in degraded performance indicators.

6. The culture of the staff and the plant organization are structured to accomplish effective risk management.

   Evidence of this criterion is everywhere among the Catawba Station staff:

- Individuals responsible for the risk-management activities described above are aware of the most risk-important equipment, initiating events, human actions, and accident sequences for Catawba Station. They do not hesitate to consult with PRA Section staff before making decisions affecting these risk-important elements.
- The independent safety assurance director and staff are prominent with numerous risk-informed oversight functions.
- Management has supported risk-informed decisions, even when these decisions have had high near-term costs. Examples include the service water system cleaning; potable water backup for RCP seal cooling, and very recent changes in design, operations, and maintenance in response to heightened security. Management encourages proactive steps to avoid high-risk conditions, such as the CCM plans for infrequent maintenance evolutions, attention to train unavailability at 50 percent of its level of concern, and the weekly rolling safety reviews of the five most critical safety systems.
- Expert panels and technical review and oversight groups are staffed with appropriate subject-matter experts to produce the best technical product for management decisions, as opposed to direct management control of these groups. Subsequently, management decisions give safety-risk full considerations as manifest in Catawba's determination of optimal refueling outage length.

A.6 Conclusions

This appendix set out to demonstrate, for one well run U.S. nuclear plant, that effective safety-risk-management activities are inherent in the processes that support plant operations. The case study of Catawba Nuclear Station provides such a demonstration. These activities can be characterized as a risk-management overlay on the formal plant programs and processes.

Furthermore, these risk-management activities, as well as recent plant responses to opportunities and events, satisfy six criteria that are proposed as indicators of an effective risk-management program.

Having established that an effective risk-management overlay exists at a well-run plant, the appendix proposes that these activities provide a sound basis for more risk-informed and performance-based regulatory changes. These activities monitor performance and risk subsequent to the change and appear to very effectively maintain risk at or below the levels intended by the regulatory changes. In fact, these activities constitute the "performance-based" part of risk-informed and performance-based regulations.

Furthermore, these activities are effective in providing quantification and prioritization of risk by providing configuration, failure rate, and availability information that is used for continuous or periodic risk monitoring. Therefore, the costly, time-consuming, and overly conservative risk assessment and uncertainty analysis that often must accompany a risk-informed regulatory change request can be relaxed.

There is reason to believe that the benefits of risk management that are observed at Catawba Nuclear Station can be expected to be applied generically to other plants as long as the risk-management overlay demonstrates the basic attributes of a complex interactive system. That is, the risk-management system can more effectively manage risk than an approach that sets requirements based on precisely predicted risk levels and uncertainty from a PRA.

Finally, the benefits of RM also apply to other than public-safety risks (such as asset protection, plant reliability, and other financial risks). Evidence of these benefits was observed at Catawba Station but is beyond the scope of this case study.

The risk-management overlay at Catawba Station has many attributes of a complex interactive system. Such systems are characterized by broadly distributed responsibility versus tight procedural or hierarchical structure. Information is disbursed and used broadly. Activities evolve quickly in response to new experience. Leading indicators are identified and actions are taken continually to maintain the desired end state (in this case, acceptable risk).

So, the elements are now in place to define a process to move more quickly and efficiently toward the objective of risk-informed and performance-based regulation and operation of nuclear power plants. The process will have both safety benefits and cost benefits for nuclear plant operators. Furthermore, the process will not require a significant change in plant organization, functions, or culture for those plants that have effective risk-management activities.

B
MAPPING OF NEI/EUCG STANDARD NUCLEAR PLANT PROCESS MODEL TO PLANT ORGANIZATIONAL FUNCTIONS

B.1 Core Processes

B.1.1 Plant Operation

(OP001) Operate and monitor structures, systems, and components.

(OP002) Monitor and control effluents.

(OP003) Monitor and control plant chemistry.

All of these functions typically are part of normal plant operations and are either directly performed by or are under the control of the operations organization. Process OP001 has immediate and direct impact on nuclear safety. This function has significant interface with the work management, equipment reliability, and loss-prevention functions. These interrelationships are of paramount importance in ensuring that the function is successful in ensuring plant safety. Functions OP002 and OP003 also affect nuclear safety. However, their effects are typically manifest over longer time periods. Particularly, function OP003 has important consequences for the long-term condition of passive components (such as piping systems) and plant structures (such as containment systems).

B.1.2 Configuration Control

(CC001) Provide configuration control.

(CC002) Provide design changes.

(CC003) Provide design-basis changes.

(CC004) Provide fuel-management services.

(CC005) Provide a decommissioning plan.

Function CC001 is a day-to-day normal operational activity and under the direct control of plant operations. Plant technical specifications also require operations to maintain control of plant configuration. This function has significant interface with the work management, equipment reliability, and loss prevention functions. These interrelationships are of paramount importance in ensuring that the function is successful in ensuring plant safety. All of the remaining functions (CC002–CC005) address configuration-control issues, which can impact plant safety in the long term. Typically, these functions do not vary appreciably over the short term. Functions CC002 and CC003 are both part of the plant modifications process. These changes occur in discrete intervals. From a safety standpoint, once implemented, they result in a change to plant design/configuration. Significant changes can be modeled in the plant PRA, from which quantitative estimates on the impact on plant safety can be made. These processes typically are controlled by the plant engineering organization with significant support from corporate engineering organizations. Function CC004 is also an engineering function to determine the most economical fuel for use in the plant. From a nuclear safety viewpoint, once a fuel configuration is selected, the reactor physics characteristics are determined for the remainder of the fuel cycle; thus this function serves as a physical constraint on plant operation for the entire length of the fuel cycle. Finally, function CC005 is also an engineering function that has minimal impact on day-to-day plant safety.

B.1.3 Work Management

(WM001) Perform planning.

(WM002) Perform scheduling.

(WM003) Perform preventive maintenance.

(WM004) Perform corrective maintenance.

(WM005) Maintain non-plant equipment.

(WM006) Perform plant-improvement maintenance.

(WM007) Monitor and control radiation exposure.

(WM008) Monitor and control contamination.

The work-management functions achieve the objective of ensuring proper operation of plant equipment and that plant systems are capable of achieving their design objectives in a reliable manner. Functions WM001 and WM002 are responsible for ensuring corrective and preventive maintenance activities are properly planned and executed (use of proper procedures, tools, and adequately trained personnel) and that the work is scheduled with proper prioritization and coordination. At many nuclear plants, these activities are segregated into two separate organizations. The detailed work activity planning is typically the responsibility of the maintenance organization, while scheduling is assigned to a dedicated scheduling organization. It should be noted that the interaction of these organizations is vital to the degree to which these

functions are successfully implemented. Functions WM003–WM006 constitute the conduct of the actual maintenance activities and typically are the responsibility of the plant maintenance organization. All of the functions listed above have a direct impact on nuclear plant safety, with critical interfaces between different organizations within the maintenance department and with plant operations and engineering. The final functions (WM007 and WM008) are associated with meeting governmental regulations and ensuring safety of plant personnel. As such, they have only a small impact on the major nuclear safety risk parameters (core damage frequency and large early release frequency).

B.1.4 Equipment Reliability

(ER001) Develop and maintain long-term maintenance plan (preventive maintenance and predictive-maintenance programs).

(ER002) Conduct surveillance and performance tests.

(ER003) Analyze performance and reliability of structures, systems, and components.

(ER004) Perform predictive maintenance.

Each of these functions is directly related to the monitoring and control of plant performance. The engineering organization typically has primary responsibility for conduct of each of these functions. However, some plants place the responsibility for predictive maintenance (ER004) within the maintenance organization. Additionally, many of the surveillance and performance test activities are also conducted by the plant operations and maintenance organizations (particularly testing of instrumentation and control devices). To successfully achieve their objectives, each of these functions must interface with the plant operations and work management functions to a great extent. Additionally, there is an important interface between results obtained from these activities and the configuration control process.

B.1.5 Materials and Services

(MS001) Provide inventory management.

(MS002) Provide materials and services.

(MS003) Provide contract services.

(MS004) Provide warehousing.

(MS005) Provide returns and maintenance.

(MS006) Provide disposal and surplussing.

(MS007) Provide and transport fuel.

(MS008) Provide handling, storage, and disposal of fuel.

Functions MS001–MS005 directly support the work management core process (plant maintenance) and have significant interaction with personnel responsible for performing those functions. Organizationally, these functions are increasingly viewed as a separate discipline and are embedded in a separate plant support organization. Function MS006 provides an economic function to the plant with minimal impact on plant safety. Functions MS007 and MS008 have nuclear safety impact but are independent of the primary function of generating electricity. These activities have independent, standalone regulatory requirements and procedural controls. Additionally, if safety risk is modeled for these functions, it is accomplished as a separate stand-alone model (it is not modeled as part of the plant PRA).

B.2 Enabling Processes

B.2.1 Support Services

(SS001) Provide information technology services.

(SS002) Provide business services.

(SS003) Provide records management and document control services.

(SS004) Provide human resource services.

(SS005) Maintain grounds, facilities, and vehicles.

(SS006) Support community and government services.

(SS007) Support industry professional and trade associations.

Each of these functions provides support to each of the core processes. However, they do not provide a direct impact on plant safety. As such they contribute implicitly to nuclear plant safety through their support of the core processes. Additionally, for critical core process activities, contingency methods are available to perform these functions in the event of failure of one of these processes. As an example, all plants have manual methods to process necessary work orders (support the work management core process) in the event that the electronic work order system is not operating (failure of the function to provide information technology services). Thus, although these functions have a significant business benefit, they have only minor impact on nuclear safety. Performance of these functions typically is the responsibility of a plant services organization (using either plant or central office corporate personnel resources).

B.2.2 Loss Prevention

(LP001) Provide security measures.

(LP002) Provide performance monitoring and improvement services.

(LP003) Maintain licenses and permits.

(LP004) Perform emergency planning.

(LP005) Provide fire protection.

Each of these functions provides direct support to maintaining plant safety. These functions each have the attribute that they are performed off-line—that is, they typically do not need to be inserted directly into the core processes on a daily basis. However, these processes are necessary to ensure that plant safety and performance are maintained over the long term. Function LP001 is typically the responsibility of a dedicated security organization. The remaining functions (LP002–LP005) are typically the responsibility of the plant engineering organization. Of particular (and paramount) importance for nuclear safety is function LP002. This function includes all aspects of event and performance analysis, including self-assessment, root-cause determination, corrective-action specification and effectiveness monitoring, human factors performance and analysis, regulatory compliance, supplier qualification, and plant quality assurance. This report includes the risk assessment functions (PRA and technical support) within function LP002. Some plant organizations include the risk assessment functions within configuration control. For consistency at such plants, the assessment could be moved to the other process. Function LP002 has significant interaction with all of the core processes, and its successful application depends directly on these interactions. The other functions (LP003–LP005) are very specialized functions using dedicated specialists. Organizations providing these functions are occasionally part of a plant-support organization rather than part of the plant engineering line organization.

B.2.3 Training

(T001) Develop training programs.

(T002) Conduct training.

(T003) Attend training.

Each of these functions provides support to each of the core processes. As such they contribute implicitly to nuclear plant safety through the core processes. However, they have a direct impact on plant safety as reflected in the capabilities of site personnel. Because of this direct relationship to safety, programs to train various plant personnel—particularly operations, maintenance, and engineering personnel—are strictly controlled as to both the content and methods used. Plant training programs are externally accredited by INPO, which provides a strong measure of control

and consistency. For example, all training modules have formal lesson plans with specific student learning objectives and example test questions. In addition to these attributes, implementation of many activities requires demonstrated on-the-job skill proficiency with sign-off of qualification standards by experienced instructors and/or supervisors in the responsible discipline. These controls help to ensure a basic level of competence in the performance of the various work tasks and are particularly applicable for maintenance and operations applications.

C
RISK-MANAGEMENT EFFECTIVENESS EVALUATION QUESTIONS

Provided in this section is the set of questions developed for each of the first-level processes from the Standard Nuclear Plant Process Model (SNPM) identified as having either a direct or supporting impact on plant risk. These questions incorporate the insights gained from application of the assessment approach during the limited proof of concept and validation and full plant application. This includes a set of "cross-cutting" questions that transcend process boundaries. However, as applications of risk management increase and additional knowledge is obtained, it is anticipated that these questions will be expanded upon and modified as risk management develops into a mature approach.

The questions are arranged by their respective SNPM process/sub-process. A relative importance weighting (high/medium/low) is provided for each question, which indicates the attribute's importance to nuclear plant safety risk. The relative importance was selected based on the researcher's experience. As application of risk management matures and the techniques employed are subject to more thorough critical review, the relative importance of the various questions may be modified based on the additional knowledge acquired.

C.1 Plant Operations

C.1.1 Process OP001: Operate and Monitor Structures, Systems, and Components

- Plant controls, visual displays, and alarms are configured to support human factors enhancements and minimize personnel errors. (Wt = High)
- Operations procedures (both normal and abnormal) are clear and readily interpretable by typical operators. The procedures contain human factor consideration/enhancements, which help reduce potential misinterpretations and errors. (Wt = Med)
- Emergency operational procedures have been field-verified to ensure that they can be successfully completed within the expected time constraints. All required tools and equipment (jumpers and so on) are verified to be present in a secured accessible location. (Wt = Low)
- Operations personnel provide feedback to improve accuracy and usability of plant operations procedures. These changes are then reviewed and implemented within a reasonable time, with feedback provided to the suggestion initiator(s). (Wt = Med)

- A comprehensive set of metrics exists and is monitored to determine overall effectiveness of plant operations. The metrics are monitored and applicable corrective actions are developed and implemented. (Wt = Med)
- Operations personnel routinely inspect plant equipment for operational abnormalities/degraded condition and report any identified conditions to engineering personnel responsible for equipment/system performance. (Wt = High) – Inter-Process Interface
- During operations that can impact nuclear plant safety functions (such as core cooling and containment cooling), operations personnel notify appropriate management of status and conditions throughout the evolution of the task/event. (Wt = High) – Safety Culture
- Operations understands and utilizes appropriate risk-assessment information and expertise in operational decision-making. (Wt = High)

C.1.2 Process OP002: Monitor and Control Effluents

Out of Scope

C.1.3 Process OP003: Monitor and Control Plant Chemistry

Systems subject to corrosion-related degradation mechanisms (such as IGSCC and boric acid) have well defined chemistry operating bands that are directly traceable to engineering analyses. Operations is cognizant of and sensitive to these SSCs and appropriately monitors their condition. (Wt = High)

C.2 Configuration Control

C.2.1 Process CC001: Provide Configuration Control

- Status of current plant configuration is maintained and easily queried by plant operators. Particularly, status (such as in-service, standby, and inoperative) of important equipment not indicated in the control room is available. (Wt = Med)
- For equipment with significant identified deficiencies or imposed operational limits, these deficiencies/limits are readily identified and displayed to plant operators. (Wt = High)
- Information listing status of major plant safety functions (such as core cooling and containment cooling) is available to operations personnel, including available level of redundancy and prioritized usage. (Wt = Med)
- Changes in plant configuration are assessed for impact on plant safety functions (such as core cooling and containment cooling) in a timely manner, and appropriate compensatory actions are implemented (if necessary). (Wt = High)
- Risk-informed programmatic requirements are incorporated into plant configuration controls. (Wt = Med)

- Operations personnel participate in review of newly identified equipment deficiencies and provide input on setting priorities of the associated maintenance tasks. (Wt = High) – Inter-Process Interface
- Operations personnel provide input during work-planning process to group work activities to ensure that equipment is removed from service for a minimum amount of time. (Wt = Med) – Inter-Process Interface
- During operational evolutions, shift operators consult relevant resources to determine preferred courses of action. These resources can include procedural controls (such as technical specifications, design basis information, and FSAR), software tools (such as ORAM/SENTINEL and EOOS) or knowledgeable experts (such as PRA analysts). (Wt = High) – Safety Culture
- Prior to removing SSCs that impact nuclear plant safety functions (such as core cooling and containment cooling) from service for maintenance, the operating condition/health of alternative equipment is specifically evaluated to ensure that high levels of availability and reliability are maintained. (Wt = High) – Safety Culture
- During unanticipated events, impact of the event is evaluated to determine potential impact on nuclear safety risk. This evaluation can include analysis of impact on CDF/LERF using available software (such as ORAM/SENTINEL or EOOS) or consultation with knowledgeable experts (such as PRA analysts). (Wt = High) – Safety Culture

C.2.2 Process CC002: Provide Design Changes

- Engineering personnel responsible for equipment/system performance participate in the engineering of all design changes impacting their assigned systems. (Wt = High) – Inter-Process Interface
- Operations personnel participate in the engineering of all design changes to provide operational input. (Wt = Med) – Inter-Process Interface
- Maintenance personnel participate in the engineering of all design changes to provide maintainability input. Changes are analyzed to provide appropriate preventive and predictive maintenance activities. (Wt = Med) – Inter-Process Interface
- Design changes are analyzed to provide performance requirements prior to implementation. Performance is monitored after installation to verify that performance objectives have been achieved. (Wt = Med)
- Application of instances requiring dedication of commercial-grade parts are identified, and information on any limitations is provided to responsible engineering personnel. (Wt = Med) – Inter-Process Interface
- Decision-making process for implementation of design changes includes analysis of the potential impact on nuclear safety risk as a specific input parameter impacting the decision. (Wt = High) – Safety Culture

C.2.3 Process CC003: Provide Design-Basis Changes

- Implementing procedures affected by design-basis changes document the basis of the change and specify any limitations derived from them. (Wt = Med)
- Decision-making process for implementation of design-basis changes includes analysis of the potential impact on nuclear safety risk as a specific input parameter impacting the decision. (Wt = Low) – Safety Culture

C.2.4 Process CC004: Provide Fuel-Management Services

Fuel design safety analysis expertise is applied and integrated to address applicable operational and engineering issues. (Wt = Low)

C.2.5 Process CC005: Provide a Decommissioning Plan

Out of Scope

C.3 Equipment Reliability

C.3.1 Process ER001: Develop and Maintain Long-Term Maintenance Plan

- Equipment preventive maintenance tasks are determined based on a combination of equipment functional importance, duty cycle, and operating environment using a defensible documented engineering-based methodology (such as RCM). (Wt = High)
- Selection of equipment preventive maintenance tasks account for the risk importance of the equipment. (Wt = Med)
- Craft feedback is utilized to continually improve preventive-maintenance tasks (both content and frequency) to account for recent plant operating experience. (Wt = Low) – Inter-Process Interface
- Criteria are established for designation of equipment that is identified as run-to-failure. (Wt = Med)
- Equipment preventive-maintenance tasks are assigned with an assessment of (1) the potential failure mechanisms to which the maintained equipment is susceptible, (2) specification of applicable tasks to address each credible failure mechanism, and (3) an understanding of the level of protection/effectiveness that the task will provide for that failure mechanism (such as protection against random failure mechanisms will be low). (Wt = Med)
- Where sufficient data exist (such as by grouping similar component types/applications), quantitative data/failure distributions are constructed to optimize preventive-maintenance task intervals (cost/benefit). (Wt = Low)
- Currently known equipment aging mechanisms are identified, and effective methods to monitor/retard them are in place. (Wt = High)

- Plant/corporate personnel are actively involved in industry research to identify new aging mechanisms and develop methods for their monitoring/retardation. (Wt = Low)
- Failures due to age-related mechanisms are identified, and generic implications are evaluated. (Wt = High)
- For equipment subject to age-related failure mechanisms (such as wear-out), quantitative evaluation methods are utilized to predict remaining useful life. (Wt = Low)
- A comprehensive set of metrics exists and is monitored to determine overall effectiveness of preventive maintenance program. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)
- Maintenance personnel provide input to responsible engineering personnel on recommended preventive-maintenance tasks to improve equipment reliability. (Wt = Med) – Inter-Process Interface
- Plant resources used to proactively maintain the health and performance of plant SSCs are prioritized such that the effort expended and level of analysis is commensurate with the SSC's impact on nuclear plant safety. (Wt = High) – Safety Culture

C.3.2 Process ER002: Conduct Surveillance and Performance Tests

- Operational rounds are conducted with expectations for operators to identify abnormalities and degraded SSC condition. Minor abnormalities (such as loose covers) are immediately corrected; other abnormalities are expeditiously entered into the plant work order system for evaluation/prioritization. (Wt = High)
- System/equipment surveillance and performance data are routinely monitored and trended to ensure that minimum established performance is maintained. (Wt = High)
- Surveillance and performance data are routinely analyzed in conjunction with predictive maintenance data to assess equipment health. (Wt = High)
- Functional verification surveillance activities (such as safety function instrumentation) are integrated into the normal maintenance schedule with appropriate priority with tasks performed on schedule. (Wt = Med)
- A comprehensive set of metrics exists and is monitored to determine overall effectiveness of the surveillance-testing program. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Low)
- Applicable surveillance and performance programs (such as ISI, IST, and MOV) are risk-informed. (Wt = Med)

C.3.3 Process ER003: Analyze Performance and Reliability of Structures, Systems, and Components

- SSCs that affect plant safety have applicable performance objectives identified, including SSC availability and reliability. These performance objectives/criteria are derived from a systematic defensible methodology and documented with supporting bases. (Wt = High)
- Performance of SSCs that affect plant safety are routinely monitored and trended to ensure that minimum established performance is maintained. (Wt = High)
- Mechanisms are in place and used to notify senior management of plant SSCs that are performing at a level of performance that is not acceptable or that exhibit degrading performance trend. (Wt = High)
- Statistical techniques are used to analyze SSC performance data and to predict future SSC performance/remaining life. (Wt = Low)
- Component failure data are obtained, analyzed, and used to update PRA results (such as via Bayesian updating). (Wt = Low)
- Results of SSC performance analysis are provided to operations personnel and used to modify preferences for use of equipment/trains/systems as appropriate. (Wt = Low) – Inter-Process Interface, Safety Culture
- Results of SSC performance analysis are provided to planning and scheduling personnel and used to modify plant-work schedule for equipment/train/system outages as appropriate. (Wt = High) – Inter-Process Interface
- Plant resources used to monitor the health of plant SSCs are prioritized such that the effort expended and level of analysis is commensurate with the SSC's impact on nuclear plant safety. (Wt = Med) – Safety Culture
- The balance between plant SSC availability and reliability is evaluated and input provided to applicable programs/processes (PM program, plant maintenance schedules, and so on). (Wt = High)
- Engineering personnel understand and utilize appropriate risk-assessment information and expertise in decision-making. (Wt = High) – Safety Culture

C.3.4 Process ER004: Perform Predictive Maintenance

- Equipment predictive maintenance tasks are determined based on a combination of equipment functional importance, duty cycle, and operating environment using a defensible documented methodology (such as RCM). (Wt = High)
- Selection of equipment predictive-maintenance tasks account for the risk importance of the equipment. (Wt = Med)
- Predictive maintenance data are routinely monitored and trended to ensure that minimum established performance is maintained. (Wt = Med)

- For applications of multiple complimentary technologies (such as spectral vibration and ferrography), results for the technologies are integrated to determine equipment condition. (Wt = Low)
- Analytical techniques are used to analyze predictive maintenance data and to predict future SSC performance/remaining life. (Wt = Low)
- Equipment predictive maintenance tasks are assigned with an assessment of (1) the potential failure mechanisms to which the maintained equipment is susceptible, (2) specification of applicable tasks to address each credible failure mechanism, and (3) an understanding of the level of protection/effectiveness that the task will provide for that failure mechanism (such as protection against random failure mechanisms will be low). (Wt = Med)
- A comprehensive set of metrics exists and is monitored to determine overall effectiveness of the predictive maintenance program. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)
- Maintenance personnel provide input to responsible engineering personnel on recommended predictive-maintenance tasks to improve equipment reliability. (Wt = Low) – Inter-Process Interface
- Plant resources used to perform predictive maintenance activities on plant SSCs are prioritized such that the effort expended and level of analysis are commensurate with the SSC's impact on nuclear plant safety. (Wt = Med) – Safety Culture

C.4 Work Management

C.4.1 Process WM001: Perform Planning

- Corrective actions are effectively prioritized and implementation occurs in accordance with the assigned priority. (Wt = High)
- Planning and scheduling utilize results from performance monitoring/predictive maintenance in development of work plans. (Wt = Med)
- Work instructions are written clearly and indicate appropriate procedures, required tools, craft skill level, and other necessary requirements to accomplish desired actions. (Wt = Med)
- Maintenance procedures exist that provide explicit instructions, with accompanying drawings and schematics, to permit typical craftsman to properly perform the desired maintenance activity. (Wt = Med)
- Risk-significant activities and evolutions are identified, and any special precautions or requirements (such as procedures, training, and mockups) are developed, reviewed, approved, and implemented prior to performing the activity. (Wt = High)
- Work instructions provide post-maintenance operability testing requirements. (Wt = Med)
- A comprehensive set of metrics exists and is monitored to determine overall effectiveness of corrective actions. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)

- A comprehensive set of metrics exists and is monitored to determine overall effectiveness of the planning process. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)
- The work-planning process interfaces with scheduling to identify all activities (including preventive maintenance) that should be performed simultaneously on the component and includes these activities in the work package. (Wt = High) – Inter-Process Interface
- The work-planning process interfaces with scheduling to identify all activities (including preventive maintenance) that should be performed simultaneously on related components (such as MCCs for rotating equipment and air supply SVs for AOVs) and include these activities in the work package. (Wt = High) – Inter-Process Interface

C.4.2 Process WM002: Perform Scheduling

- A formal work management process is used to identify, prioritize, schedule, track, and communicate work progress. Each step in the process has identified single points of accountability, allowing all involved work groups rapid access to obtain current status and resolve emerging issues. (Wt = High)
- Mechanisms exist to rapidly resolve minor problems such that resource impact is minimized (fix-it-now self-directed work teams). These mechanisms provide explicit instructions on work activities permitted (versus those requiring use of the formal work planning and scheduling process). (Wt = High)
- A comprehensive set of metrics exists and is monitored to determine overall effectiveness of the scheduling process. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)
- Schedule compliance is routinely monitored and evaluated by responsible work groups. Personnel provide feedback to improve the effectiveness and efficiency of the planning and scheduling process. (Wt = Med)
- Availability of systems/trains with significant risk impact are monitored and trended. Formal criteria exist and are used to ensure that an appropriate level of availability is maintained. (Wt = High)
- Potential risk impact (both discrete and integrated) of scheduled activities are explicitly evaluated and used to identify contingencies or modify the schedule as appropriate. (Wt = High) – Inter-Process Interface, Safety Culture
- Results of SSC performance monitoring and predictive maintenance analysis on alternate equipment from that scheduled to be maintained are provided to scheduling personnel and used to identify contingencies or modify the schedule as appropriate. (Wt = Med) – Inter-Process Interface, Safety Culture
- Work on risk significant SSCs is identified and prioritized with performance on an expedited basis, and assignment of appropriate level of management attention is specified as appropriate. (Wt = High) – Safety Culture

C.4.3 Process WM003: Perform Preventive Maintenance

- Preventive maintenance activities are integrated into the normal maintenance schedule with appropriate priority and performed on schedule (such as critical PMs are not routinely deferred due to emergent work or lack of manpower). (Wt = High)
- A formal process is in place for evaluation of requested PM deferrals. The process includes evaluation of the equipment's functional importance and task effectiveness. (Wt = Med)
- Craft personnel provide feedback of as-found conditions (CM and PM) to allow improvement of PM program effectiveness. These changes are then reviewed by responsible engineering personnel and implemented within a reasonable time, with feedback provided to suggestion initiator. (Wt = Med) – Inter-Process Interface
- A comprehensive set of metrics exists and is monitored to track and trend PM deferrals. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)

C.4.4 Process WM004: Perform Corrective Maintenance

- Corrective maintenance activities are integrated into the normal maintenance schedule with appropriate priority and performed on schedule. (Wt = High)
- A comprehensive set of metrics exists and is monitored to determine overall effectiveness of the corrective-maintenance program. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)
- A comprehensive set of metrics exists and is monitored to track and trend corrective-maintenance backlog. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)

C.4.5 Process WM005: Maintain Non-Plant Equipment

Out of Scope

C.4.6 Process WM006: Perform Plant-Improvement Maintenance

SSC degradations, failures, and plant events are evaluated for generic implications, and required changes are identified and implemented within an appropriate time frame. (Wt = High) – Inter-Process Interface, Safety Culture

C.4.7 Process WM007: Monitor and Control Radiation Exposure

Out of Scope

C.4.8 Process WM008: Monitor and Control Contamination

Out of Scope

C.5 Material Support

C.5.1 Process MS001: Provide Inventory Management

- Stocking levels and reorder points are determined based on the functional importance of the application of the parts in the plant. (Wt = Med)
- A comprehensive set of metrics exists and is monitored to evaluate effectiveness of inventory management to have critical parts and consumables available when they are needed. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)
- Materials-management personnel provide input on stocking status for parts required for scheduled maintenance activities. These updates occur throughout the planning and scheduling process. (Wt = Med) – Inter-Process Interface
- Materials-management personnel provide input to applicable ordering strategies (such as expedited delivery) for parts that are not in stock but are required for scheduled maintenance activities. These updates occur throughout the planning and scheduling process. (Wt = High) – Inter-Process Interface

C.5.2 Process MS002: Provide Materials and Services

- Materials management personnel provide input to responsible engineering personnel to analyze commercial-grade parts (commercial-grade dedication) when necessary qualified parts are no longer manufactured. (Wt = Med) – Inter-Process Interface
- Receipt inspection processes and procedures are in place and utilized. (Wt = Med)
- A comprehensive set of metrics exists and is monitored to evaluate effectiveness of receipt inspection to identify nonconforming parts. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)
- Identified risk significance of the intended use is considered when specifying ordering and receipt inspection requirements. (Wt = Low) – Safety Culture

C.5.3 Process MS003: Provide Contract Services

- A comprehensive set of metrics exists and is monitored to evaluate vendor performance. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)
- Contract personnel that perform activities with identified risk impact are made aware of the potential risk impact and any necessary precautions and contingencies. Responsible plant personnel assigned to oversee the activity ensure that these precautions and contingencies are followed. (Wt = Med) – Safety Culture

C.5.4 Process MS004: Provide Warehousing

- Formal processes and procedures are in place and utilized to perform necessary preventive-maintenance activities on warehoused spares for risk-important applications. (Wt = Low)
- Formal processes and procedures are in place and utilized to maintain environmental conditions (temperature, humidity, and so on) on warehoused spares with identified storage requirements for risk-important applications. (Wt = Med)

C.5.5 Process MS005: Provide Returns and Maintenance

Out of Scope

C.5.6 Process MS006: Provide Disposal and Surplussing

Out of Scope

C.5.7 Process MS007: Provide and Transport Fuel

Out of Scope

C.5.8 Process MS008: Provide Handling, Storage, and Disposal of Fuel

- Nuclear safety risk is evaluated with appropriate controls and contingencies established for movement/storage of nuclear fuel within the spent-fuel storage pool. (Wt = Med)
- Nuclear safety risk is evaluated with appropriate controls and contingencies established for movement/storage of nuclear fuel within dry-cask storage. (Wt = Med)

C.6 Support Services

C.6.1 Process SS001: Provide Information Technology Services

- Plant operation, maintenance, and engineering provide input to proposed changes in information-management systems used to conduct plant operational or maintenance activities to provide operational perspective. (Wt = Med) – Inter-Process Interface
- Information-management systems for risk evaluations, system health, corrective actions, and work management are up-to-date, integrated, and support timely use of information to support decision making. (Wt = High)

C.6.2 Process SS002: Provide Business Services

Out of Scope

C.6.3 Process SS003: Provide Records Management and Document Control Services

A comprehensive set of metrics exists and is monitored to track and trend proper procedure use, including proper procedural compliance and improper use of outdated procedure revisions. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Low)

C.6.4 Process SS004: Provide Human Resources Services

- A formal personnel-evaluation process is in place with explicit job skills defined and evaluation criteria for performance classification specified. (Wt = Med)
- Mechanisms are in place to ensure that necessary knowledge and skills are maintained among plant staff. These include recruiting, retention, assignment, and training of personnel. (Wt = High)

C.6.5 Process SS005: Maintain Grounds, Facilities, and Vehicles

Out of Scope

C.6.6 Process SS007: Support Community and Government Services

Out of Scope

C.6.7 Process SS007: Support Industry Professional and Trade Associations

Out of Scope

C.7 Loss Prevention

C.7.1 Process LP001: Provide Security Measures

- Formal security procedures for plant protection against external and internal threats are in place with risk insights. (Wt = High)
- The condition/performance of physical security measures is formally assessed, with necessary corrective actions identified and implemented in a timely manner. (Wt = Med)

C.7.2 Process LP002: Provide Performance Monitoring and Improvement Services

- Plant quality-assurance programs are in place and rigorously applied. (Wt = High)
- Plant nuclear safety review board effectively identifies and ensures resolution of risk-significant nuclear safety issues. (Wt = High)
- A causal analysis program is in place. The program has explicit criteria for classification of events (screening criteria) and determination of appropriate level of analysis. All plant events are processed through this system (at least through the screening process). (Wt = High)
- The causal-factors program analyzes events for underlying organizational and management casual factors. If management/organization causal factors are identified, they are prioritized, and corrective action is taken in a timely manner. (Wt = High) – Safety Culture
- The causal-factors program analyzes events for underling human-performance casual factors. If human-performance causal factors are identified, they are prioritized, and corrective action is taken in a timely manner. (Wt = High) – Safety Culture
- A comprehensive set of metrics exists and is monitored to determine overall plant performance (operational, economic, and regulatory compliance). The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = High)
- Plant nuclear safety risk (core damage frequency and large early release frequency) is monitored and trended over time. Any adverse occurrences or trends are investigated to identify underlying causal factors. (Wt = Med) – Safety Culture
- Plant effectiveness assessments utilize other corporate resources (such as main office or sister nuclear plants) to evaluate and trend performance. (Wt = Low)
- Plant-effectiveness assessments utilize external organizations (such as INPO peer reviews, resources from other companies nuclear plants, and contractors) to evaluate and trend performance. (Wt = High)
- Formal decision-making processes are in place to balance cost with expected benefits. (Wt = Med)

- Formal business decision-making processes (such as budgeting and staffing) include nuclear safety risk impact as an explicit factor in the decision-making process. (Wt = High) – Safety Culture
- Mechanisms are in place to document assumptions made and criteria used to make decisions. (Wt = High)
- Once decisions are made, results are monitored to verify that outcomes are as anticipated, and if not, mechanisms exist to implement corrective actions or reevaluate the decision. (Wt = Med)
- Functionally important passive components (cables, buried piping, and so on) are monitored for age-related degradation. (Wt = Med)
- SSCs subject to age-related degradations have effective systems or processes to identify and manage these mechanisms. (Wt = Med)
- Effective mechanisms are applied to evaluate equipment for obsolescence. (Wt = Med)
- Failures are reviewed to determine whether repetitive events have occurred. This includes failures of similar equipment in other plant systems and at other nuclear plants. (Wt = High)
- Effective methods exist and are used to present senior management with summary of performance of plant SSCs. This information is used to prioritize necessary improvement actions and allocate resources. (Wt = High)
- Plant programs (such as Maintenance Rule (a)(4), Risk Informed ISI/IST, MOV, fire protection, and containment leak-rate testing) are periodically reviewed to ensure continued applicability of risk insights. (Wt = High) – Safety Culture
- Regulatory oversight program is understood and used by plant staff in operational decision-making. (Wt = High) – Safety Culture
- Risk assessment personnel possess knowledge of plant design, operation, and implementing processes. (Wt = Med)
- Risk tools and methods are of high quality (for example, models accurately reflect plant design and operation) and are up to date. (Wt = High)
- Plant and corporate staff participate in industry initiatives associated with risk-informed issues. (Wt = Low)
- Expert panels possess risk-assessment expertise as an explicit contributor to the decision process. (Wt = Med) – Safety Culture

C.7.3 Process LP003: Maintain Licenses and Permits

- Personnel responsible for equipment reliability (plant engineering, operations, and maintenance personnel) provide input to proposed changes to applicable plant licenses and permits. (Wt = Med) – Inter-Process Interface
- Risk input is provided to address significant licensing issues (such as Tech Spec changes, NOED, and request for enforcement extension). (Wt = High)

C.7.4 Process LP004: Perform Emergency Planning

Risk input is provided to emergency planning and is integrated into preparedness exercises. (Wt = Low) – Safety Culture

C.7.5 Process LP005: Maintain Fire Protection

- Risk information is applied in fire-protection decision making. (Wt = Med)
- A comprehensive set of metrics exists and is monitored to determine overall effectiveness of the fire-protection program. The metrics are monitored, and applicable corrective actions are developed and implemented. (Wt = Med)

C.8 Training

C.8.1 Process T001: Develop Training Programs

- Plant and industry events are reviewed with lessons learned incorporated into applicable training modules. In particular, recent operational events are presented in licensed operator re-qualification training. (Wt = High)
- Results of plant modifications are presented to operations personnel in licensed operator re-qualification training. (Wt = Med)
- Operations personnel are trained in the fundamentals of risk management, significant results (including vulnerabilities) identified in the PRA, and methods to assess changes in the plant risk profile (including use of software packages used to evaluate risk) as a result of changes to plant condition. (Wt = High) – Safety Culture
- Personnel responsible for work planning and scheduling are trained in the fundamentals of risk management, significant results (including vulnerabilities) identified in the PRA, and methods to assess changes in the plant risk profile (including use of software packages used to evaluate risk) as a result of changes to plant condition. (Wt = High) – Safety Culture
- Engineering personnel responsible for system performance monitoring are trained in the fundamentals of risk management, significant results (including vulnerabilities) identified in the PRA, and methods used to set appropriate performance criteria. (Wt = High) – Safety Culture

C.8.2 Process T002: Conduct Training

Out of Scope

C.8.3 Process T003: Attend Training

A comprehensive set of metrics exists and is monitored to determine personnel attendance at required training. (Wt = Med)

C.9 Cross-Cutting Questions

C.9.1 Organizational Issues

- Issues are addressed via use of multidisciplinary and cross-programmatic elements. (Wt = High)
- Adequate resources are available to address issues. (Wt = High)
- Personnel assigned to address an issue possess the skills and knowledge necessary for its resolution. (Wt = High)

C.9.2 Management Issues

- Plant management is cognizant of and addresses management of nuclear safety risk throughout plant decision-making processes. (Wt = High)
- Management sets plant priorities that are risk-informed. (Wt = High)

C.9.3 Communications Issues

- Channels (both vertical and lateral) exist and are effectively utilized to communicate important information and decisions. (Wt = High)
- Issues and their resolution are addressed in a constructive and respectful manner. (Wt = High)

C.9.4 Human Performance Issues

Human error does not provide an unduly large contribution to significant plant events (when viewed across different plant processes/organizations). (Wt = High)

C.9.5 Cultural Issues

- Plant personnel at all levels in the organization apply a questioning attitude with respect to nuclear safety risk. (Wt = High)
- Plant personnel at all levels in the organization recognize the need for and demonstrate continuous improvement. (Wt = High)
- Issues are addressed in a forum in which diverse viewpoints are encouraged and thoroughly explored. (Wt = High)
- Progress in achieving management objectives and desired performance improvements is observed and recognized. (Wt = High)

D
ASSESSMENT QUANTIFICATION AND TRENDING

The assessment method is capable of providing a large amount of important data from which an evaluation of the effectiveness of risk management at the plant can be obtained. It would be desirable to be able to compare the evaluation results with those obtained at a later time. Thus, it would be beneficial to be able to quantify the assessment results for the purposes of benchmarking and trending. This appendix provides a discussion of *one possible* approach to achieving this objective.

As discussed previously, the set of targeted questions are keyed to the individual SNPM first-level processes to which they apply. Additionally, each question is weighted to its importance to risk management. Thus, the process can be quantified by assignment of numerical values to these weightings. One possible such assignment is shown in Table D-1.

Table D-1
Importance Associated with Numerical Score

Importance Weighting	Numerical Score
High	3
Medium	2
Low	1

The weightings provided above are not intended to be prescriptive and can be modified by the user to suit the particular objectives and business needs of the plant. However, the actual weighting system employed should be documented to permit comparisons with data taken at future points in time. Additionally, the weighting system employed should be recorded to facilitate comparisons between different plants to permit benchmarking between them.

As discussed in Appendix C, each question can be answered according to a five-level quantitative scale. With the same caveats as described above, different numerical values can also be assigned to each of these responses. However, setting the midpoint of this scale to zero permits effective performance to have positive values and ineffective performance to have negative values. This scheme provides the benefit of providing a simple method of obtaining comparative values over time and between plants. Using this assignment, numerical values for individual responses can be set as shown in Table D-2.

Table D-2
Assignment of Numerical Scores to Responses to Questions for Comparison Over Time and Between Plants

Response	Numerical Score
Seldom/never	-2
Occasionally	-1
Often	0
Most of the time	+1
Almost all of the time	+2

Using these assignments, an overall evaluation score for the k^{th} question can be obtained as follows. Defining R_{jk} as the response score from the j^{th} respondent and w_k as the question risk-weighting factor for question k, the performance score, P_k, can be calculated from:

$$P_k = \sum_j R_{jk} w_k . \qquad \textbf{Eq. D-1}$$

It should be noted that this equation could be applied generically to evaluating performance at each different level within the assessment. For example, to assess overall risk-management performance, the sum is taken over all of the questions utilized in the conduct of the assessment:

$$P = \sum P_k \qquad \textbf{Eq. D-2}$$

Because processes with more impact on plant risk have more questions associated with them, they are automatically more heavily weighted using this approach. The same equation can be applied at each of the level-zero and level-one processes to obtain overall performance scores at these levels. Again, because those first-level processes that have more impact on plant risk have more questions associated with them, they are also automatically more heavily weighted in the assessment of performance at level zero. The numerical values obtained provide relative performance values that will be useful for comparison and trending purposes. In this context, positive values indicate effective risk management with commensurate decrease in plant risk below the inherent level, whereas negative values indicate ineffective risk management and increased levels of plant risk.

The intent of the discussion provided above is not to provide a rigid procedure for quantifying the risk-management effectiveness evaluation. The process described above is intended to provide a benchmarking approach that can evaluate the extent to which risk management is in place and to monitor changes in its effectiveness over time. Implementation of such a benchmarking and monitoring approach is considered vital to support the desired transition to a risk-informed, performance-based regulatory structure.

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