IEEE Guide for the Definition of Reliability Program Plans for Nuclear Power Generating Stations

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Abstract: Guidelines for the definition of a reliability program at nuclear power generating stations are developed. Reliability programs during the operating phase of such stations are emphasized; however, the general approach applies to all phases of the nuclear power generating station life cycle (e.g., design, construction, start-up, operating, and decommissioning).
Keywords: alert and action levels; corrective action; performance monitoring; problem analysis; reliability, availability, and maintainability (RAM); reliability program

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Introduction

(This introduction is not part of IEEE Std 933-1999, IEEE Guide for the Definition of Reliability Program Plans for Nuclear Power Generating Stations.)

The IEEE recognizes the importance of safe, reliable, and efficient nuclear power generation and seeks to provide guidance for constructing a reliability program to help achieve improved plant safety and performance. This guide is part of a continuing effort in which the IEEE and other industry groups have been engaged since the beginning of the commercial nuclear power industry. Related IEEE activities include the publication of the following guides and standards:

— IEEE Std 352-1987, IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Stations Safety Systems (a basic reliability tutorial);

— IEEE Std 500-1984, IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear Power Generating Stations (a document that has become a standard source of generic reliability data);

— IEEE Std 577-1976, IEEE Standard Requirements for Reliability Analysis in the Design and Operation of Safety Systems for Nuclear Power Generating Stations.

This guide's main objective, to provide a basic framework for operational reliability programs, has been adapted to nuclear power generating stations. However, principles contained in the guide are not limited to these stations or the power industry exclusively. Other station types and industries are encouraged to tailor the guide to meet their specific needs.

The guide has been developed to aid nuclear utilities in tailoring the principles of an effective reliability program to their own particular organization structure and approach. As an IEEE guide, it cannot establish specific reliability activities that might already be in place. Rather, the program elements discussed in the guide are provided for the review of, and possible inclusion into, either centralized or decentralized reliability program plans.

Other recent industry efforts include the activities of

— The Institute of Nuclear Power Operations (INPO), such as the Nuclear Plant Reliability Data System (NPRDS), the "Focus on Performance," the Significant Event Evaluation and Information Network (SEE-IN), and the Safety System Unavailability Monitoring Program

— The Nuclear Energy Institute (NEI)

— Reactor vendor owners' groups, such as the group on scram reduction

— The Electric Power Research Institute (EPRI)

Another important effort that correlates to effective reliability program planning is the Maintenance Rule enacted by the U.S. Nuclear Regulatory Commission (NRC), described in the following excerpts from Regulatory Guide 1.160, Revision 2, dated March 1997:

> The NRC published the maintenance rule on July 10, 1991, as Section 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," of 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities." The NRC's determination that a maintenance rule was needed arose from the conclusion that proper maintenance is essential to plant safety. As discussed in the regulatory analysis for this rule, there is a clear link between effective maintenance and safety as it relates to such factors as the number of transients and challenges to safety systems and the associated need for operability, availability, and reliability of safety equipment. In addition, good maintenance is also important in providing assurance that failures of other than safety-related structures, systems, and components (SSCs) that could initiate or

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adversely affect a transient or accident are minimized. Minimizing challenges to safety systems is consistent with the NRC's defense-in-depth philosophy. Maintenance is also important to ensure that design assumptions and margins in the original design basis are maintained and are not unacceptably degraded. Therefore, nuclear power plant maintenance is clearly important in protecting public health and safety.

Paragraph (a)(1) of 10 CFR 50.65 requires that power reactor licensees monitor the performance or condition of SSCs against licensee-established goals in a manner sufficient to provide reasonable assurance that such SSCs are capable of fulfilling their intended functions.

The NRC staff encourages licensees to use, to the maximum extent practicable, activities currently being conducted, such as technical specification surveillance testing, to satisfy monitoring requirements. Such activities could be integrated with, and provide the basis for, the requisite level of monitoring. Consistent with the underlying purposes of the rule, maximum flexibility should be offered to licensees in establishing and modifying their monitoring activities.

Licensees are encouraged to consider the use of reliability-based methods for developing the preventive maintenance programs covered under 10 CFR 50.65(a); however, the use of such methods is not required.

These excerpts indicate that a natural tie exists between reliability program planning, the identification of preventive maintenance programs, and the extension of existing performance or condition monitoring programs to meet the scope and intent of the Maintenance Rule. Further, the concept of determining SSC equipment [through such tools as probabilistic risk assessment (PRA)] can act as a means for identifying the critical systems and components whose failure would severely affect the top level plant mission of availability and safety and, therefore, indicate a structure for the scope and detail of a reliability program. At this writing, however, specific links to the Maintenance Rule have not as yet been incorporated into this guide.

The members of the working group responsible for the development of the guide believe the guide to be a living document that should be revised regularly to include references to proposed and enacted rulemaking activities and to incorporate improvements as reliability programs mature (such as guidance for human reliability and software reliability). Therefore, both comments and participation in future activities related to the guide are encouraged, and input on this topic is hereby solicited from any interested, knowledgeable parties.

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IEEE Guide for the Definition of Reliability Program Plans for Nuclear Power Generating Stations

1. Overview

The need for reliable equipment performance at nuclear power generating stations has long been recognized. As a result, numerous methods to improve equipment performance have been developed. Some are empirical (such as determination of component availability based on maintenance records); some are predictive (such as condition monitoring and performance trending); while others are pragmatic (such as root cause analysis). This diversity among methods (empirical, predictive, and pragmatic) provides a comprehensive set of tools to engineers faced with equipment performance issues. However, this diversity can also be confusing to the novice reliability engineer. In addition, management may experience difficulty in coordinating the use of these methods and the interpretation of their results by various organizations.

This guide discusses the organization of reliability engineering techniques into a comprehensive program, or plan. The purpose of the planned program is to ensure reliable equipment performance. While the program described in this guide is comprehensive, it can be selectively applied to a component, system, plant, or entire utility grid; and it can be applied in a phased fashion. Clause 4 describes the technical elements of a reliability program and their integration into an effective technical approach. The applicability of various methods (empirical, predictive, and pragmatic) to each element is discussed. In addition, the information inputs and outputs of each element are detailed, along with the flow of information among the various elements. Clause 5 discusses the reliability program's interfaces with current utility organizational structures. Resources within a utility that may supply both information and expertise to each program element are identified. Four informative annexes are included to further illustrate the ideas presented in this guide. Annex A discusses the management of a reliability program; Annex B provides a sample reliability program; Annex C provides a sample reliability, availability, and maintainability (RAM) specification; and Annex D provides an annotated bibliography to aid the user of this guide in selecting additional resources.

1.1 Scope

This document provides guidelines for the definition of a reliability program at nuclear power generating stations. The document emphasizes reliability programs during the operating phase of such stations; however, the general approach applies to all phases of the nuclear power generating station life cycle (e.g., design, construction, start-up, operating, and decommissioning).

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1.2 Purpose

The purpose of this guide is to describe a basic framework (i.e., the program elements, guidelines on implementation, element interaction, and their scope of application) directed at improving nuclear power generating station performance through the effective implementation of reliability programs. It is oriented toward station availability, encompassing balance-of-plant and safety-related equipment. Effective implementation of these guidelines should also improve plant safety by reducing challenges to safety systems in addition to enhancing reliable operation of the components of those safety systems.

2. References

This guide should be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

IEEE Std 352-1987 (Reaff 1999), IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Stations Safety Systems.[1]

IEEE Std 577-1976 (Reaff 1992), IEEE Standard Requirements for Reliability Analysis in the Design and Operation of Safety Systems for Nuclear Power Generating Stations.

3. Definitions and acronyms

3.1 Definitions

For the purposes of this guide, the following terms and definitions apply. IEEE Std 100-1996 should be referenced for terms not defined in this clause.

3.1.1 acoustic monitoring: The detection of sound patterns emitted by equipment to determine its operating condition for predictive monitoring.

3.1.2 alert level: A probability value placed on equipment failure rates to identify when systems, trains, or components are not achieving their target availability or reliability values.

3.1.3 analysis: A process of mathematical or other logical reasoning that leads from stated premises to the conclusion concerning specific capabilities of equipment and its adequacy for a particular application. (IEEE Std 100-1996)

3.1.4 availability: The characteristic of an item expressed by the probability that it will be operational at a randomly selected future instant in time. (IEEE Std 100-1996)

3.1.5 common-cause failure: Multiple failures attributable to a common cause. (IEEE Std 100-1996)

3.1.6 complete (catastrophic): Failure of equipment that is both sudden and total.

3.1.7 components: Items from which the system is assembled. (IEEE Std 100-1996)

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3.1.8 condition monitoring: Observation, measurement, or trending of condition or functional indicators with respect to some independent parameter (usually time or cycles) to indicate the current and future ability to function within acceptance criteria. (IEEE Std 323-1983)

3.1.9 critical components: Equipment whose failure will result in complete system or functional failure.

3.1.10 degraded: A failure that is gradual, partial, or both; for example, the equipment degrades to a level that, in effect, is a termination of the ability to perform its required function.

3.1.11 failure: The termination of the ability of an item to perform a required function. (IEEE Std 100-1996)

3.1.12 failure modes and effects analysis (FMEA): A systematic procedure for identifying the modes of failure and for evaluating their consequences. (IEEE Std 352-1987)

3.1.13 failure rate: The expected number of failures of a given type, per item, in a given time interval. (IEEE Std 100-1996)

3.1.14 fault tree analysis (FTA): A technique by which failures that can contribute to an undesired event are organized deductively and represented pictorially. (IEEE Std 352-1987)

3.1.15 generating availability data system (GADS): Reliability information available from the North American Electric Reliability Council.

3.1.16 GO: Availability analysis method similar to reliability block diagram with operators and event actions included.

3.1.17 importance measures: A quantitative analysis to determine the importance of variations in equipment reliability to system risk and/or reliability.

3.1.18 incipient: An imperfection in the state or condition of equipment that could result in a degraded or immediate failure if corrective action is not taken.

3.1.19 inherent availability (IA): A measure of availability for a system operating in an ideal support environment in which schedule maintenance, standby, and logistic time are ignored. (IEEE Std 352-1987)

3.1.20 licensee event report (LER): Reports submitted by the licensee to Nuclear Regulatory Commission (NRC) under Regulatory Guide 1.16.

3.1.21 logistics time (LT): The downtime occasioned by the unavailability of spares, replacement parts, test equipment, maintenance facilities, or personnel.

3.1.22 mean logistics time (MLT): The mean downtime occasioned by the unavailability of spares, replacement parts, test equipment, maintenance facilities, or personnel.

3.1.23 mean time between failures (MTBF): The arithmetic average of operating times between failures of an item. (IEEE Std 100-1996)

3.1.24 mean time to repair (MTTR): The arithmetic average of time required to complete a repair activity. (IEEE Std 100-1996)

3.1.25 mission: The singular objective, task, or purpose of an item or system. (IEEE Std 352-1987)

3.1.26 mission time: The time during which the mission should be performed without interruption. (IEEE Std 352-1987)

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3.1.27 NRC bulletins: Publications titled NRC Information Notice and published by the Office of Nuclear Reactor Regulation (NRR) of the Nuclear Regulatory Commission (NRC).

3.1.28 nuclear plant reliability data system (NPRDS): A reliability database maintained by the Institute of Nuclear Power Operations (INPO) that receives failures reports from utilities within the United States.

3.1.29 nuisance failure: Intermittent or sustained failure of equipment secondary to system safety or reliability.

3.1.30 operational availability (A_O): The measured characteristic of an item expressed by the probability that it will be operable when needed as determined by periodic test and resultant analysis.

3.1.31 operational reliability: The assessed reliability of an item based on operational data.

3.1.32 operations and maintenance: Plant staff organized to perform these functions.

3.1.33 outage time: Mean time to repair plus time for logistics and approval.

3.1.34 performance evaluation: The analysis, in terms of initial objectives and estimates, usually made on site to provide information on operating experience and to identify required corrective actions.

3.1.35 performance monitoring: Determining whether equipment is operating or capable of operating within specific limits.

3.1.36 preventive maintenance: A procedure in which the system is periodically checked and/or reconditioned to prevent or reduce the probability of failure or deterioration in subsequent service.

3.1.37 probabilistic risk assessment (PRA): A calculation of the probability and consequences of various known and postulated accidents.

3.1.38 program evaluation review technique (PERT): A diagrammatic method for establishing program goals and tracking.

3.1.39 quality assurance (QA): All planned and systematic actions necessary to provide adequate confidence that a system or component will perform satisfactorily in service. (IEEE Std 100-1996)

3.1.40 reliability, availability, and maintainability (RAM): Elements that are considered as unified for reliability enhancement.

3.1.41 reliability-centered maintenance: A series of orderly steps for identifying system and subsystem functions, functional failures, and dominant failure modes, prioritizing them, and selecting applicable and effective preventive maintenance tasks to address the classified failure modes.

3.1.42 reliability monitoring: Direct monitoring of reliability parameters of a plant, system, or equipment (e.g., failure frequency, downtime due to the maintenance activities, outage rate).

3.1.43 reliability program: A description of activities and techniques associated with reliability technology, not necessarily a formalized program or entity unto itself, and may be integrated with design and operations.

3.1.44 reliability targets: The reliability goals to be achieved by the plant systems.

3.1.45 repair rate: The expected number of repair actions of a given type completed on a given item per unit of time. (IEEE Std 100-1996)

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3.1.46 risk: The expected detriment per unit time to a person or population from a given cause. *Note:* In this document, risk is used in a broader context that includes the expected financial detriment per unit time to an organization (e.g., utility) from a given cause. (IEEE Std 100-1996)

3.1.47 robustness: A statistical result that is not significantly affected by small changes in parameters, models, or assumptions.

3.1.48 root cause: The underlying or physical cause of problem/failure.

3.1.49 SEE-IN: The Significant Event Evaluation and Information Network, an information database maintained by the Institute of Nuclear Power Operations (INPO).

3.1.50 single point failure analysis: A reliability analysis that identifies single components or subsystems whose failure results in system failure.

3.1.51 standby equipment: Equipment not normally in operation that is available on demand to perform a specific function.

3.1.52 statistical indicators: Parameters based on past plant-specific or generic experience used to predict the failure of identical or similar equipment based on time or stress histories.

3.1.53 surveillance test: The test that can determine the state or condition of a system or subsystem. (IEEE Std 352-1987)

3.1.54 system reliability service (SRS): A United Kingdom reliability information and database service.

3.1.55 time to repair (TTR): Time required to accomplish corrective maintenance or repair successfully. It includes all of the time required for diagnosis, set-up, replacement, reassembly, and test, but does not include logistics scheduling and approval.

3.1.56 unavailability: The numerical complement of availability. Unavailability may occur as a result of the item being repaired (that is, repair unavailable) or as a result of undetected malfunctions (that is, unannounced unavailability). (IEEE Std 352-1987)

3.1.57 UNIRAM: A modeling methodology and software for the performance of reliability, availability, and maintainability (RAM) analysis of power production systems.

3.1.58 wearout: The state of a component in which the failure rate increases with time as a result of a process characteristic of the population.

3.2 Acronyms

EPRI	Electric Power Research Institute
INPO	Institute of Nuclear Power Operations
NERC	North American Electric Reliability Council
NRC	Nuclear Regulatory Commission
NRR	Nuclear Reactor Regulation

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4. Program elements

For a reliability program to be well constituted, it should provide a means for recognizing when a reliability problem exists and, conversely, when it does not so resources are appropriately utilized. Also, the program should be capable of anticipating or predicting potential reliability problems that are likely to occur in the future based on historical performance or observed deterioration in equipment that has not yet failed and problems that have occurred elsewhere in the industry. If a problem is predicted or diagnosed, the reliability program should be able to prioritize its severity as compared to other reliability problems so the most serious problems are corrected first. The program should be capable of determining the cause of the problem and devising corrective actions to rectify it. Finally, the reliability program should possess the means to monitor the efficacy of corrective actions to ensure the adequacy of problem solution.

A reliability program should possess the following elements to accomplish its objective of enhancing plant availability and safety:

a) Performance monitoring

b) Performance evaluation

c) Problem prioritization

d) Problem analysis and corrective action recommendation

e) Corrective action implementation and feedback

These elements define a closed-loop process; once corrective actions are commenced to address detected reliability problems, the emphasis is directed back toward monitoring to ensure the effectiveness of the corrective action. Figure 1 illustrates the closed-loop process of which reliability program plan elements are a part. Each of these elements is detailed in 4.1 through 4.5.

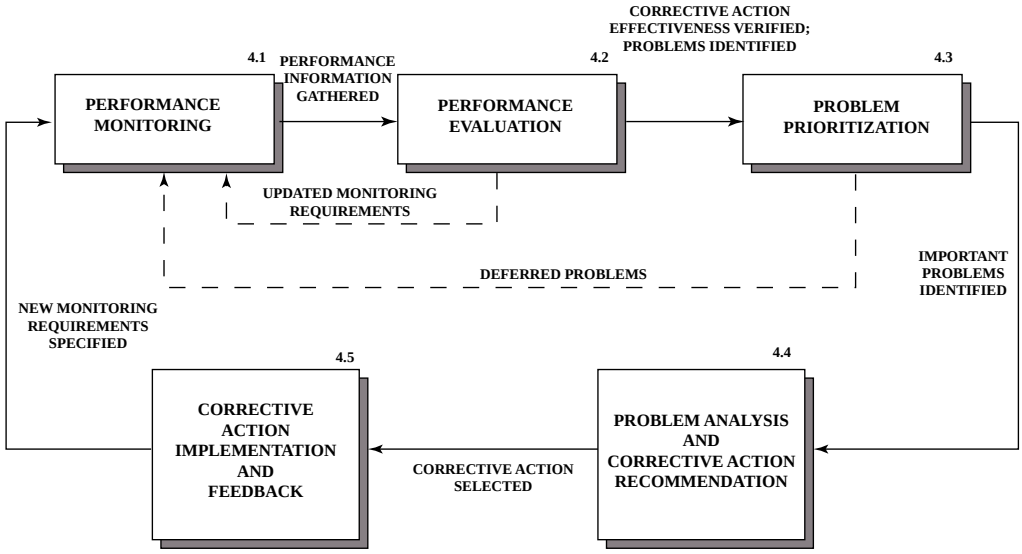

Figure 1—Reliability program process: elements and interfaces

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4.1 Performance monitoring

4.1.1 Explanation

Performance monitoring is the act of gathering pertinent failure detection and in-plant reliability information. Data include both reliability monitoring (e.g., observation of failure frequency, outage rate, maintenance durations, outage times) and condition monitoring (e.g., observation of conditions related to failure, such as degraded performance; changes in equipment parameters as measured by nondestructive tests, such as ultrasonic inspections, electrical continuity tests, and acoustic vibration monitoring). Data should include human errors, equipment failures, and maintenance actions and should be collected at a level consistent with the mission of the program (e.g., they may be collected at the component, system, and plant levels). As a minimum, data should be collected on complete failures; in addition, the practice of collecting data on both incipient and degraded failures may provide early indication of potential problems before they become serious. Interfaces of this task to other elements of a reliability program are shown in Figure 2.

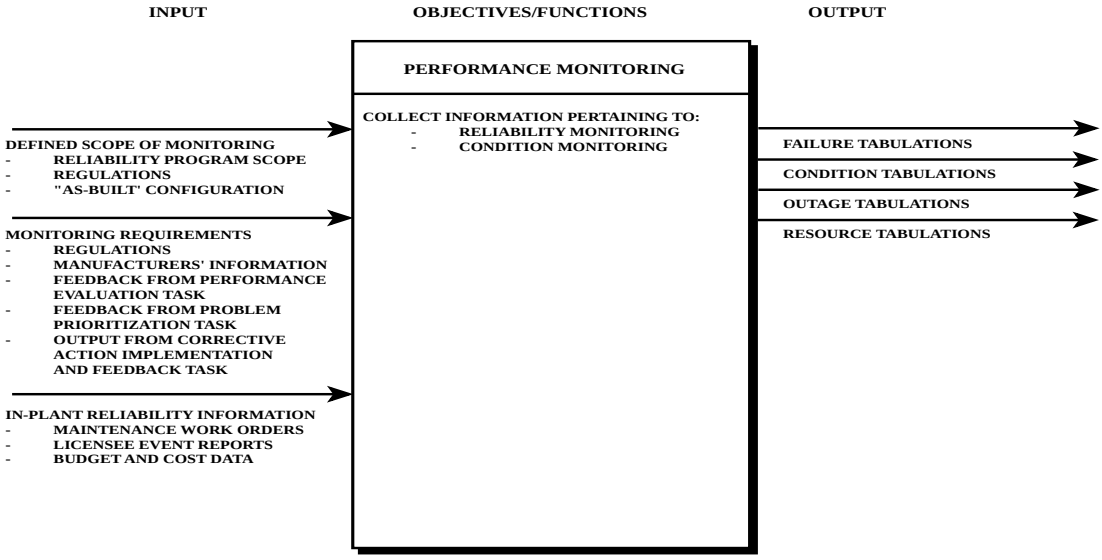

Figure 2—Performance monitoring interfaces

4.1.2 Objective

The objective of performance monitoring is to provide basic data about actual in-plant reliability. Sample uses are

a) To collect statistics on equipment failures to
   1) Detect the existence of a reliability problem
   2) Determine the severity of problems
   3) Verify the efficacy of corrective actions
   4) Measure the efficiency of equipment surveillance
b) To collect information relevant to poor equipment performance to aid in root cause determination
c) To collect statistics and information that can be used to predict catastrophic failures (and, hence, to either prevent their occurrence or mitigate their effect)
d) To identify equipment that is performing well

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e) To relax resources where they are not being used most effectively

f) To optimize inventory

g) To optimize design

h) To make procedure and training changes

4.1.3 Inputs

Inputs to performance monitoring include

a) Definition of the scope of monitoring established by the reliability program or mandated by regulations (such as technical specifications);

b) Monitoring requirements mandated by regulations or established by equipment manufacturers;

c) Updated monitoring requirements based on the outputs of the performance evaluation task, the problem analysis and corrective action identification task, or the corrective action implementation and feedback task;

d) Utility and plant-specific information systems (e.g., maintenance work orders, licensee event reports, records of human errors, budget and cost data, plant and systems descriptions) that provide data for use in identifying, assessing, and prioritizing reliability problems and solutions.

4.1.4 Outputs

The major output of the performance monitoring task is a tabulation of performance information on all equipment encompassed by the reliability program. Such a listing should include

a) A complete identification of the affected equipment [i.e., tag number, serial number, Nuclear Plant Reliability Data System (NPRDS) identification]

b) The date and time of failure detection

c) The type of failure (complete, degraded or incipient)

d) The method of failure discovery (e.g., during operation, maintenance, testing, or inspection)

e) Conditions prior to failure (e.g., plant mode, power level, temperature) and the impact of the failure

f) The date and time the equipment was restored to service

g) A description of the nature and extent of damage and a preliminary assessment of the cause

h) A description of how the affected equipment was repaired

i) Referenced documents [i.e., work order number, quality assurance or quality control (QA/QC) inspection reports]

Specific performance monitoring requests should be consistent with the needs of the reliability program objective. For example, a condition monitoring program would include far more extensive physical parameter requests. Such data requests should be established by a needs analysis prior to data collection. The needs analysis describes all the activities, organizational units, and data flow in an organized manner, such as with flow diagrams.

4.1.5 Implementation

Many of the inputs to and outputs from the performance monitoring task already exist at nuclear power generating stations. It has been long recognized that benefits are to be gained by a careful assessment of equipment performance. Past efforts related to equipment reliability have mainly been directed toward components

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important to plant safety. The current industry and regulatory interest is broadening to include components whose failure results in plant reduction or shutdown, spurred by the recognition of the fact that reduction of safety system challenges also reduces plant risk. Equipment with historical reliability problems and equipment whose failure is absolutely unacceptable (e.g., reactor shutdown systems) have been addressed by performance monitoring tasks. A recent development is the advent of reliability-based surveillance activities that systematically organize past and present practices. Reliability-based surveillance is based on the following concept: The unique reliability characteristics of a component, along with the component's importance for achieving an acceptable level of availability or risk and the practicality of implementation, should dictate the type and intensity of the surveillance for that component. (For one possible implementation of these concepts, see Lofgren [B12].[2])

Implementation of the performance monitoring task should focus on two concerns: utilization of existing information and expansion or tailoring information-gathering activities to suit the needs of the reliability program. However, first, it should be recognized that peculiar reliability requests may require collection of information not available. All performance monitoring data collection activities should be integrated into overall data collection activities to prevent double counting failures and overloading staff. Addressing these concerns should include consideration of the following items:

a) Much existing information may be stored in an electronically compatible medium (in particular, maintenance records); thus, the information for the performance monitoring task may be easily extracted. However, other types of information (such as the qualitative descriptions of failure or the results of tests conducted to measure equipment degradation like acoustic monitoring and other nondestructive methods) are not as easily recorded and extracted.

b) The present and future needs of the reliability program should be carefully assessed when modifying existing information-gathering activities. First, it is desirable to use a single procedure to document component maintenance and testing, independent of whether the component is included within the scope of the reliability program. This practice simplifies the plant record-keeping effort and allows easy addition of equipment to the reliability program in the future. Second, the level of detail should be balanced so all pertinent information is gathered without collecting an excessive volume of information that will not be utilized [IEEE Std 352-1987[3], IEEE Std 577-1976]. Third, some highly desirable information (e.g., qualitative descriptions of events, subjective opinions about the causes of failures) is transitory; it should be quickly recorded to preserve its quality.

4.2 Performance evaluation

4.2.1 Explanation

Performance evaluation is the qualitative or quantitative analysis that compares selected event and physical parameter data to plant performance targets, improvement goals, or alert levels to identify deviations from expected performance. This task includes setting both qualitative objectives and quantitative targets, goals, alert levels, or action levels in the start-up phase of a reliability program and routinely conducting both diagnostic and prognostic work to identify current reliability problems and to predict likely future problems. Included in this effort is the specific consideration of the validity of any collected historical data set in light of programmatic or design changes that have occurred in the interim. For example, if a previous analysis has indicated a need to change a surveillance interval, the data set collection process should reflect the potential for significant change in the failure rate as a result of this new interval. Detailed inputs and outputs are illustrated in Figure 3.

[2]The numbers in brackets correspond to those of the bibliography in Annex D.

[3]For information on references, see Clause 2.

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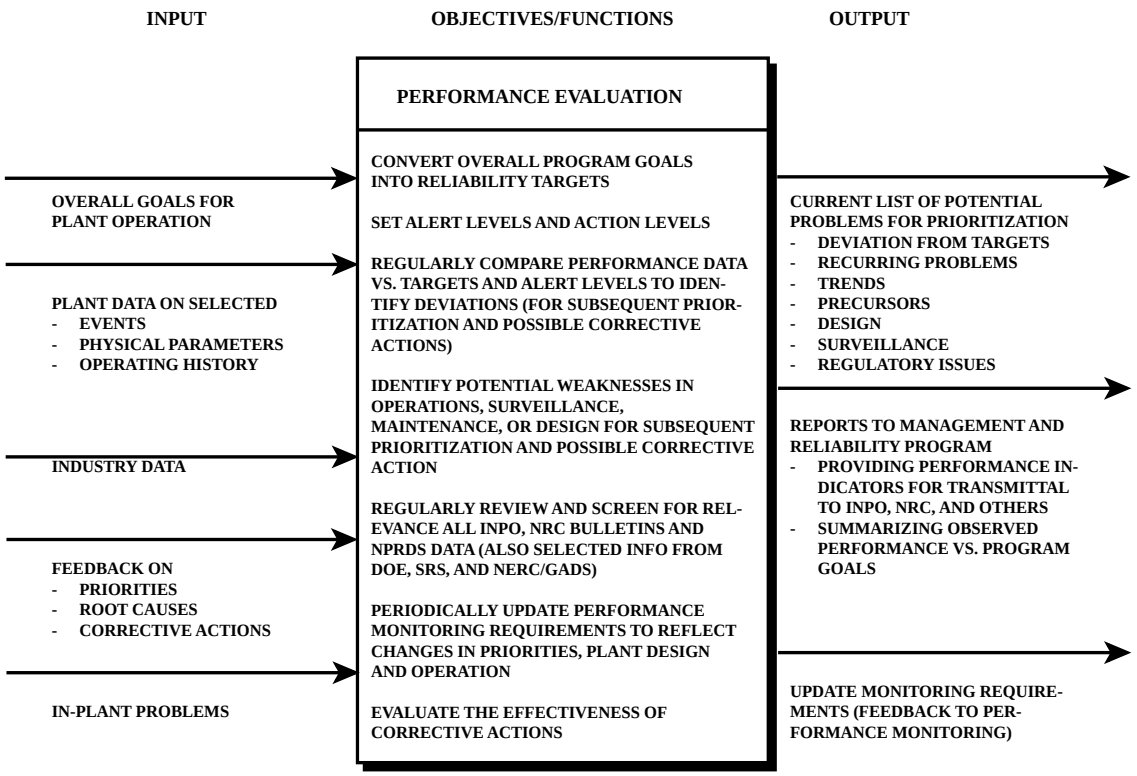

Figure 3—Performance evaluation interfaces

4.2.2 Objective

The objectives of performance evaluation are to identify problems or potential problems related to reliability in operations, surveillance, and maintenance; to indicate where requirements might be relaxed without significantly affecting performance (or optimized to ensure overall performance) adequacy; and to indicate where requirements might be relaxed in design without serious problems occurring. Accomplishing these objectives requires performing the following tasks:

a) Convert overall utility goals to plant reliability performance targets or improvement goals;

b) Allocate plant performance targets or improvement goals to important systems or events to serve as alert levels and action levels to stimulate appropriate action if they are not being achieved;

c) Regularly compare monitored performance parameter values with established plant reliability performance targets, improvement goals, or alert levels to identify deviations;

d) Use such deviations and other information [see 4.2.2 e)] to identify potential problems or weaknesses in operations, surveillance, maintenance, or design for subsequent prioritization and possible root cause analysis and corrective action;

e) Review and screen for relevance the information from the Institute of Nuclear Power Operations (INPO), Nuclear Regulatory Commission (NRC), and other applicable sources (i.e., Department of Energy);

f) Periodically update performance monitoring requirements to reflect changes in priorities, plant design, operation, and maintenance;

g) Evaluate corrective measures (after they are implemented) by comparing the goals of these corrective measures to the performance achieved.

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4.2.3 Inputs

Inputs to performance evaluation include

a) Overall utility goals for the plant and for the reliability programs (such as plant capacity factor and a planned reduction in feedwater upsets);

b) Plant-specific data on selected events (such as transients, equipment failures, and human errors) and physical parameters (such as temperature, vibration, and resistance to ground) to indicate malfunctions, errors, failures, or degradation;

c) Industry-wide data (such as NPRDS and SEE-IN) on selected events and physical parameters related to malfunctions, errors, failures, or degradation;

d) Feedback from other tasks in a reliability program to suggest changes in priorities, root causes of problems, and corrective actions;

e) Identification of in-plant problems to be addressed by the reliability program;

f) Plant, system, and equipment run times and demands.

4.2.4 Outputs

Outputs of performance evaluations include

a) A current list and definition of problems and potential problems with related notations, such as deviations from target, recurring problems, trends, precursors, and design problems.

b) Indication of areas where existing requirements may be relaxed with either an increase in resulting reliability or with no significant reliability decrement, for example, relaxation of the test interval of particular equipment.

c) Summary reports to plant management or outside organizations (e.g., INPO) providing plant performance indicators and comparing observed plant performance against performance targets, improvement goals, or alert levels.

d) Current documentation of monitoring requirements, reflecting changes in priorities, identification of root causes of problems, and corrective action taken.[4]

4.2.5 Implementation

The performance evaluation task may include

a) The establishment and review of plant performance targets
b) The establishment and review of alert levels and action levels
c) The evaluation of plant-specific and industry-wide data
d) The assessment of the as-built design
e) The assessment of surveillance requirements
f) The comparison of plant performance to targets

Each of these areas is discussed further in 4.2.5.1 through 4.2.5.6.

[4]For example, consider a situation in which corrective action is taken to improve specific areas of the operator training program. An out put of the performance evaluation task could be the specification of additional short-term operator monitoring requirements. This output is needed to verify that the corrective action, operator training improvements, has indeed achieved its goal by correcting the problem.

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4.2.5.1 Plant performance targets

Plant performance targets may be developed in the initial phase of reliability programs and are updated periodically (for example, annually). These targets are intended to be compared with actual plant performance to identify deviations from expected performance. Management can then focus on these deviations (as described in 4.2.5.2) to identify potential problems in plant operation, surveillance, maintenance, and design; prioritize them (as described in 4.3); and, where appropriate, find their causes and take corrective action.

Several reliability performance targets or improvement goals may be established. Two of the categories of goals that could be included are economic (e.g., a target for capacity factor) and safety/environmental/regulatory (e.g., a target of less than five failures to start in 100 demands for a diesel generator). These performance targets or improvement goals should be realistic and should represent the expected achievable performance.

Approaches to the development of plant performance targets or improvement goals include

a) The establishment of configurations using generic data and, later, the modification of the targets using actual experience;

b) The comparison of past performance with industry averages, INPO goals, and company goals;

c) The identification of known problem areas that need improvement (for example, an objective of performance evaluation might be to identify the top five contributors to lost generating hours and cut their contribution by one-half);

d) The estimation of the cost and benefit expected from levels of performance goal achievement. These cost-benefit estimates can be used to select the performance targets or improvement goals and guide the actions to achieve them.

For additional information on developing plant and/or equipment performance targets, see Smith [B21] and Mueller and Bezella [B17].

Top-level targets (such as plant capacity factors) can be reflected in reliability targets for individual systems, subsystems, or components in order to more effectively evaluate the performance of these systems or trains versus expected performance. The establishment of lower-level reliability targets is an iterative process, based largely on current plant performance and engineering judgment (see Jeppesen [B8]). The process should not be misused; that is, lower-level reliability targets should not lose sight of the higher target from which they were derived. An analytical aid to this apportionment is described in Modarres [B15]. These performance targets allocated to the system or train level, instead of an overall plant-level target, will help the utility identify specific areas where performance may be improved in order to achieve plant performance targets or improvement goals. It may also identify areas where surveillance requirements may be relaxed without any significant detriment to overall goals (and yet continue to maintain reliability level). Also, since system-level, subsystem-level, and component events occur more frequently than overall plant-level events, performance trending is enhanced by their use.

4.2.5.2 Alert and action levels

Reliability and availability performance data are periodically compared with expected performance in order to identify operations or equipment where performance is degrading or deviating from targets. In this process of comparing performance with standards, two levels of performance standards are useful: alert levels to flag an item that needs attention and action levels to indicate a more serious problem.

Alert levels are set to ensure that management is informed if performance degrades below preset bounds and may require action to prevent significant problems, such as failures, from developing. These alert levels may

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be set on physical parameters (such as turbine vibration) or on reliability performance (such as diesel-generator reliability or human errors). For example, alert levels could be part of a maintenance program to help schedule when maintenance is needed to prevent equipment damage or failure from occurring. Similarly, alert levels on trends in human errors could be part of a management program to focus training.

Action levels are wider bounds. They are preset to ensure that management is informed that earlier actions have not been effective and performance has degraded to a level of financial or safety concern.

Methods for setting alert and action levels may be based on methods for statistical quality control as applied to process control charts. One method used by a utility to help distinguish real changes from random variations is described in Basu [B2].

4.2.5.3 Plant-specific and industry-wide data

The routine inputs to performance analysis include plant-specific and industry-wide data. Plant-specific data can be provided from the performance monitoring function of the reliability program as described in 4.1. The input data should be processed into the form needed for comparison with reliability targets and alert levels. For example, in addition to information on all failures and actions taken, relevant data should be processed into a form that will allow failure rates to be compiled over the reporting period reflecting both number of failures and population exposure.

The other principal inputs to performance evaluation include industry-wide data regarding important events, failures, and trends at other plants such as the INPO data systems (NPRDS and SEE-IN), NRC bulletins, North American Electric Reliability Council (NERC) GADS, and vendor service and technical information letters. The utility should systematically screen these data to determine relevance to its plant. Even though other plants may be different in design, problems such as human errors, wearout of a component, or design errors may be relevant. Therefore, a wide-scope review is useful in identifying useful experience at other plants.

4.2.5.4 As-built design

The purpose of a reliability program is to be preventive as well as corrective. The initial phase of a reliability program for operating plants should assess the current design to identify reliability weaknesses, particularly unexpected system interactions and potential common-cause failures. The methods the utility selects for this design assessment reflect the mission and scope the utility has established for performance evaluation. For example, methods might range from a minimal effort based on discussion with operators and maintenance staff, to a moderate effort that also includes a strategy to detect common-cause failures (see Bourne [B4] and Worledge [B27]), to a major quantitative effort (see Jeppesen [B8] and NUREG/CR-2300 [B23]).

4.2.5.5 Surveillance requirements

If specific systems are selected for either reliability improvement or degradation prevention, it may be useful to evaluate and, if appropriate, alter the surveillance of these systems.

For example, important failure modes can be identified by failure modes and effect analysis (FMEA) and then compared with the surveillance program to ensure that the surveillance effort is focused on the failure modes that are important in terms of reliability (see Azarm [B1]). Also, surveillance intervals can be evaluated and (within pragmatic constraints) optimized (increased or decreased) to further focus surveillance resources and improve productivity.

4.2.5.6 Plant performance comparison to targets

The comparison of performance to reliability targets identifies specific problem areas that the utility can prioritize. Evaluation of reliability performance versus targets or alert levels should be performed periodically.

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These evaluations may also help to verify whether a particular target is practical. If the target is repeatedly missed, it may be found to be impractical or an alternative way to achieve it may be needed.

The analyst should also evaluate the factors that may impact the validity of the historical database (e.g., design, maintenance, and training change the expected future performance).

As the utility gains experience with using a reliability program and as initially addressed problems are resolved, new problems will arise and priorities may change. Performance monitoring and evaluation will also change as appropriate. For example, as obvious problems are resolved and more subtle problems are addressed, more sophisticated analytical methods may be appropriate. However, for effective initial use of performance evaluation, simple approaches are recommended.

4.3 Problem prioritization

4.3.1 Explanation

Problem prioritization is an assessment process that compares all the identified problems and ranks each problem relative to the others using pre-established criteria.

The prioritization process need not produce absolute measures, only measures that are consistent for purposes of prioritization. The most important aspect of prioritization is a straightforward ranking system that is consistent with economic and safety goals.

4.3.2 Objective

The objective of problem prioritization is to permit the utility to focus its efforts on the most important problems as they relate to the reliability targets.

4.3.3 Inputs

The inputs to the prioritization process are the major outputs of the performance evaluation task (see 4.2), namely, a list of potential problems that includes deviations from targets, recurring problems, trends, precursors, design information, and surveillance and maintenance information.

4.3.4 Outputs

The output of problem prioritization is a list and description of the problems to be considered by problem analysis (see 4.4) and their corresponding priorities. Deferred problems are referred back to performance monitoring (see 4.1).

4.3.5 Implementation

The prioritization process is accomplished by ranking problems based on a set of criteria as shown in Figure 4. These criteria allow each problem to be described in a common fashion. Suggested criteria could be based upon

a) Reliability or availability impact (i.e., benefit) of each problem elimination

b) Safety or risk impact of each problem elimination

c) Number of times problem has appeared on the list of problems (e.g., a recurring problem or one that previously has been given low action priorities)

d) Maintenance impact

e) Cost impact

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Other considerations might be used for specific sets of problems. Furthermore, it is also possible that, during problem analysis (see 4.5), other considerations may be identified that could necessitate the revision of the prioritization criteria. Once the criteria are established, each problem can be scored relative to these criteria or some combination of them according to a weighting scheme.

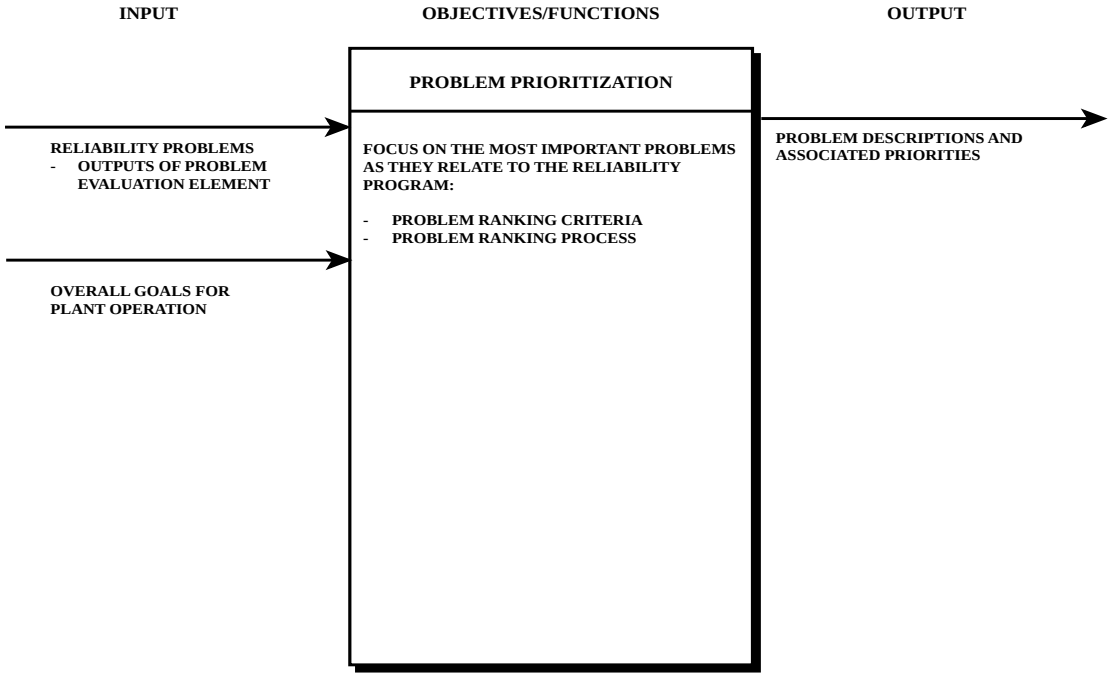

Figure 4—Problem prioritization interfaces

4.3.5.1 Selection of problem-ranking criteria

Potentially, many considerations relate to the importance of a problem. The task is to select a set of considerations that will allow prioritization to occur at an appropriate level as directed by the scope of the reliability program.

In a prioritization process, each criterion is given a value for each problem. There is no need for a common measure for all criteria. That is, one criterion could be “unavailability” and another “risk,” (i.e., the product of failure likelihood and failure consequence).

It should be understood that during the prioritization process, some problems may be considered that have relatively low scores in the direct measure criteria (e.g., availability, risk) and, therefore, would receive little or no action. However, when the list of problems is periodically reformulated, some of these items may continually reappear. These recurring items might become issues despite their low assessed priority because they are an irritant to the plant personnel. Hence, it is recommended that a criterion be included that addresses a problem’s nuisance impact (that is, the fact that it frequently recurs). Therefore, the prioritization process includes criteria that are both objective and subjective.

4.3.5.2 Problem ranking

After the criteria have been determined and values assigned, the problems are evaluated based on these criteria and ranked. See Vesely [B26] and NUREG-1115 [B22] for methods compatible with the process described in 4.3.5.1. If the problem set and/or the number of criteria is large, a computer-based method may be desirable.

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While mechanistic numerical ranking can be useful for ordering problems, it should be understood that the values obtained serve only as a guide and should not be blindly applied. Final prioritization is often based upon a combination of numerical ranking and consideration of subtle influences that cannot be easily quantified. Thus, it is not unusual to find that the final prioritization will differ from the numerical ranking of problems.

4.4 Problem analysis and corrective action recommendation

4.4.1 Explanation

Problem analysis is the process of characterizing and detailing reliability problems to identify their causes. Corrective action recommendations consist of

a) Specifying alternative methods for eliminating the causes (and thus preventing recurrence) or mitigating the consequences of the problem, and

b) Recommending a corrective action for implementation in accordance with established criteria and constraints. This task also considers the relationships among various reliability problems and their solutions (i.e., a possible solution to one problem may, in fact, exacerbate or eliminate other problems).

Finally, this program element allows the solution of some problems to be deferred, depending on factors such as cost, level of effort, and impact of the solution on the projected future availability as compared to the problem's historical availability impact.

4.4.2 Objective

The objective of problem analysis and corrective action recommendation is to determine the best possible solution to a reliability problem. In this context, the term "best" describes a solution that has a high probability of alleviating the problem within regulatory, operations, administrative, and economic constraints. This task is considered to be complete when a management decision is obtained to implement or defer the recommended corrective actions, including the commitment of required resources.

4.4.3 Inputs

As shown in Figure 5, the following inputs are required for problem analysis and corrective action recommendation:

a) A prioritized list of problems

b) Internal data sources (e.g., operating experience, maintenance records, inspection and test results, personnel interviews, equipment vendor manuals, design requirements and specifications, as-built drawings and information, procedures)

c) External data sources [e.g., expert opinion from equipment vendors and consultants; analysis of similar problems at other nuclear power generating stations by the NRC, INPO, Electric Power Research Institute (EPRI), owners' groups]

d) Criteria and constraints (e.g., regulation, licensing commitments, management policies)

4.4.4 Output

The output of problem analysis and corrective action recommendation is a set of corrective actions, approved by management for implementation, for each reliability problem. Included features are the scope

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of action, schedule for completion, basis for decision, anticipated benefits, and identification of alternative corrective actions that were rejected.

4.4.5 Implementation

The task of problem analysis and corrective action recommendation is composed of several subtasks: problem analysis, corrective action identification, and corrective action selection. These subtasks are described in 4.4.5.1 through 4.4.5.3.

4.4.5.1 Problem analysis

Problem analysis is an investigative effort to determine the underlying causes (root cause) of a specific system or component failure and their impact on plant reliability. The removal of all causes of a failure would theoretically prevent the failure from recurring. The effort involved in finding all causes can range from a very simple analysis for obvious causes to a very complex (and costly) analysis to identify inconspicuous causes. The appropriate level of effort is determined by two major factors: the cause level and economics.

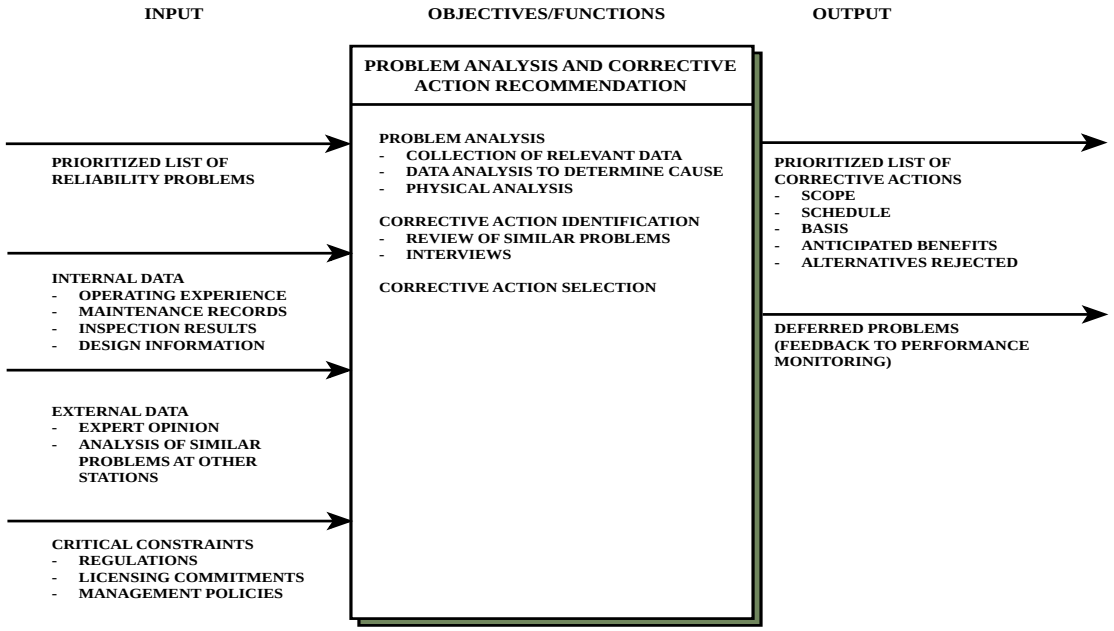

Figure 5—Problem analysis and corrective action recommendation interfaces

To identify a corrective action, the cause needs to be controllable. The problem analysis should, therefore, be limited to the level of cause over which corrective and preventive actions can be identified. The level of effort is also limited by the estimated costs of problem analysis. Other pragmatic considerations may also determine the level of effort expended in problem analysis. Because of these constraints, problem analysis will not always determine the actual cause of a failure or event. For instance, if the cost of root cause analysis is high and the component can be replaced with one which has been shown not to exhibit the same problem in an identical application, then it may be more cost effective to simply replace the component. As another example, if the cause of the failure is isolated to some problem in the manufacturing process, then it is the responsibility of the utility to inform the manufacturer of the problem. The manufacturer should in turn determine the root cause and inform the utility of the outcome. In another instance, an outside agency, such as a testing lab, may perform the specific root cause determination and report the results to the utility. In both these instances, when outside agencies are utilized, it is important that the results are reported back to the utility in a timely fashion to close the root cause loop.

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The major steps in problem analysis are the following:

a) Identification of the approach to determining the root cause

b) Collection of historical data relevant to the problem

c) Data analysis

d) Additional analysis

4.4.5.1.1 Root cause determination approach

No specific guidance can be given to assist in the selection of root cause determination techniques; the particular techniques will depend on the nature of the problem. In other words, the use of various root cause determination techniques is an iterative process, depending on experience and the results of previous techniques. However, regardless of the specific techniques chosen, the root cause investigation should consider, to a level consistent with the impact of the failure, the following:

a) The establishment of operational conditions just prior to failure;

b) The control of access to the failed component and the failure site;

c) Structured teardown of the failed component including photographic and video documentation of the teardown process, if required;

d) The collection of critical samples and failure evidence correlated to each stage of the teardown;

e) The establishment of secured storage and laydown area and access procedures to failed component piece-parts.

See Nixon [B18] and Kepner and Tregoe [B10] for general guidance on selecting analysis techniques to solve problems.

4.4.5.1.2 Data collection

The collection of data relevant to the reliability problem may be restricted to a single event, such as a procedural error, or may have to be extended to include performance data for the entire system and its support systems. Interviews with plant personnel, particularly maintenance personnel, may be important. The collection of data need not be restricted to internal sources, but may include external sources, such as EPRI and INPO reports, NPRDS, and licensee event reports (LERs).

4.4.5.1.3 Data analysis

The analysis of data involves the study of plant records, such as operating and maintenance records. Comparison of design documents and component specifications with as-built conditions can reveal discrepancies that may be the causes for component failures. An example would be a component operating in a harsh environment for which it is not designed. The comparisons may not only reveal the cause for a failure but also suggest simple corrective actions.

4.4.5.1.4 Additional analysis

In some cases, physical analyses may be needed to pinpoint the cause of a problem. Such analyses include chemical analyses, metallurgical analyses, stress analyses, and other similar processes that yield a detailed explanation of the phenomena involved. Physical analyses are conducted to obtain an in-depth understanding of the problem, from first principles. This perspective may suggest ways to eliminate or alleviate the problem.

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4.4.5.2 Corrective action identification

For the identification of corrective actions, a thorough understanding is required not only of the problem's cause but also of the equipment and its design, operation, and maintenance. The study of reports of corrective actions for similar problem causes at other plants may be a good source of background information for the analysis. Other sources for clues to corrective actions can be the performance of similar equipment in the plant and interviews with plant operating and maintenance personnel.

As discussed in 4.4.5.1, it will not always be feasible or economical to determine the actual (root) cause for a problem. Furthermore, even if a single root cause is determined, it is often possible to identify more than one corrective action for a problem. The identified corrective actions may remove the actual cause (thus preventing the problem from recurring), reduce the frequency of occurrence, or mitigate the consequences of the failure. However, it should also be understood that the alternative to maintain the situation "as is" may be chosen, but that this alternative represents a conscious decision to accept the problem.

An integral part of identifying corrective action is an analysis of the effects a proposed corrective action may have on the operation of the plant. In particular, licensing requirements should not be violated, the safety of the plant should not be compromised, and new reliability problems should not be introduced.

It may also be desirable to consider for each proposed corrective action the benefits in terms of availability and plant improvement (e.g., increased capacity factor, reduced replacement power costs, reduced operating and maintenance expenditures), and to propose methods to monitor the benefits of implemented improvements. Furthermore, it is part of this subtask, if required, to provide reliability specifications for new equipment as input to the improvement project cost estimation and procurement.

4.4.5.3 Corrective action selection

Prior to the selection of any corrective action, it is essential to clearly identify the objectives that the selected corrective action is to achieve.

These objectives may then be converted into criteria for the selection of the appropriate corrective action. The most commonly used criterion for selection of corrective action is the cost-benefit ratio. Typical criteria and constraints to be considered in the prioritization and selection process are

a) Reliability or availability improvement (benefit)

b) Cost of implementation

c) Safety or risk impact

d) Likelihood of successful implementation

e) Economic constraints

While these criteria are most prominent, it should also be recognized that other objectives external to the problem enforce constraints on the selection of the corrective action.

The proposed corrective actions can be prioritized for each problem under consideration of the above and other criteria using the same methods as discussed in 4.3.

Once the corrective actions for each analyzed problem are prioritized, one or more problems may be selected and recommended to management for corrective action.

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4.5 Corrective action implementation and feedback

4.5.1 Explanation

Following management approval of the recommended corrective action is the implementation and feedback program element. Corrective action implementation is the identification and performance of tasks that are necessary to incorporate specified changes to the design or operation of the facility. Feedback, in this context, refers to the verification that the corrective action has been implemented as planned and that it has resolved the identified problem. It also includes, in the longer term, monitoring the degree of achieved improvement, degradation from anticipated targets, and impact on performance at the plant, system, and/or component level. In the case of some problems, lack of recurrence may be the appropriate feedback mechanism.

4.5.2 Objective

The objectives of corrective action implementation and feedback are to accomplish the selected corrective action and verify that the selected corrective action achieves its objectives. Corrective actions may be changes to policies, procedures, or equipment. Specific objectives to be accomplished may be quantitative, qualitative, or both.

After a corrective action has been selected, the tasks associated with implementation and feedback are the following:

a) Initiating the proper process within the organization to implement the actions;

b) Participating actively in the corrective action tasks, if appropriate;

c) Reporting on the completion of the corrective action tasks or any hindrances incurred;

d) Verifying conformance to predetermined performance criteria and specifying additional monitoring, if any, necessary to verify such conformance;

e) Identifying statistical indicators to be monitored in order to assess the contribution of the corrective action to system and/or overall plant reliability;

f) Feeding new goals, their evaluation criteria, and plant reliability parameters back into the reliability program.

Figure 6 illustrates the interfaces of corrective action implementation and feedback with the remainder of the reliability program.

4.5.3 Inputs

The main input to corrective action implementation and feedback is documentation that identifies the specific corrective action to be taken. It is essential that all corrective actions to be implemented first go through the analysis and identification process. It is important to resist the temptation to bypass the analysis and identification process unless a critical emergency situation exists; otherwise, the corrective action may be focused on the treatment of symptoms rather than their causes. Likewise, the elimination of the prioritization process may result in expending resources upon fixing minor problems at the expense of major problems.

Along with the corrective action to be implemented, knowledge concerning the action and problem is also an input. For the corrective action, knowledge of the scope, schedule, basis for decision, anticipated benefits and alternatives that were considered is important in order to determine when and if the cost of such action begins to outweigh the possible benefits. Also, the validity of the underlying bases and assumptions, including the need for problem definition, analysis, and priority justification information, should be provided.

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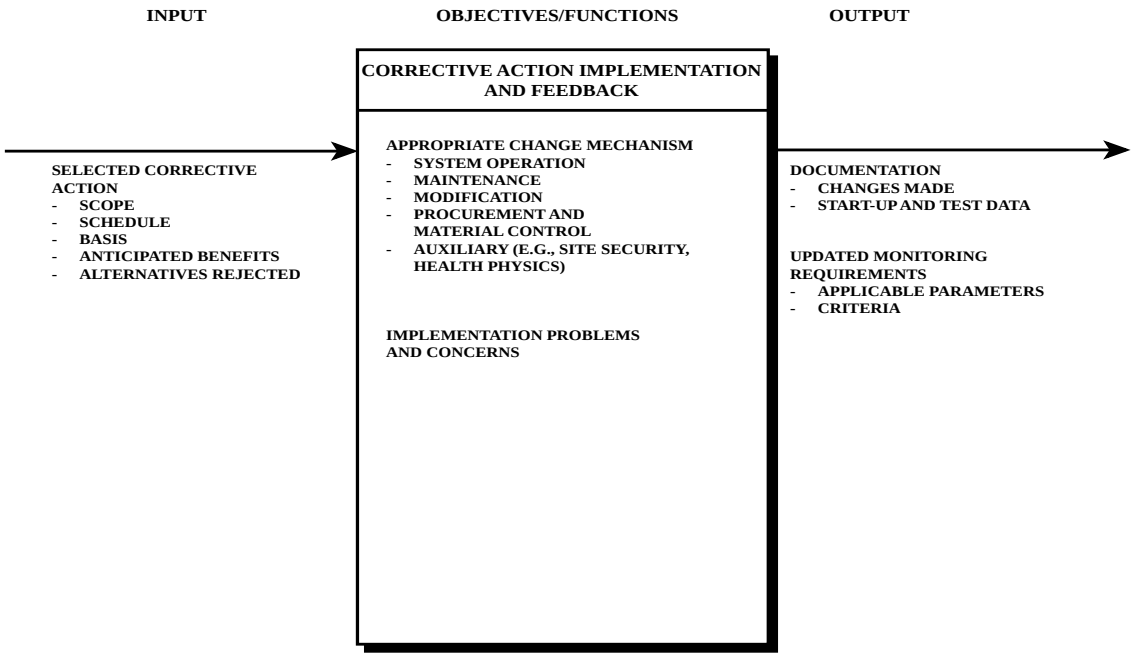

Figure 6—Corrective action implementation and feedback interfaces

4.5.4 Outputs

Updated monitoring requirements are transmitted to performance monitoring (see 4.1) along with applicable parameters and criteria. Corrective action completion is then documented, with any changes for eventual problem closeout, and maintained along with pertinent start-up and test data. Documentation may include outputs from start and stop counters, elapsed time, on-line vibration, etc.

4.5.5 Implementation

Upon completion of the corrective action, conformance to predetermined reliability or physical performance criteria should be established, if required. Statistical indicators to be tracked in the long term should be identified so that they can be correlated to the correction for future benchmarking. In this way, the corrective action's contribution to system or plant reliability can be assessed. Finally, new goals with their evaluation criteria and forecasts of new plant reliability parameters are fed into the program for iteration.

5. Major programmatic resources

For reliability improvements to occur in an operating nuclear plant, many plant groups and organizations should become involved. These plant organizations work under management guidance and take their direction from the broad goal to improve plant availability and safety within the constraints of limited human and financial resources. To ensure cost effective plant improvements and address reliability concerns in a structured and programmatic fashion, the following are required:

— Optimum use of existing resources

— Firm management direction

— Flexibility within the plant organizations

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Further, management should be confident that each plant organization participating in the reliability program understands what it needs to provide and what it should expect to get from reliability improvement.

The success of the reliability program is a function of the amount of cooperation and integration with which the various program elements operate. Management is responsible for ensuring this merging of the different program elements. An appropriate management style should be tailored to the existing corporate culture. Annex A offers guidance on selecting an appropriate management style that addresses key components of quality management.

Typical plant organizations involved in reliability improvement programs are operations, maintenance, engineering, safety, licensing, quality assurance, training, and procurement. Table 1 depicts an example to illustrate where each element of a reliability program might exist in the utility organization. The contributions each of these groups could make are discussed in 5.1 through 5.7.

Table 1—Example of major programmatic resources[a]

Organizational element	Program elements				
	Performance monitoring	Performance evaluation	Problem prioritization	Problem analysis and corrective action recommendation	Corrective action implementation and feedback
Operations	P	S	P	S	—
Maintenance	P	S	S	S	P
Engineering	—	P	P	P	—
Safety	—	P	P	P	—
Licensing	—	S	S	—	—
Quality assurance	—	—	—	—	—
Training	—	—	—	—	—
Procurement	—	—	—	—	—

P = Direct role in performing functions of the element
S = Secondary role in performing functions of the element

[a]This table is only an example. Actual tables would be specific to the reliability program being implemented.

5.1 Operations

The operations organization has the general responsibility to operate the plant safely, efficiently, and reliably on a day-by-day basis. This responsibility typically results in participation by operations in all aspects of a reliability program.

The initial contribution of operations to reliability improvement comes from the awareness of how equipment performs under various plant conditions and configurations and how it fails to perform under various system demands. This performance information falls under the definition of performance monitoring and requires communication to other plant organizations for appropriate action. Operations may be either

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directly or indirectly involved in performance evaluation and/or prioritization. These functions could be performed by an operations technical support group, if such a group exists. If the function is primarily performed in another organization, then operations provides review on the evaluation results.

Plant operating procedures are developed to ensure that equipment is operated within the manufacturer's recommendations and within the plant's design basis. These procedures, related operator training, and operator observations can provide the basis to optimize equipment performance levels and maximize safety. Operators also have a responsibility to the reliability program to resolve deficiencies in performance or plant safety, if possible. If immediate resolutions are not possible, then operators are responsible for ensuring that the deficiencies are documented and entered into the reliability program for resolution. Operator skill in spotting problems and taking appropriate action can be used in determining the cause of the anomalies and assisting other plant organizations in their improvement efforts.

The reliability program can aid the operators in spotting problems through the use of trending programs based on component conditions, out-of-tolerance operating limits, vibration indication, leakage detection, thermography, and other means. The operations organization is directly involved in the implementation of the corrective action. Operations personnel should review hardware changes and implement procedural changes. Final modifications should be accepted by operations. Finally, operations is directly affected by improved plant availability, which is the goal of the reliability program.

5.2 Maintenance

In a broad sense, the maintenance organization is primarily responsible for maintaining the plant equipment and system so that their performance meets or exceeds reliability targets. The maintenance organization is responsible for

a) Maintaining equipment in accordance with applicable vendor recommendations and previous experience, and
b) Specifying methods and procedures to ensure that quality craftsmanship and materials (parts) are used in repair efforts. Typically, the maintenance organization will have a primary role in two reliability program elements as shown in Table 1; it also will support three other elements.

The maintenance organization is the primary collector of data (such as work requests and the results of condition monitoring) for the performance monitoring element. In addition, the performance prioritization element requires potential manpower allocation restrictions from maintenance management, which could influence the timing of ultimate problem resolution. Problem analysis may require the dismantling of equipment or interviews with maintenance personnel. Finally, the maintenance organization is frequently expected to implement the corrective action.

Improvements in failure trends can come about by judicious use of preventive maintenance and consistent corrective maintenance. Many times, equipment is serviced before actual corrective effort is needed. This preventive effort is usually undertaken based on diagnostics, the equipment vendor's recommendation, or a set periodic schedule. Past experience and availability can be used to guide this prevention effort. Reliability-centered maintenance is one technique that uses reliability principles to improve maintenance (see Nowlan and Heap [B19] and Hook [B7]).

5.3 Engineering

The typical engineering organization is often separated into two distinct groups called "technical support" and "design engineering." Each group has its responsibilities to reliability improvement efforts.

Based on data obtained from other organizations (in particular maintenance and operations), technical support systems engineers can help determine critical equipment necessary for reliable operation. This critical

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equipment list can establish the scope of the reliability program. Alternatively, this critical equipment list can be monitored for effect on system-level or plant-level availability targets. Engineering establishes corrective action priorities and provides guidance for an appropriate, cost-effective solution to problems. Engineering is thus directly involved in performance evaluation and prioritization.

Improvements over existing plant designs can be obtained from operational experience and the other feedback mechanisms. Industry information, design enhancements, and reliability improvements can come from the reactor vendor owner's group, other owners, networks, and LERs. Input to optimize equipment selection can be obtained from plant maintenance records and trending data, as well as from industry sources such as NPRDS.

Once design engineering has obtained inputs from all relevant sources, a review should be made to determine the applicability (i.e., reduction of equipment failures or repair times) and efficiency (i.e., whether the change is worth the cost to realize a reliability or availability improvement) of each design change. This process is included in problem analysis and corrective action recommendation.

Design engineering can assure that reliability objectives are incorporated where appropriate into each design change that is performed at the plant. These design changes may have come from regulatory requirements; corrective action identification by maintenance, operations, or technical support; or other sources. Then, assuring that the plant's design basis is properly addressed, as well as industry codes, standards, and regulations, conceptual design document and specifications can be prepared that describe performance reliability and maintainability objectives, among other things. With these objectives clearly stated, other plant organizations and plant management can be assured that the engineering design is in accordance with the plant performance goals.

Technical support engineering and design engineering should jointly ensure that plant configuration changes include a thorough review of past equipment performance so that optimized choices to improve reliability and safety are made.

5.4 Safety

An independent safety review organization aids in ensuring proper plant operation. This independent review, encompassing factors necessary to ensure minimal risk and high levels of operating (e.g., nuclear) safety, deals with the safety side of reliability and, therefore, tends to focus on operating procedures, safety system capabilities, and off-normal operation rather than power production.

The safety organization may serve a primary role in three elements of a reliability program.

— First, in performance evaluation, the safety organization can help in developing system performance targets, such as system unavailability targets, which could then be a part of corporate or plant performance targets. These system targets can directly affect operations (e.g., surveillance test frequency), maintenance (e.g., predictive monitoring techniques), or licensing (e.g., technical specification relaxation). Also, the safety organization reviews performance trends to ensure that potential safety problems are recognized and appropriate action is taken.

— Second, the safety organization reviews priorities placed on resolving identified safety problems and, in some organizations, may take the lead in setting those priorities.

— Third, the safety organization reviews the problem analysis and corrective action recommendations to help ensure that safety concerns are addressed and resolved. In addition, the safety organization follows up by reviewing the status of implementation and the resulting effectiveness of corrective actions intended to resolve safety problems.

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While the independent safety organization can bring considerable expertise to reliability and safety improvement efforts, it can also benefit from the successful implementation of a reliability program to support continuing plant operational refinements and to prevent major safety problems from occurring.

5.5 Licensing

Regulatory agencies and industry groups primarily interface with a reliability program through the utility licensing organization. The day-to-day power production activities of a utility are supported by the licensing organization; hence, licensing usually assumes a secondary role in performing the reliability program elements. In addition, licensing will primarily concern itself with safety-related equipment reliability issues.

The licensing organization interfaces with four or five reliability program elements.

— First, licensing injects regulatory concerns and requirements into the process through the performance evaluation element.

— Second, information pertaining to problem prioritization (e.g., required deadlines) will be transmitted to the reliability program by licensing.

— Third, licensing may relay data and information relevant to problem analysis and corrective action recommendation. Some regulatory concerns suggest a course of corrective action; further, licensing may have more direct access to industry groups (e.g., INPO, EPRI, the reactor vendor Owners' Groups), which can provide assistance in areas such as root cause analysis and corrective action formulation.

— Fourth, licensing is required to formally respond to regulatory concerns; hence, it has a vested interest in the effectiveness of corrective action.

5.6 Quality assurance

The quality organization, including QA and QC, supports two elements of a reliability program by independently reviewing

— The problem analysis and corrective action recommendation

— The corrective action implementation and feedback elements

A QA organization can aid plant reliability improvements by actively participating in procurement decisions, vendor qualification, and material integrity. First, QA/QC can verify that the engineering and maintenance organizations have incorporated reliability concerns into design specifications, procurement documents, and acceptance tests. Second, QA/QC can ensure that vendors and suppliers are qualified to supply reliable components. Third, QA/QC can verify that the specific reliability concerns of the purchasing organization are addressed and documented by a vendor in a logical, precise manner using known measures of reliability assurance. Vendor work inspections (i.e., shop inspections) can aid in determining how the vendor is building reliability into the physical product. Fourth, QA/QC can ensure during the site receipt inspection that the final delivered product has the correct documentation (e.g., reports of reliability demonstration tests) to demonstrate compliance with reliability requirements. Finally, QA/QC can provide assistance to the maintenance organization in the form of spare parts quality reviews. Such reviews ensure that the reliability concerns of the original design are also reflected in the design procurement of spare parts. Further, spare parts quality reviews may be extended to reflect plant experience so that the reliability of spare parts equals or exceeds the original design requirements.

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5.7 Procurement

The procurement organization (including contract and legal functions, as necessary) can play a supporting role in corrective action implementation and feedback by providing the procurement framework to obtain equipment and services that meet or exceed the desired reliability requirements. These reliability requirements are a product of the problem analysis and corrective action selection activities.

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Annex A

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Reliability program management

Annex A indicates how a reliability program might be managed and how it might fit into existing organizational structures at a utility.

Active support in the form of justification and persuasion is sometimes necessary by program personnel in the implementation or initiation phase of the corrective action. Corrective actions completion reports are forwarded to reliability program management. Problems and concerns that arise during implementation should be channeled to the proper corporate management authority for resolution. For these reasons, it is important that the management of a reliability program is well integrated into the overall corporate management if it is to be successful.

A successful reliability program is characterized by applying a systematic sustained management process to the problem of maintaining acceptable performance. Essential management elements of this process are

— Planning activities necessary to achieve reliability program goals
— Integration of the reliability program into other ongoing programs
— Organization of responsibilities and resources
— Controlling the reliability program by monitoring the progress and allocating resources to correct identified problems

In addition to these management elements, a key facet of reliability program management is to provide leadership to motivate the program participants over the program duration.

These elements are addressed in detail in A.1 through A.5.

A.1 Planning

Planning is the definition and scheduling of activities necessary to achieve the goals of the reliability program. It includes defining specific tasks at an appropriate level of detail, establishing the logical connections between the tasks, estimating the resources required, and setting the time sequence and overall program schedule.

The goals of a reliability program may come from various sources. The majority will likely come from upper management; however, some may originate from outside sources such as NRC, INPO, or industry working groups, while others may be intradepartmental. These goals will range from high-level and general to working-level and explicit. All of these goals will have to be refined and allocated into measurable objectives for which responsibility and accountability can be assigned. For each of the working-level goals, specific tasks designed to accomplish them should be defined. During this process of reducing the high-level goals to specific tasks, there should be periodic reviews to ensure there is continuity between them.

While the sources of the reliability goals may vary, management controls the allocation of resources available for their accomplishment.

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The specific tasks that have been identified may require more resources than management has designated, thereby creating the need for prioritization. The tasks should be prioritized according to their contribution toward meeting the goal from which they originated. Often, this prioritization can be accomplished with the aid of a reliability model or a probabilistic risk assessment (PRA). It is important, however, that the reliability model or PRA be up-to-date with the current plant design. In the absence of these models, good engineering judgment coupled with a review of the pertinent reliability data may suffice. Once the final set of tasks has been established and the time and resources for each task have been set, standard tools for scheduling and coordination, such as program evaluation review technique (PERT) and critical path method (CPM), can be utilized.

A.2 Integration

Integration is the coordination of the reliability program with other ongoing programs at a nuclear power generating station. It includes establishing and maintaining a reliability program within the existing organizational framework of a utility and working within the various organizational departments as appropriate to best implement a reliability program.

Integration of a reliability program with other plant programs will help ensure its success. Program integration requires senior management support: it is very helpful to have a corporate policy or directive that establishes the company's commitment to the reliability program. The policy should emphasize the program's objectives, scope, and responsibilities. This policy will help ensure the necessary cooperation and commitment needed from all management and staff for the program's success.

Integration should

— Foster operations and maintenance plant staff awareness of safety and reliability insights
— Factor operations and maintenance plant experience into the decision process
— Provide sensible, expeditious, and cost-effective implementation of corrective actions
— Keep management aware of plant performance and availability
— Address design feedback and safety improvements

A.3 Organization

Organization includes the assignment of specific responsibilities and resources for the specific tasks. It includes defining a structure for responsibility and authority and establishing the necessary mechanisms or system for communication and control. Organizing is the arrangement of people and resources to match the plan.

The responsibility for a given task may be shared by different organizations within the utility. For example, the performance monitoring task requires obtaining, recording, and appropriately transmitting selected performance data and then converting that data to a form suitable for reliability evaluations. The first subtask may involve personnel from operations or maintenance. The second could involve either a dedicated reliability program staff or any of the above-mentioned groups.

The commitment of management is required for task interfaces to be properly implemented. Management should not only be apprised of the goals and needs of the reliability program, they should be a part of the goal-setting process.

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Resource allocations are, of course, a compromise between the reliability program and other needs. Senior management should formally endorse the reliability program goals to ensure the cooperation of the interfacing organizations' management. Monitoring the progress the reliability program at the upper management level can be assisted by selected publication of reliability performance data, for example, in quarterly management summary reports.

The organizational structure by the utility to implement a reliability program should be suited to the utility's organizational style. There is no generic "best organization"; the structure to be preferred depends primarily upon the current organization, the corporate culture, and the personnel available.

The organizational aspect of reliability program management includes the identification of reliability task responsibilities, their assignment to particular reliability-related individuals or organizations, and the specification and allocation of reliability resources for accomplishing the identified reliability tasks. Organizing implies an organizational structure that promotes the completion of the assigned tasks. While many types of organizational structures exist, organizations can generally be categorized as either centralized or decentralized. Each of these categories has its advantages and disadvantages.

A.3.1 Centralized organization structure

In a centralized organizational structure, the reliability program plan implementation and the accomplishment of the associated tasks are assigned to staff members within a reliability group (RG). This group of individuals is ordinarily assigned line responsibilities on tasks only with the reliability program. This type of organizational structure is advantageous because it provides for a clear definition of who is responsible for the reliability tasks and it concentrates reliability technical resources, which can allow more sophisticated analyses to be performed.

However, the design and operations groups can become complacent and begin to feel that maintaining an acceptable level of reliability is the sole responsibility of the RG. Correspondingly, the centralized RG can lead to the development of a reliability expertise isolated from the plant design and operational expertise. This isolation makes the RG dependent on other staff members with design, operations, and maintenance expertise. This dependency can be minimized by providing education to the reliability personnel on ongoing operations and plant design. However, without the continuing day-to-day interaction that occurs in an operational setting, reliability personnel will always be, to some degree, dependent upon operational personnel. In any case, intergroup communication is crucial to the success of the reliability program.

A.3.2 Decentralized organizational structure

In the case of a decentralized organization structure, expertise is provided to the line organization so that the personnel with problem and plant knowledge will perform the reliability analysis. This structure thereby eliminates the communication problem inherent in the centralized structure. A decentralized structure has the additional advantage of promoting a reliability awareness throughout the organization by having a reliability presence within each organizational entity within the utility.

Decentralization also allows reliability technology to be directly focused upon resolving problems that have been recognized by the organization itself. In order to provide leadership and accountability, the lead responsibility for each reliability program element should be assigned to an appropriate organizational group. For example, the lead responsibility for performance monitoring could be given to maintenance while the lead responsibility for performance evaluation could be given to engineering.

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As useful as the decentralized approach may be, it suffers from the potential for duplication of effort and for placing priority upon the solution of problems that would not necessarily be considered as important from a global perspective. Additionally, decentralization allows for the reliability task assignments of personnel and organizations to be set aside in favor of the completion of what may be perceived to be more pressing line organization tasks; and it may inhibit the type of interchange of reliability technology that is often inherent in centralized approaches. These deficiencies can be minimized by the assignment of an individual with significant corporate stature as the reliability program focus and by providing periodic meetings of the line staff assigned reliability responsibilities. These meetings can aid in establishing technical interchange and in establishing better balance for task priorities. However, without the continuing day-to-day interaction with a peer professional group that occurs in a centralized reliability organization, there is always the danger of misdirected, duplicative, or inappropriate reliability efforts being undertaken.

A.3.3 Selection of appropriate reliability organizational structure

The preferred structure to be chosen for a reliability organization depends upon the environment in which the organization will operate. Whether a centralized, decentralized, or some intermediate approach is to be chosen cannot be determined a priori. What can be determined, however, is that when a centralized approach is chosen, care should be taken to establish strong lines of communication between reliability, design, and maintenance personnel and that reliability personnel should be educated in the design and operational aspects of the plant. Further, if a decentralized approach is chosen, an individual should be selected as the corporate reliability focal point. This individual should arrange for reliability technical training and regular technical exchanges among the line personnel assigned reliability responsibilities.

A.4 Controlling

The control function of reliability program management monitors the progress, identifies problems that arise during the implementation of the plans discussed in A.1, and allocates resources required to correct the problems.

Performance monitoring provides quantitative indicators of progress through such measures as increases in equipment reliability, reduction in operations or maintenance errors, and improvements in plant availability. The comparisons of the indicators with pre-established targets provide a measure of success of individual program initiatives. These comparisons should be published in periodic reports to plant and utility management to provide top-level awareness of program success. Lack of improved performance points to areas where different initiatives may be required.

A.5 Leadership

Leadership involves the motivation of the organization to implement and support the program. Management support provides the key to success in reliability improvement efforts. Management should provide the vision as to what can be achieved and the benefits that will flow from improvement efforts in order to motivate the program participants. By making program goals clear, making explicit commitments to utilize results for plant betterment, and communicating program successes throughout the corporate organization, management gives clear direction as to what to do and why it is being done.

As the program progresses and as management shows its continued involvement in the decision-making process, changes to program organization or a reallocation of resources may be necessary. This natural fine-tuning of the program shows that program participants are communicating their results and additional needs to management, and management is communicating to the participants its understanding that additional direction is necessary to keep the program progressing.

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In addition to planning, integration, organization, and control, many other factors are important in the successful management of a reliability program, for example:

— *Coverage of all the elements of the reliability program*. One can emphasize some elements more than others, as, for example, when a program is set up to address a set of previously identified problems. However, the program cannot ignore any element. If, for example, performance evaluation is ignored, the program will ultimately fail because its benefits will not be highlighted.

— *Clarity of responsibility and authority.* The program manager should be sure someone is responsible for each task and that, where overlaps exist, the individuals involved collaborate efficiently.

— *Flexibility in both planning and organizing a reliability program*. No single correct way to organize and no single correct sequence of tasks exist. A particular structure may not fit a given utility culture, and task sequence is bound to be affected by unforeseen occurrences. Part of successful control is recognition of these facets and employing the flexibility to tailor the approach to fit the situation and environment while maintaining progress towards the goals.

— *Constant and effective communication*. Attention should be given both to internal communication among the participants and to external communication with others affecting or affected by the program. More programs have failed because of ineffective or inadequate communication than from any other cause. Team members should understand their roles and the impact of their tasks on others. People outside the team should understand the program generally and the benefits for them if they are to support the plan.

All these factors should be considered by management in order to implement a successful reliability program.

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Annex B

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Case study—Application of Excelsior Power Company's reliability program plan to service water pumps

B.1 Overview

Annex B describes uses of a reliability program to improve service water pump performance. The activities described in this annex occur at a hypothetical utility, Excelsior Power Company (EPC). Any resemblance between EPC and any actual utility is coincidental. In order to make the presented example realistic, the following assumptions have been made:

— A reliability program based on this guide has been established at EPC.

— A centralized organizational structure (see A.3) exists at EPC so that the program can address the several nuclear power generating stations located across its service area.

B.2 Service water pump performance

The elements of the reliability program have worked together to improve service pump performance at several of EPC's nuclear power generating stations. The elements' contributions to this goal are discussed in B.2.1 through B.2.5.

B.2.1 Performance monitoring (see 4.1)

The RG periodically collects records of repair activities at each plant from the respective maintenance departments. Other records related to condition monitoring are kept and screened by maintenance; only trends of poor performance are routinely transmitted to the RG.

B.2.2 Performance evaluation (see 4.2)

During the review of maintenance records, the RG noticed that the number of maintenance records pertaining to service water pumps at one unit had exceeded the target value. [During the initial phases of the reliability program, the target value for service water pumps had been set at a few maintenance records above the number generated by preventive maintenance actions. Since the service water system has redundant pumps, it had been decided that a target based on system unavailability would not provide adequate warning of a problem. Nor did regulatory or industry (e.g., INPO, EPRI) guidance on service water system or equipment performance exist when the target was established. EPC had conducted a PRA on the plant in question, which showed that service water pump performance had a significant risk impact on certain accidents and that the major cause of service water pump unavailability was maintenance.] Due to this background information, the RG started a further investigation of service water pump performance.

First, investigators noticed that an increasing number of service water pump repairs were instigated by complete pump seal failure. Second, review of the condition monitoring records showed a steady increase in pump seal leak-off rate. The third step was to expand the investigation's scope to all service water pumps within the utility. This action reduced the chance of a "false alarm" by increasing the amount of information while ensuring that similar problems with other pumps were not overlooked. Fourth, the RG consulted

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industry sources (e.g., NPRDS) to see whether similar service water pump seal problems had been experienced at other utilities. As a result of this investigation, the RG decided that a performance problem existed with service water pump seals at certain units.

B.2.3 Problem prioritization (see 4.3)

The RG assigned a high priority to resolving the service water pump performance. Several factors were considered during this decision. First, the service water system is required for power operations; a loss of all service water pumps due to seal failures would reduce plant availability. Second, plant safety could be reduced since service water is required to mitigate some accidents. Third, service water pump seal failures were increasing. Fourth, the preliminary investigation conducted during performance evaluation showed that the problem may exist at other plants within the utility.

Once the problem's priority was assigned, the RG immediately mobilized other utility organizations as specified in the corporate nuclear reliability program. Since the vice president of nuclear operations (VPN) had established a centralized organizational structure through a corporate directive, the RG already possessed the necessary authority to assign resources and coordinate activities needed to solve the problem. (A decentralized structure could also rapidly respond if responsibilities are clearly delineated in the reliability program plan. The important feature is that the complete plan be in place before reliability problems are discovered.)

B.2.4 Problem analysis and corrective action recommendation (see 4.4)

An analysis was conducted by the engineering organization to determine the root cause of the service water pump seal problem. Following a review of the available data (including maintenance records, conversations with maintenance personnel and the pump manufacturer, and metallurgical analysis of the seals), it was decided that service water pump seals were failing due to the entrainment of silt in the pump suction water. Such silt causes accelerated wear of the sealing surfaces, thus leading to complete seal failure. An accumulation of silt in the service water intake structures was found at the units that had experienced the greatest number of seal failures; no such accumulations were found at units with low rates of seal failures.

Several solutions to the silting problem were suggested. First, the inlet service water could be further filtered to remove the silt. Second, the seals could be redesigned to better accommodate the silt. Third, the cleaning and inspection frequency of service water intake structures could be increased, and all pump seals could be replaced. Based on cost and ease of execution, the third option was recommended for implementation. Also, the cleaning and inspections were extended to all units at the utility.

B.2.5 Corrective action implementation and feedback (see 4.5)

Management concurred with the recommended corrective actions, which were completed as soon as the plant operating schedule permitted. Increased periodic cleaning inspections of the service water were added to each plant's preventive maintenance program. The RG closely monitored service water pump performance after the corrective actions were completed. No failures of the pumps due to complete seal failures have since occurred.

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Annex C

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Sample RAM specification for replacement service water pumps

Annex C provides a sample RAM specification for replacement of any component. In this instance, service water pumps are used as an example. Such a specification is intended to form a part of procurement documentation. It may be adapted to other equipment as required.

The activities described in this annex occur at a hypothetical utility, EPC. Any resemblance between EPC and any actual utility is coincidental. In order to make the presented example realistic, the following assumptions have been made:

— A reliability program based on this guide has been established at EPC.

— A centralized organizational structure (see A.3) exists at EPC so that the program can address the several nuclear power generating stations located across its service area.

Following the principles of Annex A, it is presumed that the VPN has organized a corporate nuclear RG consisting of a few engineers with expertise in reliability engineering techniques. This group is charged with the day-to-day operation of the corporate nuclear reliability program. Various utility organizations have been assigned responsibilities to interface with the RG as discussed in Clause 5 (see Table 1). As discussed in Annex A, these assumptions are not the only organizational choices possible, nor are they necessarily the best approach for any particular utility. They are simply presented as a reasonable set of assumptions to allow Figure C.1 to be placed in a reasonable realistic context.

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EXCELSIOR POWER COMPANY*

RELIABILITY, AVAILABILITY & MAINTAINABILITY

(RAM) SPECIFICATION REL 86-102

FOR

REPLACEMENT SERVICE WATER PUMPS

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	4.5 [C.4.5] Spare parts list	
5 [C-5]	Availability demonstration	
6 [C-6]	Root cause analysis	

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*Not a real company.

Figure C.1—RAM specification

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RAM SPECIFICATION REPLACEMENT FOR SERVICE WATER PUMPS

C.1 Section 1: General

The Excelsior Power Company (EPC) requires its equipment be designed, fabricated, installed, operated, and maintained to generate power at the lowest possible life-cycle cost. This reliability, availability, and maintainability (RAM) specification has been written to help our contractors meet this requirement. It is the intention that the specification be employed to ensure that RAM is addressed as an integral part of the equipment acquisition process.

C.2 Section 2: Scope

This specification defines and describes the various elements required of RAM programs implemented on equipment and its integral components ("the Equipment") purchased by EPC. Section 3 lists the specific RAM requirements. Section 4 is designed to indicate the minimum detail to be achieved in the RAM program and to describe the factors to be considered and goals that should be met.

C.3 Section 3: Specific RAM requirements

The seller shall sequentially address each statement of this specification by maintaining the assigned paragraph number and title to facilitate the compliance review. Exceptions to the specification or seller suggested alternatives shall be clearly identified.

C.3.1 Section 3.1: Applicable RAM activities

The applicable RAM activities required for this procurement are listed below:

a) A preliminary copy of the RAM program plan shall be submitted with each bidder's proposal. Bidders shall submit in their proposals a failure modes and effect analysis (FMEA) describing the features that prevent or reduce the effect of present service water pump failure modes.

b) The service water pump system shall meet the following quantitative requirements and be demonstrated by the required quantitative analysis and availability demonstration:

   1) Minimum mean time between failures (MTBF) of 10 years
   2) Minimum operational availability of 99.8% for a 5-year operating period
   3) Maximum mean time to repair (MTTR) of 175 hours
   4) Maximum mean logistics time (MLT) of 240 hours

   The delivered system shall meet the MTBF, MTTR, and operational availability stated in the seller's proposal and be demonstrated by the required quantitative analysis and availability demonstration.

c) Qualitative analyses for the equipment to be performed by the bidder are listed below:

   1) FMEA—performed for electrical motors and controllers and for major component (replaceable) level for mechanical systems.
   2) Spare parts analysis—based on results of quantitative analysis.

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3) Maintainability review—performed to assure that the design has addressed the following to facilitate maintenance:
   i) Adequate man ways for accessibility of large sized personnel;
   ii) Minimal or no need for special tools or fixtures;
   iii) Major preventive maintenance intervals to coincide with scheduled plant outages (12–18 months);
   iv) Operations and maintenance manuals that include maintenance schedules, exploded view drawings with identification of parts, care of inspection equipment, and mockups.

d) The level of quantitative analysis shall be the same as specified for the qualitative analysis discussed in item (c). The analysis shall be performed with a 90% confidence level. Bidders shall describe the methods they intend to use for each of the analyses in their proposals. Quantitative analyses for the equipment to be performed by the bidder are listed below:
   1) Reliability prediction (MTBF)
   2) Maintainability prediction (MTTR, MLT)
   3) Operation availability

e) Three design reviews shall be held. Location will alternate between EPC and the bidder's facility.

C.3.2 Section 3.2: Documentation

The following documentation is required for EPC review and approval:

a) RAM program plan
b) Failure rates, repair rates, and their source(s)
c) RAM predictions
d) Design review reports (__copies)
e) Design review minutes
f) Operations and maintenance manual(s)
g) Spare parts analysis
h) Final RAM report

C.4 Section 4: RAM tasks

The seller has sole responsibility for performing these tasks and demonstrating compliance with RAM requirements.

C.4.1 Section 4.1: RAM program development, management, and documentation

The purpose of this task is to develop a RAM program plan and to manage, implement, and document the program.

Section 4.1.1: RAM program plan

This plan shall include, but not be limited to,

a) A description of how the RAM program will be conducted to meet the requirements of the contract;

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b) A detailed description of how each RAM task will be performed or complied with;

c) Identification of the organization unit with the authority and responsibility for executing each task;

d) A schedule with estimated start and completion points for each RAM program activity or task.

When approved by EPC, the RAM program plan shall become, together with the contract, the basis for contractual compliance.

Section 4.1.2: Design and program reviews

The seller shall conduct RAM program reviews to ensure that the RAM program is proceeding according to the contract and that the quantitative RAM requirements will be achieved.

The RAM program shall be planned and scheduled to permit EPC adequate opportunity to review program status. The formal review and assessment of contractual RAM requirements shall be conducted at the design reviews held at major program points, as specified by the contract. As the program develops, progress shall also be assessed at additional RAM design reviews if necessary. The seller shall schedule reviews as appropriate with its subcontractors and suppliers and ensure that EPC is informed prior to each review.

The reviews shall identify and discuss all pertinent aspects of the RAM program, for example,

a) At the preliminary design review (PDR)
   1) Updated RAM status including
      i) RAM modeling
      ii) RAM predictions
      iii) RAM content of specification
      iv) Design guideline criteria
      v) Other tasks
   2) Other problems affecting RAM
   3) Spare parts program

b) At intermediate design reviews
   1) RAM predictions and analyses
   2) FMEA
   3) Critical items
   4) Fault tree analyses or quantitative analyses
   5) Spare parts program
   6) Other problems affecting RAM

c) At final RAM program review
   1) Discussion of items reviewed at prior design reviews
   2) Results of all RAM analyses
   3) Status of assigned action items

Figure C.1—RAM specification (Continued)

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Section 4.1.3: Program management

The RAM program should be managed to ensure that

a) The program proceeds with the contract and program plan.

b) RAM concerns are addressed as an integral part of the overall project to minimize program delays and additional costs occasioned by the resolution of RAM problems.

Section 4.1.4: Final RAM report

The final RAM report shall summarize the results of the RAM program and provide a final statement on the equipment's ability to meet EPC's RAM requirements. It should also include full details of the final RAM models, data, and analysis. The form for these items should be acceptable to both the seller and EPC. EPC retains the option of maintaining the analyses as "living documents."

C.4.2 Section 4.2: Qualitative reliability analysis

The seller shall identify potential design weaknesses through systematic, documented consideration of all likely ways in which a component or equipment can fail and identify the causes, likelihood, and consequence of each failure mode.

In general, this analysis should be accomplished using an FMEA. However, other analytical techniques [e.g., hazard and operability studies (HAZOP)] are acceptable if they fulfill the same role.

The FMEA shall be performed to the level specified by EPC (e.g., subsystem, equipment, functional circuit, module, piece-part level). All failure modes shall be postulated at that level; and the effects on all higher levels shall be determined unless a critical item that would benefit from a more detailed analysis is being addressed or unless RAM data are available only for lower levels of detail. This analysis will encompass the design of the equipment, its handling, storage and installation, potential extremes in environmental and operation conditions, possible secondary effects of degraded but not yet failed equipment, operating and maintenance procedures, and the action (or inaction) of operators. This analysis shall be performed concurrently with the design effort so the design will reflect the conclusions and recommendations of the analysis. The results and current status of the FMEA shall be used as inputs to maintainability, logistic support analysis, test equipment design and test planning activities, etc.

The FMEA will identify

a) Failures that would critically affect system safety, be major contributors to system unreliability or unavailability, or cause extensive or expensive maintenance and repair;

b) Unproven items or those advancing beyond the state-of-the-art;

c) Items whose failure will also inevitably cause system failure;

d) Items that will be stressed in excess of specified operating criteria;

e) Items that have limited operating or shelf life, particularly when exposed to factors such as vibration, or that warrant a controlled surveillance under specified conditions;

f) Items requiring special handling, transportation, storage, or test precautions;

g) Items that are difficult to procure or manufacture;

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h) Items that have exhibited an unsatisfactory operating history;

i) Items without sufficient history (or similarity to other items that have demonstrated high reliability) to provide confidence in their reliability or maintainability;

j) Items whose past history, nature, function, or processing exhibit deficiencies warranting total traceability.

C.4.3 Section 4.3: Quantitative reliability analysis

Section 4.3.1: Methodology

EPC requires that quantitative RAM analyses be conducted using clearly defined models. The methodology selected should allow all factors that influence the reliability or availability of the equipment to be modeled. EPC also requires that particular attention be paid to common-cause failures and the response of operators to problems. The level of detail shown in the model should equal that achieved in the qualitative analyses (FMEA). The analysis should result in the prediction of the equipment's reliability, the identification of the causes of equipment failure, and the determination of the likelihood of these causes. EPC is prepared to consider the use of any methodology that meets these requirements. In general, the seller will propose to use fault tree analysis, Electric Power Research Institute's (EPRI) GO or UNIRAM methods, or an approach based on reliability block diagrams.

The reliability model of the system or equipment shall be developed and maintained as the design evolves. The components of the model shall be traceable to the functional block diagram, schematics, and drawings and shall provide the basis for accurate mathematical representation of reliability. The nomenclature of items shall be consistent with that used in functional block diagrams, drawings, and schematics; weight statements; power budgets; and specifications.

The model shall be updated with information resulting from reliability and other relevant tests as well as changes in item configuration and operational constraints. Inputs and outputs of the model shall be compatible with the input and output requirements of the equipment.

Section 4.3.2: Data acquisition

The seller will provide the failure and repair rate data for use with the RAM models. EPC will also provide any available relevant data in its possession to the seller upon request. The sources of all data shall be provided to EPC and the use of any data is subject to EPC's approval. Other failure rate adjustment factors for standby operation and storage shall be as specifically agreed to by EPC.

The seller should pay particular attention to

a) Identifying items whose failure rate is anticipated to vary significantly over the equipment's lifetime;

b) Distinguishing between the MLT and the MTTR;

c) Ensuring that logistics and repair times reflect total system or equipment downtimes where a failure triggers system or equipment outages.

The seller shall identify the data in which it has little confidence. Should the predicted reliability or availability be critically dependent upon certain data, EPC may require additional clarification or verification of these data.

Figure C.1—RAM specification (Continued)

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C.4.4 Section 4.4: Maintainability prediction

The seller will predict the maintainability (MTTR) of the equipment using the data employed in the reliability and availability analyses. The prediction should be used to ensure the design and proposed maintenance procedures meet EPC's maintainability requirements, optimize the maintainability requirements, and optimize the maintainability design and other trade-offs. All trade-offs that would compromise the maintainability design should be documented. The use of all data in the maintainability prediction is subject to EPC's approval and possible test; the sources and rationale for all data should be documented.

The maintainability predictions shall be made at a level of detail appropriate for the current design and shall be revised as the design develops.

The accessibility, ease of installation and replacement of parts, large man ways, etc. should also be addressed and incorporated into the design. Operations and maintenance manuals shall have "blow-up" or exploded view drawings showing sufficient detail of parts assembly for easy maintenance of the equipment. By increasing accessibility and ease of maintenance, the MTTR should be decreased.

C.4.5 Section 4.5: Spare parts list

The seller will formulate an optimal spare parts list. This list should not compromise the achievement of EPC's RAM requirements. It should be based on component failure rates, logistics, and repair time resulting from the absence of a spare, the cost of the spare, and the cost of lost generation should an outage result from the failure of the equipment.

C.5 Section 5: Availability demonstration

The seller shall demonstrate a minimum operational availability of 99.9% for the system. The operational availability shall be demonstrated over a five-year period. The time frame shall start with commercial operation (after start-up problems have been resolved) and end at the close of the five-year period. The total time shall be exclusive of planned outages or outages caused by equipment not supplied by the seller. Time for maintenance actions performed on the seller's equipment during planned outages shall be counted. If the operational availability is not met, the seller shall, at its cost, take immediate corrective action to raise the availability to meet this specification. Necessary corrective action may include, but not be restricted to, redesign, replacement with higher reliability parts, or scheduled replacement of wearout items.

C.6 Section 6: Root cause analysis

The seller shall perform a root cause analysis for each service water pump failure that may occur and suggest the appropriate repair or redesign as indicated by the analysis. These analyses and their results shall serve as evidence that the seller is committed to achieving the specified availability goal. These analyses shall be provided for as a part of the seller's proposal and included in the proposed price. Whether the actions suggested from the root cause analyses are taken shall be at the seller's option; however, the availability goal discussed in Section 5 shall be met in any case.

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Annex D

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