ELECTRIC POWER RESEARCH INSTITUTE

2013 TECHNICAL REPORT

Nuclear Maintenance Applications Center: Preventive Maintenance Basis for FLEX Equipment

Project Overview Report

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

YES NO

EPRI Project Manager
M. Bridges

ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue
Palo Alto, CA 94304-1338
USA

PO Box 10412
Palo Alto, CA 94303-0813
USA

800.313.3774
650.855.2121

askepri@epri.com

www.epri.com

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

Asset Performance Technologies, Inc.

NOTE

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

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

Asset Performance Technologies, Inc.
P. O. Box 159
Corrales, NM 87048

Principal Investigators
D. H. Worledge
G. R. Hinchcliffe

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Product Description

This report describes the status of the EPRI Preventive Maintenance Basis Database (PMBD) and recent modifications that will assist nuclear power plant management in responding to new U.S. federal regulatory requirements known as the Flexible Response (FLEX) program. The FLEX program stems from lessons learned about emergency response to disaster scenarios from the Fukushima Dai-ichi earthquake and related tsunami events in Japan. It requires additional equipment to be stored for long periods to supplement existing nuclear power plant defenses in the event of low-probability but extreme environmental conditions, such as large earthquakes and floods. The enhanced PMBD will contribute engineering insights and a valid technical basis for FLEX equipment PM programs.

Background

EPRI nuclear membership are now required to define and deploy strategies that provide flexible responses to extreme environmental scenarios such as large earthquakes or floods as a result of new requirements known as FLEX. The FLEX program stems from the effects of earthquake and tsunami events at the Fukushima Dai-ichi nuclear power plant in Japan. The additional equipment that will perform these responses will likely require somewhat unusual maintenance actions while in standby for long periods, potentially followed by high-intensity usage during disaster response.

To develop PM programs for the most important equipment types using a valid technical basis, utilities require information on the most appropriate tasks and task intervals that address the ways the equipment degrades while accounting for the influences of duty cycle and service conditions. Before the PMBD was developed, these data did not exist in an accessible form—often resulting in arbitrary and unsuitable tasks and intervals that increased maintenance costs and diminished reliability. The PMBD is a natural tool for application to maintenance requirements for the FLEX equipment. However, the FLEX requirements demand additions and format changes to the PMBD which, together with some aspects of the database that have been modified over the years, require explanation in this report.

Objectives

The PMBD is being modified to encompass the equipment and standby conditions of the FLEX program and will continue to serve the nuclear utility maintenance community as an essential reference for PM task selection on common major components. The PM Basis data sets contain maintenance task contents, task interval recommend-dations, and a synopsis of the associated technical basis for all major components. The technical basis states the reasons for each task and the relationship between the equipment's failure locations, mechanisms, and timing and the influences on equipment degradation.

Approach

Expert panels composed of individuals from EPRI, EPRI-member utilities, and manufacturers formulated the bases and range of PM task options presented for the selected equipment. Most of the expert panels for non-FLEX equipment addressed a small number of closely associated component types. However, the FLEX component types mostly consist of several components connected in a skid combination. Several hundred non-FLEX equipment types have been added to the PMBD over a 17-year period, and continue to be added, whereas the anticipated few tens of FLEX component/skid types are being prioritized for inclusion by the needs of utility FLEX programs over a much shorter time. Although the decision to include equipment-specific recommendations is made by the individual expert panels, the EPRI Nuclear Power Division with input from the nuclear membership maintains purview over the project structure and process, selects and prioritizes component types, assists with expert panel member recruiting, and approves the methodology employed for establishing the PM tasks, task intervals, and rationales.

Results

This report describes the objectives, project organization, and the process employed to develop, explain, and use the PM programs and supporting technical bases for FLEX and non-FLEX equipment.

Applications, Value, and Use

The PMDB is an essential reference for utilities seeking to 1) validate their current PM program, 2) perform PM tasks less frequently as part of a living maintenance program, 3) improve PM tasks as appropriate corrective action, 4) improve equipment reliability, 5) develop more consistent PM programs across a fleet of plants, and 6) establish maintenance recommendations for FLEX equipment, either during long-term standby or during intensive use in extreme circumstances. The U.S. NRC in Interim Staff Guidance (ISG) for the FLEX program states that for developing valid technical bases for appropriate PM programs, "This ISG endorses, with clarifications, the methodologies described in the industry guidance document, Nuclear Energy Institute (NEI) 12-06...." NEI-12-06 states that "Standard industry templates (for example, EPRI) and associated bases will be developed to define specific maintenance and testing...."

Keywords

Component reliability
Diverse and flexible coping strategies
Maintenance optimization
Preventive maintenance

Abstract

This project overview report updates the Preventive Maintenance (PM) Basis Database project objectives and content. It explains the process by which the database information is now obtained and describes its current content and use, especially its extension to address the new Flexible Response Program (FLEX) requirements. Since the early days of nuclear power, PM programs in U.S. nuclear power plants have evolved from strict compliance with vendor recommendations with the aim of better matching the equipment operating context and functional importance and thus becoming more economical. Initially, the development of improved PM used judgment and historical information that was previously not well documented, with the result that technical justifications for PM changes were often not sufficiently complete while the programs remained overly conservative. The lack of a comprehensive technical basis has often hindered or even prevented improvements from being made, particularly given the significant costs of such efforts. Nevertheless, considerable advances in PM programs have occurred, partly through use of the PM Basis Database (PMBD) as a source of maintenance recommendations, but the benefits in terms of better equipment reliability, plant availability, and cost-effectiveness have, for many legitimate reasons, remained unclear or mostly qualitative. Over the past two decades, increasing regulatory requirements and consolidation within the industry in response to changing market regulation and competitive cost pressures have led utilities to become more active users of the PMBD, to continually add to the database equipment types, and to make more use of its technical basis and analytic tools. There has been increased recognition of the value of harnessing the collective maintenance knowledge of the industry with the added benefit of being able to project the benefits of PM changes. In consequence, the PMBD has now developed into a major technical resource for supporting changes to maintenance tasks in an evolving regulatory environment.

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Executive Summary

Need and Objectives

The PM Basis project provides the utility user with the technical basis for PM tasks and task intervals and gives information to adapt the recommendations to plant conditions. A recommended PM program, a synopsis of the task content and intervals, and the reasons that these choices are technically valid in a variety of circumstances are presented for every component type in the database—including the special conditions that will apply to the FLEX equipment being added to the database.

The project has always had two major objectives. The first was to summarize industry experience on the tasks and task intervals that make up a sound, cost-effective PM program for a large number of major component types. This provides a starting point for utility analysts based on industry experience. Recognizing that utilities must be able to adapt the recommendations to their own plant history and current operating conditions, the second objective was to make the technical basis for the recommendations sufficiently dynamic so that utility users could modify the recommendations and still preserve a valid technical basis for the changes.

A third objective has arisen as experience with the database has grown. The complexity of industrial equipment means that there exist many ways for the equipment to degrade, driven by many mechanisms and causes that each has its own failure pattern, time scale, and environmental stressors. Potential mitigating actions each address subsets of these degraded states, to greater or lesser effect, and their spheres of influence often overlap to a greater or lesser extent. The result is that it is not easy to determine weaknesses in a PM program and decide how best to improve it. Therefore, a third objective has been to provide easy-to-use diagnostic software that can help the PM analyst to recognize where the gaps in PM exist and to find a better solution that is well adapted to his or her plant conditions. The PMBD dynamically adapts the technical basis to the changes.

The PM Basis Product

PMBD exists as a web-based application with web access security provided by the hosting EPRI servers. This overview report is a sequel to the original 1998 EPRI Overview Report, TR-106857. It is presented in a similar format as an update of the entire project to detail the process by which the PM Basis continues to be developed and to outline its current and potential uses—of which there is a particular focus on applications to FLEX requirements.

The PM Basis was tasked by its original utility steering committee to be a body of information that supports and includes an interpretive summary of utility power plant experience on preventive maintenance for each component type. Each data set should contain, as much as practical in one place, all of the PM tasks, task intervals, task rationales, and the most important influences on equipment degradation and maintenance for that specific component.

FLEX requirements bring additional applications of the PMBD beyond those already in use, for example, 1) to formalize in the PMBD structure the operating experience from other industries on equipment hitherto outside the scope of nuclear power plants, 2) to validate PM recommendations that preserve the functional readiness of the equipment over long periods in a latent or standby condition, 3) to recommend interim changes in PM whenever this equipment is used occasionally for short periods for other purposes, and 4) to recommend maintenance during high-intensity usage in emergency conditions for periods that may turn out to be longer than anticipated. There are also changes in the way that the FLEX program views functional criticality and duty cycle that have obliged modifications in the format and content of the customary PM Templates, for example, greater use of run time instead of calendar time to express task intervals.

As always, the information in the PMBD is intended to complement, not to replace, the PM instructions in vendor manuals and other sources of industry knowledge, such as EPRI Nuclear Maintenance Applications Center (NMAC) reports. In fact, a considerable effort has been made to ensure that information on PM in NMAC reports continues to be well aligned with PMBD recommendations.

Project Organization

In 1996, the original PMBD steering committee, accountable to EPRI's Utility Advisory Committees, was composed of the EPRI project manager, a utility chairman, and 10 other utility members supported by the project staff. The steering committee was granted purview over the structure of the PM Basis project, the prioritization and selection of the component types to be analyzed, the composition of the expert panels, and the methodology employed for the development of the component PM rationales. Although the steering committee ceased to exist after the product became well established, the basic strategy, structure, functions, and information gathering process remain largely the same today even though vastly more equipment has been added. There are, however, some notable additions, mainly of diagnostic software that assists in optimizing a PM program, an improved user interface that plays a similar role, and a significant improvement in quality assurance (QA) measures appropriate for an important industry database.

For each component type, an expert panel of utility component experts continues to provide the raw data on equipment degradation and the range of PM task options for the selected equipment. Each panel is composed of very knowledgeable individuals from EPRI-member utilities, manufacturers, EPRI, and others. FLEX expert panels will need to draw increasingly on sources of such individuals who are not familiar with the constraints and demands of the nuclear industry. Although the expert panels develop the preferred PM practices and raw material on equipment degradation in tabular form, consultants shape the task rationale from the data supplied and submit the resulting data to EPRI and the expert panel members for comment and approval.

Overview of the Expert Panel Workshop Process

The most far-reaching aspects of the process are the means by which equipment types are selected and the QA efforts that are exerted to ensure that only consistently high-quality information goes into the database. Originally, the most fundamental driver of the need for the database was the recognition by utilities that had performed reliability centered maintenance (RCM) analysis during the 1980s that they often did not possess a sufficiently high level of engineering and maintenance expertise on a given component type to be confident in getting the best results. An important function of the PMBD is thus to bring together the most experienced personnel from all over the Unites States, and sometimes beyond, to extract the essential information and present it in a structured way for use across the industry.

For this, the networking capability of EPRI among operating plants, manufacturers, and service companies is unparalleled. The chairpersons of numerous industry task forces, user groups, and ad hoc study groups are polled annually by EPRI project managers to determine priority work and identify the best experts to contribute the knowledge. Experienced RCM facilitators extract this knowledge from the selected experts in small, focused workshops using a 20-step process that has remained stable since the earliest days of the database. Annually, the need for updates is initiated by the consultants who manage the database and is reviewed by NMAC and EPRI project managers who add input from the EPRI advisory structure. Input is also sought from the relevant industry groups that may also recommend updates or new equipment to be added. Prioritization of the final list of requested work is done by NMAC and EPRI personnel to fit overall industry needs, budgets, and schedule.

In constructing the rationale for a PM program, it has been found that a large amount of information is required from the component experts. The information elicitation workshops are for this reason highly structured, closely following a multistep process to ensure disciplined coverage of all of the required aspects.

Information obtained from the expert panels consists of the subcomponents that are the sites of degradation and failure, brief descriptions of the kind of degradation experienced and the main factors that influence it, the time development of the degradation processes and failures, the means to detect equipment condition and to intervene, and the higher level PM tasks that would be used to implement these measures, with their associated line-item task content.

Definitions of duty cycle and service conditions applicable for individual component types differ considerably and are a strong influence on rates of degradation and hence on task intervals. In the PMBD, duty cycle and service conditions are each described by binary categories to enable users to determine which subset of maintenance recommendations they should use. The same Hi/Lo categories for duty cycle are being retained for FLEX equipment even though they are being defined in a way different from non-FLEX equipment.

Other, more qualitative discussion of 1) the risk to reliability of doing intrusive maintenance, 2) the most common failure locations and mechanisms, 3) the principal focus of each PM task, 4) summaries of how the timing of the PM task may be influenced by the time scale of development of the degraded states of the equipment and the performance of other PM tasks, and 5) several TIPs on the tasks that contribute most and least to reliability all provide sanity checks and guidelines that help the less experienced user to appreciate the risks, benefits, and nuances of this complex subject.

The most important elements of the process for developing the rationale for each task are shown in Table ES-1.

Table ES-1
Steps Performed in the PMBD Expert Elicitation Workshop

Workshop Step	Purpose
1. Review relevant NMAC reports.	Ensures compatibility.
2. Decide the grouping of equipment into families.	Aids subsequent efficient generation of other family members.
3. Develop the Component Boundary.	Lists the hardware that is included and excluded.
4. Add notes on Equipment Application and Operating Context.	Explains the unusual duty cycle and service factors that apply to FLEX equipment, but sometimes can be useful for non-FLEX equipment.
5. Define Critical versus Non-Critical functional importance for the component.	Is a major determinant of PM resources that should be applied.
6. Define High and Low duty cycle.	Affects many degradation rates.
7. Define Severe and Mild service conditions.	Affects many degradation rates.
8. Discuss and list possible candidate PM tasks.	Avoids confusion between experts later in workshop.
9. Develop these fields in the FMEA table: - Failure Locations. - Degradation Mechanisms. - Degradation Influences. - Stressors. - Time Codes.	These fields consist of 1) the location of the degraded conditions, 2) a brief description, 3) their causes, 4) stress factors needed to initiate them, and 5) statistical pattern of failure times and rate of degradation. Results are more consistent if all are addressed at the same time for a given mechanism.
10. Complete the Discovery Opportunities field in FMEA if not already added.	Suggests potential PM actions that could mitigate failures.
11. Add typical Repair Times after failure for each row in the FMEA.	Provides a measure of indirect cost of failure.
12. Finalize the recommended PM tasks.	The PM entries in Steps 13 through Step 17 are completed for each of these tasks.

Table ES-1 (continued)
Steps Performed in the PMBD Expert Elicitation Workshop

Workshop Step	Purpose
13. In the FMEA, add the effectiveness (Hi, Medium, Low) of each action in every PM task for the degraded states it can mitigate.	Task effectiveness varies greatly even if actions are done well and at the right time. A task that is very effective for a subset of degraded states frequently also has significant effectiveness for other degraded states.
14. Develop the Task Content for each recommended PM Task.	States line by line what must be done in each PM task.
15. Develop the PM Objective for each task.	Is a high-level summary of why the task is done.
16. Add work-hours to complete each task and the clock hours that the component is out of service during task execution.	Provides a measure of direct PM cost and possible impact on indirect PM cost, respectively.
17. Develop task intervals for each column in the PM Template.	User needs to be able to find the recommended task intervals for his or her combination of functional importance, duty cycle, and service conditions.
18. List the risks of performing intrusive maintenance on this component type.	Provides warning of pitfalls that may help improve training.
19. List the most common causes of failure for this component type.	Provides empirical experience that failures can still occur even when good PM is performed.
20. Develop a list of current industry references.	Provides the most useful and frequently used sources of information on maintaining this equipment.

PM Task Rationale

Once the basic data have been documented, they are screened in various ways to discover 1) the more common types of degradation and failures addressed by each task, 2) the mechanisms most responsible for the timing of the task, and 3) the tasks that have the largest, and the least, impacts on reliability. This analysis also identifies whether the failure rate of the equipment is sensitive to the interval at which the task is performed. Consultants run internal PMBD analysis to validate the task intervals that have been assigned by the expert panel. The technical basis for each PM task is presented under the following headings:

Task Objective: A high-level statement of why the task is done.

Failure Locations and Causes: Provides an overview of the main focus of the task by stating the failure locations and degradation mechanisms that the task is designed to deal with, generally with the most commonly encountered situations described first.

Progression of Degradation to Failure: Summarizes the failure patterns and times of occurrence of the dominant failures. It shows the predominant time periods that are expected to be free of failures for wearout behavior and notes whether random behavior might also be common.

Fault Discovery and Intervention: Explains remaining aspects of the choice of one task over another, significant interactions among tasks, and whether the failure rate is sensitive to the task interval. Task intervals that are not sensitive in this way can offer opportunities for improving cost effectiveness.

The PM Template

Each component data set includes a table—the PM Template—which summarizes the program of tasks and task intervals for the component type in terms of the eight combinations of binary categories of functional importance (Critical/Non-Critical), duty cycle (Hi/Lo), and service conditions (Severe, Mild). Differences stemming from the Non-Critical designation for all FLEX equipment are described in detail. The programs displayed in the Template are technically defensible PM programs, but they may not be the optimum for a particular plant. Each plant should also base its PM program on appropriate vendor recommendations and its own history of preventive and corrective maintenance. For a plant that already has a PM program that is based on its own history, the Template can serve as a baseline for comparison, and the rationale section will probably indicate why their program is appropriate or if it may not be appropriate in some aspects. For a plant that does not have an extensive operating history for a particular component type, the Template can be used in conjunction with vendor recommendations directly as a default program, with gradual changes anticipated as information is fed back in the future from a living program. FLEX equipment is unlikely to have extensive plant history, so it is possible that more dependence may be placed on PMBD recommendations in the early years of its deployment than is customary for non-FLEX equipment.

Analysis Tools

In addition to PM recommendations on several hundred types of equipment, the PMBD is equipped with sophisticated analysis tools. These enable the user to quickly find out exactly which degraded states are best addressed by a given task, which mechanisms contribute the most to equipment degradation, and which contribute the most to in-service failures even when a PM program is in place. One can find this information for any variation of PM tasks and task intervals that are in the database for the component. The PMBD is also configured to show the differences in these results between different PM programs, for example, between the plant's current program and the recommended program. These results are quantitative because the PMBD estimates the contribution of each degraded state to the overall failure rate and the level of mitigation provided by each PM task for each degraded state. The estimated failure rates have compared very favorably when benchmarked against published failure rates from French nuclear power plants.

The value of these software tools is that they provide an immediate "look ahead" when PM tasks are being adjusted. As long as the results are complemented by sound engineering judgment, they provide excellent "X-ray vision" into gaps in mitigation by PM tasks or where overkill can confidently be eliminated with no ill effects on reliability. Use of the software most easily demonstrates the real value of having a detailed technical basis for the PM program.

Uses of the PM Basis

The information in the PM Basis reports was originally intended to be used during large-scale updating of a whole plant PM program. In such an application it would make task selection more efficient, promote consistency among analysts, and support justifications for relinquishing vendor recommendations or for making other changes. It could also be used when modifying any individual PM task as a result of changes in performance, modifications to equipment, or equipment aging.

The PMBD also finds use for validating corrective actions and other goals when these consist of changes to PM. Important aspects include explaining why the task or interval change is the correct response and the most important aspects of the PM activities the task should include.

Many other uses of this information have been implemented by utilities, including support of plant life extension, the systemwide optimization of PM task intervals, and cause evaluation. Most of these uses are informed by the quantitative ranking of competing effects. However, it is important to recognize that the quantitative results are used only to provide guidance to the user as to which PM changes have the most or the least impacts. They are not used for quantitative inputs to risk assessment.

As a repository of industry experience on equipment degradation and PM effectiveness, the PMBD continues to play a major role in preserving good practices in the industry at a time of considerable aging of the workforce and other demographic changes.

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Section 1: Introduction

1.1 Background

EPRI has long recognized the need to provide its members with guidelines and information for maintenance optimization. During the 1980s, EPRI was the first to promote the use of reliability centered maintenance (RCM) in optimizing PM activities in the power industry. As good a tool as RCM proved to be, it was not as completely embraced by the nuclear utility community as it had been by the commercial aircraft industry, where the high resource demands of RCM analysis could be amortized over a fleet of more or less identical airplanes. Due to deregulation of the electric power industry and other demographic and competitive pressures over three decades, many utilities—especially those with nuclear units—recognized that they must reduce operational and maintenance costs to be a low-cost producer of electric power. This trend continues today.

Following the lessons learned from RCM, U.S. nuclear plants have pursued this goal by more closely matching PM tasks with the functional importance of equipment and by focusing on exactly how the actions in a PM task address specific degraded states of the equipment.

Both cost pressures and federal regulation have spurred the need to know the most appropriate tasks and task intervals to address the degraded states of important equipment types while accounting for the influences of functional importance, duty cycle, and service conditions. Commencing in 1996, the PM Basis Database (PMBD) [1] was created to extract this information from the best industry experience available and to make the resulting recommendations and technical basis accessible in a "Template" format. This enables utility personnel to get the benefit of applying RCM principles but in a much more resource-efficient and transparent manner than by performing RCM.

The near-term emergence of U.S. Nuclear Regulatory Commission FLEX program requirements [2] is giving new urgency to the use of the PMBD because the NEI Guidelines [3] for implementation of FLEX regulations encourage the use of the PMBD Template approach when establishing PM programs for different kinds of duty cycles than are encountered in normal plant operation.

1.2 Objectives of the PMBD Project

The project started with two major objectives that are still imperatives today. The first is to summarize industry experience on the tasks and task intervals that make up a sound, cost-effective PM program for a large number of major component types. This provides a starting point for utility analysts based on industry experience. The second objective is to make the technical basis for the recommendations sufficiently dynamic so that utility users could easily modify them but still preserve a valid technical basis for the changes.

A third objective has arisen as experience with the database has grown. The complexity of industrial equipment means that there exist many ways for the equipment to degrade, driven by many mechanisms and causes that each has its own failure pattern, time scale, environmental stressors, and potential mitigating actions. The result is that it is not easy to determine weaknesses in a PM program and decide how best to improve it even when less-than-desirable mitigation can be identified. Thus, a third objective has been to provide easy-to-use diagnostic software that can help the PM analyst to recognize where the gaps in PM exist and to find a better solution that is well adapted to his or her plant conditions. The PMBD dynamically adapts the technical basis to the changes.

1.3 Purpose of This PMBD Overview Report

This overview report is presented as a master report to update the entire PMBD project by describing the current PMBD content and the process by which it is developed and to indicate how it may be used. Section 1 of this report provides the historical context of the PMBD, its motivation and organization, and essential information for understanding the database content. Section 2 contains descriptions of the information collection process, including how special constraints have influenced the workshop data collection process for FLEX equipment. Section 3 describes recent changes in format and content of the database content to accommodate FLEX components. Section 4 describes the most common uses of the PMBD in utility projects such as PM optimization, PM audits, developing a plant PM Basis, and optimizing PM task intervals. Appendix A presents an example of the recently added FLEX Component PM Data Report. This is a printable report, introduced at the request of FLEX users, which can be generated for any equipment type in the PMBD. It contains the technical basis for FLEX PM program recommendations and has been designed to supplement plant-specific FLEX program documentation. Appendix B contains further technical explanations regarding key data fields in the PMBD, such as the coding of degradation time scales.

1.4 Project Organization

In 1996, the original PMBD steering committee was composed of the EPRI project manager, a utility chairman, and 10 other utility members supported by the project staff. The steering committee, through the EPRI project manager, was also accountable to the Utility Advisory Committee for ensuring that all utility needs were considered and met. The steering committee was granted purview over the structure of the PM Basis project, the prioritization and selection of the component types to be analyzed, the composition of the expert panels, and the methodology employed for the development of the component PM rationales. Although the steering committee ceased to exist after the product became well established, the basic strategy, structure, functions, and information gathering process remain largely the same today. There are, however, some notable additions—mainly of diagnostic software that assists in optimizing a PM program, an improved user interface that plays a similar role, and a significant improvement in quality assurance (QA) measures appropriate for an important industry database.

For each component type, an expert panel of utility component experts continues to provide the raw data on equipment degradation and the range of PM task options for the selected equipment. Each panel is composed of very knowledgeable individuals from EPRI-member utilities, manufacturers, EPRI, and others. FLEX expert panels will need to draw increasingly on sources of such individuals who are not familiar with the constraints and demands of the nuclear industry. Although the expert panels develop the preferred PM practices and raw material on equipment degradation in tabular form, consultants shape the task rationale from the data supplied and submit the component report to the expert panel members for comment and approval.

1.5 Overview of the Expert Panel Workshop Process

The most far-reaching aspects of the process are the means by which equipment types are selected and the QA efforts that are exerted to ensure that only consistently high-quality information goes into the database. Originally, the most fundamental driver of the need for the database was the recognition by utilities that had performed reliability centered maintenance (RCM) analysis during the 1980s that they often did not possess a sufficiently high level of engineering and maintenance expertize on a given equipment type to be confident in getting the best results. An important function of the PMBD is thus to bring together the most experienced personnel from all over the United States, and sometimes beyond, to extract the essential information and present it in a structured way for use across the industry.

For this, the networking capability of EPRI among operating plants, manufacturers, and service companies is unparalleled. The chairpersons of numerous industry task forces, user groups, and ad hoc study groups are polled annually by EPRI project managers to determine priority work and the best experts to contribute the knowledge. Experienced RCM facilitators extract this knowledge from the selected experts in small, focused workshops using a 20-step process that has remained stable since the earliest days of the database. Annually, the need for updates is initiated by the consultants who manage the database and is reviewed by NMAC and EPRI project managers who add input from the advisory structure. Input is also sought from the relevant industry groups that may also request updates or new equipment to be added. Prioritization of the final list of requested work is done by NMAC and EPRI personnel to fit budgets and schedule.

In constructing the rationale for a PM program, it has been found that a large amount of information is required from the component experts. It is essential that the expert meetings be used to maximum efficiency to provide this information in a short time. For this reason, the meetings are highly structured, closely following a multistep process to ensure disciplined coverage of all of the required aspects. The process used in the expert panel workshops is shown in Table ES-1 and reproduced here for convenience as Table 1-1.

Table 1-1
Steps Performed in the PMBD Expert Elicitation Workshop

Workshop Step	Purpose
1. Review relevant NMAC reports.	Ensures compatibility.
2. Decide the grouping of equipment into families.	Aids subsequent efficient generation of other family members.
3. Develop the Component Boundary.	Lists the hardware that is included and excluded.
4. Add notes on Equipment Application and Operating Context.	Explains the unusual duty cycle and service factors that apply to FLEX equipment, but sometimes can be useful for non-FLEX equipment.
5. Define Critical versus Non-Critical functional importance for the component.	Is a major determinant of PM resources that should be applied.
6. Define High and Low duty cycle.	Affects many degradation rates.
7. Define Severe and Mild service conditions.	Affects many degradation rates.
8. Discuss and list possible candidate PM tasks.	Avoids confusion between experts later in workshop.
9. Develop these fields in the FMEA table: - Failure Locations. - Degradation Mechanisms. - Degradation Influences. - Stressors. - Time Codes.	These fields consist of 1) the location of the degraded conditions, 2) a brief description, 3) their causes, 4) stress factors needed to initiate them, and 5) statistical pattern of failure times and rate of degradation. Results are more consistent if all are addressed at the same time for a given mechanism.
10. Complete the Discovery Opportunities field in FMEA if not already added.	Suggests potential PM actions that could mitigate failures.
11. Add typical Repair Times after failure for each row in the FMEA.	Provides a measure of indirect cost of failure.

Table 1-1 (continued)
Steps Performed in the PMBD Expert Elicitation Workshop

Workshop Step	Purpose
12. Finalize the recommended PM tasks.	The PM entries in Steps 13 through Step 17 are completed for each of these tasks.
13. In the FMEA, add the effectiveness (Hi, Medium, Low) of each action in every PM task for the degraded states it can mitigate.	Task effectiveness varies greatly even if actions are done well and at the right time. A task that is very effective for a subset of degraded states frequently also has significant effectiveness for other degraded states.
14. Develop the Task Content for each recommended PM Task.	States line by line what must be done in each PM task.
15. Develop the PM Objective for each task.	Is a high-level summary of why the task is done.
16. Add work-hours to complete each task and the clock hours that the component is out of service during task execution.	Provides a measure of direct PM cost and possible impact on indirect PM cost, respectively.
17. Develop task intervals for each column in the PM Template.	User needs to be able to find the recommended task intervals for his or her combination of functional importance, duty cycle, and service conditions.
18. List the risks of performing intrusive maintenance on this component type.	Provides warning of pitfalls that may help improve training.
19. List the most common causes of failure for this component type.	Provides empirical experience that failures can still occur even when good PM is performed.
20. Develop a list of current industry references.	Provides the most useful and frequently used sources of information on maintaining this equipment.

1.6 Component Expert Panels

The steering committee recommended that each expert panel consist of a minimum of 4 utility members to ensure a reasonably diverse experience level. It was found that panel sizes of 6 to 8 total members were ideal and panel sizes above 10 were too difficult to manage efficiently. Where possible, each expert panel was composed of utility personnel with collective experience in component and systems engineering, reliability engineering, and PM improvement to endeavor to produce recommendations focused on PM program improvement and not just on individual component maintenance.

Each panel met once for 3 to 4 days on average and initially began with a minimal level of understanding of the process. Each panel was given an outline of the PM Basis process and experienced its own learning curve while implementing the process, facilitated by two consultant personnel. By the end of the 4-day meeting, they were usually quite efficient at compiling the required information. It should be noted that although a few members were skeptical at first, all panel members have indicated concurrence with the process. Experience showed that between 2 and 2 and 1/2 days were required to complete the basis for the first, most complex, component to be considered by a panel. Subsequent components were much faster, taking advantage of the panel's learning curve and the results previously documented.

On rare occasions, because of last-minute emergencies, an expert panel has had as few as 2 members. Although the project did not plan for this small number, it is felt that 2 experienced engineers could still provide a high-quality set of data sufficient to meet project needs—at least until the data set was later updated in the normal way.

The recommendations of these expert panels represent a consensus of time-directed, condition monitoring, and failure finding PM tasks with supporting technical basis. Consensus here does not necessarily mean finding the "best" PM task; it means reaching agreement on a range of tasks and task intervals with an agreed-upon technical basis derived from industry experience.

1.7 Definition of Preventive Maintenance

When developing the PM Basis project, project staff quickly realized that there is no consistent definition for *preventive maintenance* among plant maintenance personnel. Broadly speaking, *preventive maintenance* is the conduct of preplanned (that is, scheduled) tasks necessary to ensure safe and reliable operation of the equipment. PM is the total aggregation of these scheduled tasks along with their assigned task intervals. The term *PM* includes such tasks as oil sampling, vibration monitoring, visual inspection, lubrication, and the scheduled removal and replacement of parts **prior to equipment failure**. Even when an overhaul is not scheduled (that is, scheduled and completed at some fixed time interval), it could be considered a PM task if it is performed as the result of another task (for example, vibration monitoring or oil sampling) whose primary purpose is to monitor equipment condition and detect a severely degraded condition. As long as the failure has not already occurred, the overhaul then becomes part of the action taken to prevent a failure. In contrast, overhauls resulting from the occurrence of failures are considered corrective rather than preventive maintenance.

The vast majority of PM tasks merely discover degraded subcomponents before they fail. Lubrication is a rare example of an action that prevents undesirable levels of degradation from developing in the first place. The PM tasks called *Failure Finding Tasks* are designed to discover whether standby equipment has already failed. In the latter case, the task has not prevented failure but does prevent the accumulation of an extended period of unavailability. This is the only sense in which pure failure finding is still a preventive task. The PM Basis database recognizes two broad classes of PM task: Condition Monitoring and Time-Based. Failure finding tasks are almost always time-based and frequently contain activities that also detect some degraded subcomponents before failure and thus also improve reliability as well as availability. These terms can thus be seen as quite ambiguous and are therefore not very useful. Another example of ambiguity: in the absence of truly continuous monitoring, most condition monitoring tasks are time-based. Even when monitored continuously, the data accumulated are sometimes assessed only periodically. As a result of these kinds of ambiguity, the PMBD makes little use of these task labels. Furthermore, PM can be performed by a variety of plant personnel, for example, Operations or Engineering—not only by Maintenance Department personnel.

To maintain a consistent focus and provide a common starting point, the following definition for PM was adopted for the PM Basis project:

Preventive maintenance is considered to be comprised of any tasks that are planned and scheduled or performed continuously, whose purpose is to prevent the unanticipated failure of a component after its introduction to service, by monitoring or inspecting equipment condition, replacing or refurbishing pre-specified subcomponents prior to their failure, or the functional testing of such equipment to determine its ability to function upon demand.

It is important to note that acceptance and qualification testing performed before new equipment is placed into service is excluded from this definition.

1.8 Overview of the Technical Basis for PM

If a task is done to supplement other tasks judged inadequate to ensure reliability or because it can better replace other tasks (that is, it is easier or cheaper), these are circular arguments unless they include explicit statements about degraded states of the equipment that the task can address. This implies several things: 1) there must be knowledge of the degree to which it can mitigate degraded states of the equipment, 2) it may also mitigate to some degree other degraded states for which it would not be the preferred means of mitigation, 3) the level of mitigation will progressively decrease if the task is not done in time, and 4) the level of mitigation may depend on the severity of the service conditions even if it is done in time. The latter is probably the result of severe conditions producing faster degradation. The technical basis for a PM task in the PMBD has therefore been designed, as a minimum, to:

1. List the degradation mechanisms of each subcomponent that can fail
2. Describe the causes of each degradation mechanism
3. State the wearout or random pattern of failure involved
4. Show the time scales for different classes of wearout mechanisms
5. State stress factors that are especially important in promoting the degradation

6. Include acceleration of wearout depending on stress factors
7. State how effective each task would be in mitigating each degraded state if done in time
8. Include how late performance of a task diminishes its effectiveness
9. Include information on how each degraded state could be discovered or prevented

Database technology enables the interaction among these variables to be examined for individual PM tasks and groups of tasks as a function of task intervals.

The data set for each PMBD component contains, as much as practical in one place, all of the PM tasks, task intervals, task rationales, and the most important influences on equipment degradation and maintenance for that specific component. This body of information provides additional context and perspective when plant personnel are seeking to interpret vendor requirements in light of plant-specific conditions or when they need to understand the motivations for and limitations of PM tasks when modifying task content or extending task intervals.

In many instances, the information can be used in concert with input from the manufacturer to understand how vendor requirements might be relaxed in specific circumstances. The information in the PM Basis reports is intended to complement—not replace—the PM instructions in vendor manuals. If changes to PM tasks are being introduced that conflict with vendor recommendations, all of the relevant industry information sources such as Vendor Bulletins, Generic Letters, Information Notices, SERs, and SOERs should be consulted as well as the history of performance and as-found condition reports at the plant in question.

The boundary of each component shows the hardware that is included and excluded. Binary definitions are given for Functional Importance (Critical/Non-critical), Duty Cycle (High/Low), and Service Condition (Severe/Mild) (collectively referred to as the *operating context*) that characterize the PM recommendations for the component type. There are thus 8 combinations of critical and non-critical functional importance, high and low duty cycle, and severe and mild service conditions; that is, there are 8 possible operating contexts. These 8 combinations (such as "Critical components with a High duty cycle and Severe service conditions, or CHS") help the user to select the most appropriate set of PM recommendations to match a component's operating context at his or her plant. The PM recommendations are presented in the concise Template format shown in Table 1-2. Explanatory notes provide the objective, focus, task content, and timing aspects for each PM task.

Table 1-2
Example PM Template Task Intervals for 8 Combinations of Operating Context

Non-FLEX Headings	CHS	CLS	CHM	CLM	NHS	NLS	NHM	NLM
Calibration	1Y	2Y	2Y	3Y	6Y	6Y	6Y	10Y
Inspection	4Y	6Y	6Y	8Y	6Y	10Y	10Y	10Y

The recommended content of each PM task is derived from a tabular summary of the degradation mechanisms of each subcomponent that is known to degrade. These are obtained by direct interviews with the expert panel members and comprise 1) Failure Location (where degradation is most likely to occur), 2) Degradation Mechanism (the degradation mechanisms), 3) Degradation Influence (the factors that cause the degradation), 4) Time Code (how the degradation progresses over time), 5) Stress Factors (factors that affect this progression), 6) Discovery and Prevention Opportunities (opportunities to recognize the status of the degradation), and 7) the effectiveness of PM strategies that could be employed to prevent the degraded state from becoming an in-service failure.

Table 1-3 shows a few rows of the component-focused portion of the degradation table for a Volute Casing Type of Single-Stage Horizontal Pump with Mechanical Seal and Rolling Element Greased Bearings. It shows the Failure Locations, Degradation Mechanisms, Degradation Influences, Discovery Opportunities, Stressor Factors, Time Codes, and Repair Times.

Table 1-3
Examples of Degraded States for Pump - Horizontal - Single Stage - Single Suction - Volute Casing Type - Mechanical Seal - Rolling Element Bearings - Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Discovery Opportunity	Stressors	Time Code	Repair Time
Bearing Seals - Lip	Wear	Normal wear	Inspection	D	UW10	12
Bearing Seals - Lip	Wear	Improper installation or material defect	Inspection		R	12
Bearing Seals - Lip	Wear	Imbalance or misalignment of shaft	Inspection		R	12
Bearing Temperature RTDs, if present	Open circuit	Age	Inspection, Calibration, Electrical tests		UW20	2

Table 1-3 (continued)
Examples of Degraded States for Pump - Horizontal - Single Stage - Single Suction - Volute Casing Type - Mechanical Seal - Rolling Element Bearings - Grease Lubed

Failure Location	Degradation Mechanism	Degradation Influence	Discovery Opportunity	Stressors	Time Code	Repair Time
Bearing Vibration Probes, if present	Open circuit	Age	Inspection, Calibration, Electrical tests		UW20	2
Bearings - Rolling Element (radial and thrust)	Wear - fatigue	Degraded lubricant – contamination, for example, water ingress	Pump bearing temperature, Vibration	C	R	12
Bearing Seals - Lip	Wear	Normal wear	Inspection	D	UW10	12

This table of degraded states and their characteristics resembles the Failure Modes and Effects (FMEA) table familiar in engineering design, equipment reliability, and failure analysis studies. The table used in the PMBD is often referred to as an FMEA, but there are many significant differences—mostly because it is an equipment-level treatment that focuses on degradation and PM mitigation rather than on failure and system/plant consequences. In the PMBD it is usually referred to as the *Degradation* table or the *PM Equipment Analysis* table. System and plant consequences of equipment failure are addressed by the assignment of functional importance and its use in the 8 columns of operating context used in the PM Template.

In the PMBD, the degradation information is supplemented by a list of the component's most common failure locations and failure mechanisms to assist the user in understanding the principal influences that drive maintenance actions. When equipment is Run-To-Failure, every significant degraded state will produce a failure at some point. The aim of a given PM task is to intervene in this process for some subset of degraded states so that these failures are mitigated to a large degree. The PMBD explicitly represents the degree of effectiveness of each PM task for each degraded state it is capable of addressing.

Industry consensus may eventually be gained as the task bases and task intervals contained in each component data set are reviewed and used by the utility community. To this end, each data set is reviewed every few years to determine when updates are needed. For some component types, these updates can occur every two or three years before the technical community is satisfied that all outstanding issues have been addressed. Other component types are updated less frequently.

1.9 The Vulnerability Algorithm

In addition to PM recommendations on several hundred types of equipment, the PMBD is equipped with sophisticated analysis tools. These enable the user to quickly find out exactly which degraded states are best addressed by a given task, which mechanisms contribute the most to equipment degradation, and which contribute the most to in-service failures even when a PM program is in place. Furthermore, one can find this information for any variation of PM tasks and task intervals in the database for the component. The PMBD is also configured to show the differences in these results between different PM programs, for example, between the plant's current program and the recommended program. These results are quantitative because the PMBD estimates the contribution of each degraded state to the overall failure rate and the level of mitigation provided by each PM task for each degraded state of the equipment. The estimated failure rates have compared very favorably when benchmarked against published failure rates from French nuclear power plants.

To use Vulnerability, the user selects the equipment type of interest and assigns the operating context by first selecting the appropriate combination of criticality, duty cycle, and service conditions. If Severe service conditions are selected, the user must also assign one or more service stressors (for example, high temperature or high vibration) responsible for the Severe characterization. The set of PM tasks and intervals from the appropriate column of the PM Template is then displayed, and the user is able to edit the task intervals. The Vulnerability software analyzes the PM program by comparing the task interval for each PM task with the timing information in the degradation table for each degraded state that task can address. It makes adjustments to the rate of degradation using the stress factors the user has selected, for whichever degraded states they affect, and assesses the level of mitigation each task will provide. When the results for all tasks and possible degraded states are combined, the result represents a good estimate of the failure rate, given the stated PM program.

There are well-known uncertainties associated with actuarial estimates of failure rates and the long timeframes and component exposures over which plant experience must be accumulated to obtain reasonably accurate historical estimates. When combined with ambiguities resulting from definitions of failure and lack of knowledge of which PM tasks have actually been performed, how frequently, and how well (in both published results and in plant experience), it becomes very difficult to align published values of equipment reliability (that is, failure rate or mean time between failures [MTBF]) with plant experience in any manner that illuminates the effectiveness of a PM program. Attempts at direct correlations of the numbers of equipment failures in a given plant with changes in the PM program are affected by many of the same difficulties. It is therefore very useful to have in the PM Basis Database a computer-aided decision process that can be deployed prospectively when potential adjustments to the PM program are actually being made.

The value of the Vulnerability analysis is that it provides an immediate "look ahead" when PM tasks are being adjusted, for whatever reason. As long as the results are complemented by sound engineering judgment, the estimates of overall failure rate and the contributions to it from each potential degraded state provide excellent "X-ray vision" into where gaps in mitigation by PM tasks exist and where overkill can confidently be eliminated with no ill effects on reliability. It demonstrates the real value added by having a detailed technical basis for the PM program.

1.10 PM TIPS

PM TIPS present information regarding the PM tasks that are very important in the overall PM program and also regarding those that are much less important. This information may be helpful when there is a need for further customization of the Template recommendations for specific site conditions. The TIPs are developed by consultants after the expert elicitation workshop by running PMBD algorithms for specific PM programs taken from the PM Template. Because the importance or otherwise of a PM task can depend significantly on the operating context, the TIPS are developed for the critical, high duty cycle, severe service operating context with all stress factors turned on. This ensures a conservative approach. However, the Vulnerability capability should always be used to verify the suggestions made in TIPS for the particular circumstances that apply. A full description of the TIPS can be found in Section 2.2.

Section 2: The PMBD Information Elicitation Process

2.1 Overview

This section describes the process that is followed to elicit information for a given component type from plant engineers in the expert panel workshop. It therefore includes development of the technical basis for each PM task. The basic premise is that the rationale for why a PM task has a certain content, focus, and time interval can be understood by asking which PM activities can most effectively address each of the causes of degradation and failure for the component. This information is well known by component engineers, system engineers, and maintenance engineers and technicians who are experienced in the types of failures that have occurred historically in power plants and the variety of subcomponent deterioration that has been observed in the industry during the performance of preventive and corrective maintenance over a long period of time. This information can be retrieved by first discussing with them the parts of the equipment that typically degrade or fail if no PM is performed, the mechanisms that are usually responsible for the degradation, the factors in the physical or operational environment that have the most effect in initiating the degradation or in making it more severe, and how long the deterioration can be expected to progress before it becomes unacceptable or results in a failure. Subsequently, the discussion can move on to the kinds of PM techniques or activities that have the best chance of discovering the degraded conditions, how effective they would be under normal circumstances, and which higher level PM tasks should include these activities.

After this information has been obtained and documented, it can be screened in various ways to discover the more common types of degradation addressed by each task, the tasks aided by other PM tasks that address the same failure locations and conditions, and the tasks that are most and least important in providing overall mitigation of failure events in service. This analysis also identifies whether a logical time interval exists for each task that is determined by the time scales of occurrence of the failures that are addressed.

For each component type, the first three of four key steps in this process occur in a workshop-like format in which skilled facilitators elicit the information from the experiences of a small number of utility plant engineers. The focus in the workshop is first on information at the level of the component as a whole, such as definitions of what is included in and excluded from the component boundary and usable definitions of functional importance, duty cycle, and service conditions that span the whole range of applications envisaged for the equipment.

Second, the focus turns to how and why the equipment degrades. This part of the workshop typically takes the most time and is developed in a table often called the *Failure Modes and Effects Analysis* (FMEA). However, for several reasons the term is not well chosen for this application. The reasons for this are important to understanding the nature of the process and will be described later in this section.

The third key part of the workshop consists of characterizing each PM task by the effectiveness with which it mitigates each of the degraded states, describing its objectives and the work-hours required to implement it, and developing a comprehensive account of what PM personnel should be looking at and for when implementing the task. This part of the workshop also prepares a summary of the whole program of such tasks in a table called the *PM Template*, in which the experts develop the task intervals for each task in a variety of different operating contexts.

Supplementary information, such as a discussion of the risk to reliability of doing intrusive maintenance and the most common failure locations and mechanisms are also added at this late stage by the workshop participants.

The fourth part of the overall process is carried out by the facilitators after the workshop is over. This activity 1) completes editorial details, 2) determines, by running the Vulnerability software, the principal mitigating aspects of each PM task (that is, the most likely degraded states that are the most strongly mitigated by the task), 3) describes the time progression of these degraded conditions, 4) determines the sensitivity of the component's failure rate to the task interval at which the task should be performed, and 5) develops the PM TIPS to give the user an idea of the most and least important of the PM tasks in the recommended program. This post-workshop phase is also capable of uncovering discrepancies that create internal inconsistencies when the Vulnerability software is run. For example, stressor factors or time codes may have been inserted incorrectly, or the reliability of the component may be found to be significantly improved if a certain PM task can be performed at a reduced time interval that was not recommended by the expert panel members.

The data set is finally reviewed by the EPRI project manager and expert panel members. When all comments have been included and discrepancies corrected, the data are loaded into the PM Basis Database and scheduled for release to EPRI-member utilities at a future time.

In what follows it will be observed that terms such as *degraded state, degradation mechanism, deterioration, failure cause, failure mechanism*, and *failure type* are used more or less interchangeably to indicate the process that leads to failure. *Degradation* is usually the preferred usage. Despite this, it is conceptually important to remember that a degraded state only becomes a failure of the component if the mitigating PM tasks are not performed in time or if they are not done properly.

The terms *task basis, technical basis*, and *task rationale* are also used interchangeably. It has been found that no purpose is served in this work by attempting to be more precise about the employment of these terms.

Failure modes of equipment, such as those used by the EPIX/ICES database [4] and reporting system and familiar in probabilistic safety analysis (for example, *fails closed*, *fails to run*, and *fails open*) are not used extensively in this work. PM tasks primarily address the *degradation* of equipment (for example, corrosion or a bent valve stem), and it matters little to a PM task in which mode the equipment eventually fails. Most degradation mechanisms can affect more than one failure mode—perhaps most or all of them, as is the case of corrosion or a bent valve stem. Although consideration of failure modes can be of value in deciding whether certain component failures can be tolerated (for example, "failed closed" may be functionally critical, whereas "failed open" may be a "fail-safe" mode), there are generally no PM tasks that are specific to "failed open" but not to "failed closed." Consequently, apart from a short experiment with the use of failure modes in the early life of the PMBD, these failure modes have not been found useful in developing a PM Basis.

The PM Basis has been prepared for components that are generally quite complex pieces of equipment. The general term adopted in this report for the hardware at this level of description (for example, medium-voltage switchgear), is *Equipment*. Subcomponents such as bearings, shafts, coils, gaskets, and stator windings, which are the sites of specific degradation processes and ultimate failures, are referred to as *Failure Locations*. The terms *Component* or *Component Type* are used interchangeably with either of these meanings, depending on the context.

2.2 The Expert Panel Workshop

Table 1-1 in Section 1 provides an overview of the steps involved in the expert panel meeting. Each step in this process is described in more detail next.

Step 1. Review Relevant NMAC Reports.

In many cases, failure cause and maintenance data from applicable EPRI NMAC Equipment and Maintenance Guides were briefly reviewed by project personnel before the expert panel meetings to promote consistency in terminology and treatment as far as possible. Additional materials such as service manuals and PM task procedures were also reviewed from time to time when easily available, as well as vendor information on the Internet regarding the design and size variations of equipment models and for general familiarization with the equipment and auxiliaries. The expert panel always determined the final choice of equipment types and their hardware breakdown.

Step 2. Decide the Grouping of Equipment into Families.

Early in the life of the database, the expert panel was often responsible for deciding how a broad group of equipment should be addressed. The expert panel would determine if the component type needed to be subdivided into logical groups by design characteristics. For example, it was decided that pumps should be divided into a "vertical pump" group, a "horizontal pump" group, and a "positive displacement pump" group because these types of pumps have enough design and maintenance differences between them to warrant separate treatment, yet each addresses a sufficiently generic set of equipment to enable a single treatment to be made for each group without further subdivision. In many cases, alternative subcomponents were included that would not be present in some applications. The user was expected to decide which ones apply, for example, horizontal pumps with oil-lubricated bearings and those with greased bearings.

Each of the various major groupings of equipment, for example, "vertical pump," was then treated to the multistep process separately. As the database matured, the major groups of equipment became more clearly defined by the industry network of advisors before the workshops took place and component types became more differentiated as to the type of lubrication, bearings, cooling, and so on. The benefit is that estimates of failure rates and leading contributions to failures become more specific as double-counting from extraneous subcomponents is reduced. This differentiation process has become quite frequent during periodic updates of component data sets. It has always been the practice for the workshop experts to select the most complex item of equipment to be analyzed first. Other members of that equipment family can then be developed efficiently by editing the larger data set.

Step 3. Develop the Component Boundary.

The definition of the equipment boundary and the components and subcomponents to be included when considering degraded states and PM tasks was made so that it is clear whether auxiliary devices such as external lubrication systems, interfacing components such as pump/driver couplings, and various control and instrumentation components are included or excluded from the PM Basis reports.

Step 4. Add Notes on Equipment Application and Operating Context.

These fields were added to provide an opportunity to explain particular aspects of the equipment that may limit its range of applications or for which the operating conditions differ from what might be expected for normal plant equipment. This is particularly important for FLEX equipment, although it may also be used when needed for non-FLEX equipment.

Step 5. Define Critical and Non-Critical Functional Importance.

To efficiently deploy maintenance resources, components are separated into two groups: 1) those that are functionally so important that it is worth spending considerable PM resources to prevent them from failing and 2) those for which only the spending of considerably lower maintenance resources can be justified. The former are referred to as *critical* components, the latter as *non-critical*. *Critical* components can be critical because of their functional importance to safety or to electricity generation or both (or on the basis of certain other user-defined criteria). Generally, a comprehensive level of PM has to be developed for critical components so that, as far as is practical, all failures are prevented.

Non-critical components may require some level of PM rather than permitting them to fail because the costs of at least some of their failures are not negligible, even though these costs are nowhere near as large as for the critical group. The PM objective is to control the reliability of non-critical components at an appropriate level, generally by preventing the most common types of failures using relatively inexpensive PM tasks.

The differentiation between critical and non-critical components depends on the plant management's risk aversion, but some guidelines are appropriate. These often vary depending more on the kind of plant and industry rather than on the kind of equipment. Relatively stable guidelines for all commercial nuclear power plants are provided in this data field; therefore, the definitions of *critical* and *non-critical* components rarely change for different component types in these plants. However, the guidelines do vary somewhat in their details for fossil power plants and for transmission and distribution assets—but they are still generally applicable to these and even other industrial installations. Although these definitions may vary among plants and industries, following RCM good practice, it is still valid to assign the most stringent PM recommendations to the most critical assets and to apply less stringent PM to non-critical assets.

Following the guidance in INPO AP-913, Revision 4 (pending) [5], component types that provide functionality under extreme emergency conditions in the FLEX program are all designated as non-critical, without exception. However, even in the FLEX program there exist two broad categories of equipment known as *FLEX Equipment* and *FLEX Support Equipment* (see explanation in Section 3.3), which have different redundancy requirements that may lead to some strategic differences in PM requirements. For ease of presentation, the PMBD will continue to use the binary critical/non-critical database structure to address these two groups of FLEX component types with suitable changes to on-screen labels that make the distinction clear.

A third group of components can be referred to as the *Run-to-Failure* group (or *Run-To-Maintenance* as in INPO AP-913, Revision 4) for which PM is neither functionally nor economically justifiable. The PM programs addressed by the PMBD obviously do not apply to the Run-to-Failure components, but the critical and non-critical types are both addressed.

Step 6. Define High and Low Duty Cycle.

The PM Template is organized so that particular duty cycles such as standby operation versus continuous operation can have an influence on the PM recommendations. The duty cycles that impact PM strategies were established at this point in the process, although it was sometimes necessary to revisit the definitions at a later stage. For consistency in using the Template, there was always provision for two duty cycles termed *High* and *Low*. This adequately covered all of the cases encountered, although occasionally two choices for duty cycle were not needed. For example, it was determined that all spring-actuated safety relief valves fell into the *Low Duty Cycle* class.

Step 7. Define Severe and Mild Service Conditions.

The PM Template is also organized so that particular service conditions such as being exposed to the weather and outside environmental stressors can have an influence on the PM recommendations. The service conditions that impact PM strategies were established at this point in the process, although it was sometimes necessary to revisit the definitions at a later stage. For consistency in using the Template, there was always provision for two sets of service conditions termed *Severe* and *Mild*. This adequately covered all of the cases encountered, although occasionally two choices for each were not needed. For example, it was determined that all spring-actuated safety relief valves are operated under Severe service conditions.

Some components required very careful definitions of *duty cycle* and *service conditions*, occasionally involving an interaction between them. For example, motor-operated valves incorporate a pressure drop consideration in the duty cycle definition. These valves also require a separate use of the Template for task intervals for the actuator and the valve whenever there is a significant pressure drop.

Step 8. Discuss and List Candidate PM Tasks.

At this point, it was also necessary to develop a preliminary list of PM tasks. Without such a list, there could be significant confusion in the expert meeting as to whether a certain technology is generically applicable as a recommended PM task in the PM Template and whether a specific PM activity would be performed under one strategic-level PM task or another. In addition, a given task at one plant (for example, *Detailed Inspection*) might be known in another plant as *Inspection* or even *Annual PM*. Similarly, two tasks known as *Inspection* in different plants may actually refer to different sets of activities, or the same task may be legitimately split into separate tasks at another plant. The expert panel members will eventually become engaged in a lot of detailed work relating to the line item activities for each recommended strategic-level PM task. This step offers an opportunity to discuss these issues and resolve such task allocation and terminological difficulties before much work is done on any of the tasks.

The higher level task labels such as *Refurbishment* or *Functional Test* are normally referred to in the PMBD as *PM tasks* or *PM strategies*. Line items that might be included in these PM tasks, such as "inspect and clean fuse holder," are normally referred to as *line items* or *activities*. Occasionally, a single activity such as "inspect and clean filter" is the main focus of the task and practically the only thing that is done in the task. Such a case would then be made into a higher level PM task such as *Filter*, *Clean*, and *Inspect*.

At this early point in the expert meeting, only the main headings for the PM tasks and a preliminary idea of the task content were required.

Step 9. Develop Failure Locations, Degradation Mechanisms, Degradation Influences, Stress Factors, and Time Codes.

Each subcomponent that is known to be a point of failure is considered in turn, with added information on the type of degradation, its causes, its statistical failure pattern (that is, random or wearout), stressor factors, and failure timing—all documented in a tabular format. The expert panel does not include speculative kinds of failures, as the PMBD should contain only types of failures that are known to have occurred somewhere in the industry.

For each failure location, the panel will assign the main degradation processes, the causes and stressors that most influence the degradation, and the time characteristics of the progression to failure. This information is documented in a table (see Table 1-3) by the meeting facilitators, on a large screen so that everyone can see and discuss it. Section 3 of Appendix A and Appendix B contain further information describing this process and the various table entries. The essence of this methodology is that the dependences between these characteristics are coded into the table to be interpreted by the Vulnerability algorithms for use over the full range of duty cycles and service conditions addressed in the PM Template.

Step 10. Complete the Discovery Opportunities Field.

This part of the table is completed by adding one or more Discovery Opportunities for each of the degraded failure locations. Sometimes these correspond to observing the degradation process in progress before the failure point is reached, as when monitoring increasing vibration levels. At other times, they could be actions that, if performed proactively, will find deficiencies such as leaks or wear that require maintenance action before a functional failure point is reached. If they correspond to finding failures that have already occurred, this corresponds—through a Failure Finding action—to an opportunity to limit the equipment unavailability that would otherwise have accumulated. The purpose of these discovery opportunities is to identify the physical act (for example, inspection) or measurement but not necessarily the PM task during which the action would be taken (for example, refurbishment), although sometimes these coincide (for example, vibration monitoring). When the panel believes that such an action is not universally applicable, the action can still be listed as a Discovery Opportunity but may not be recommended as part of a PM task.

Step 11. Add Typical Repair Times Following Failure for Each Row in the FMEA.

Each row of the table of degraded states displays one way in which the equipment can fail in service. A critical component will need to be repaired or replaced as soon as possible. The duration of such a repair when performed by a typical crew will provide a sense of the minimum time over which the indirect costs (for example, plant production losses, if any) of the failure will accumulate. To this can be added the typical times taken to diagnose the failure, to realign and tag out associated equipment, and to reverse the process after the repair, plus time for post-maintenance testing and regaining full production levels in the plant. All of these periods are variable quantities for which reasonable (that is, conservative but not too pessimistic) estimates can be made in specific cases. However, the actual wrench times for repair are extremely variable, from a fraction of an hour to hundreds of hours in many cases. One cause of this variability is the degree of wear or damage that has to be repaired, but another is provided by the particular failure location and degraded state that causes the failure. This quantity cannot be known before the next failure occurs. However, the expert panel can provide an estimate for this wrench time under average circumstances for each degraded state. This parameter provides one gauge of the likely cost of the various failures that can occur. Long repair or replacement times obviously are important in determining spares requirements and are markers that show where extremely effective PM mitigation is most needed.

Step 12. Finalize the Recommended PM Tasks.

Step 11 marks the end of work focused on the degraded states of the equipment that can arise over time. Most of the remaining effort in the workshop goes into characterizing the recommended PM tasks. This step now engages the panel in selecting the PM tasks that are to be recommended from the preliminary list of candidate tasks prepared in Step 8. Changes are made as necessary now that the experience of completing the descriptions of the degraded states has provided a common perception of the challenge that the PM program has to face. Each recommended PM task heads a new column at the right-hand edge of the table of degraded states.

Step 13. Add the Task Effectiveness of PM Tasks.

This step requires the expert panel to work with one PM task at a time. Going down the column for that task, at each row in the degradation table the panel decides whether some action in the scope of the task can discover the degraded state to a degree that will lead to its being repaired. If so, they insert an *H* (High Effectiveness) if they believe that the task is almost certain to lead ultimately to restoring the degraded condition to a “good as new” condition (or almost as good as new). They insert an *L* (Lo) if the likelihood of discovery and restoration is no better than about 50% and an *M* if they believe that the chance of discovery and restoration is between high and low, about 80%. The meaning of this is that for a degraded state that is nominally addressed by a PM task with medium effectiveness, there will be a 20% chance that the condition is not repaired so that a failure will occur despite the PM task being performed. No H, M, or L is inserted if the task is not able to detect the degraded condition.

Each of the recommended PM tasks is evaluated against all of the degraded states in this way. Two cautions must be observed when doing this. The first is to keep in mind that the entry must be the "intrinsic" task effectiveness that applies, assuming that the task is done "in time," that is, assuming that the task is performed when the degraded state is observable (visible, testable, measurable) but not so late as to invite almost certain failure. The second is that the task action is directed at the degraded state of a specific subcomponent and not at its cause, which is usually unknowable when the task is being performed. Therefore, it is good practice to hide the Degradation Influence column while the task effectiveness entries are being developed. Nevertheless, it sometimes happens that because of the briefness of the format, the Degradation Influence may offer a clue about the nature of the degraded state that is not evident from the entry in the Degradation Mechanism field. The facilitators should keep alert to this possibility while the panel members are focused only on the Failure Location and Degradation Mechanism.

Step 14. Develop the Task Content for Each Task.

The Task Content for each PM task is an outline of the generic items it should include to encompass all available opportunities for identifying deterioration of the equipment and providing appropriate intervention. The list of task contents is not intended to be exhaustive in the sense of including PM actions that are specific to a particular make or model. Therefore, it is not equivalent to a procedure, and it does not explain how to perform the actions. Specific information on how to perform the task is contained in the appropriate vendor manuals and NMAC Equipment and Maintenance Guides.

Two forms of task content have been used historically. In the early years of the database, the task content was developed as a list of actions determined during the workshop by the expert panel members. To save time, this evolved into a list of key actions determined by the panel, which was extended by consultants after the workshop. More recently, in response to consultants' concerns about completeness, this format of task content has been augmented by adding a list of every degraded state that should be addressed by the task. The list is simply a query on the table of degraded states that selects each state for which a PM task has an entry of H, L, or M for task effectiveness. The shortcoming of this list is that it does not identify whether the stylized format of "should address…(failure location)…for….(degradation)" is an observation, a test, or a measurement. However, the combination of formats helps to overcome this deficit.

Step 15. Develop the PM Objective for Each Task.

The expert panel members are asked to state the main objectives for each PM task. Sometimes a Task Objective is entirely focused on a few subcomponents and the way in which they deteriorate. For tasks that address a wide range of issues, the objectives are usually more subtle and may include obtaining an integral view of equipment condition or verification of correct working coordination between major parts of the equipment, or they may refer to other tasks that may be dependent on the results of performing the task in question. The idea is to answer the question, "Why are we doing this?"

Step 16. Add Task Work-Hours and Component Unavailability During Task Execution.

By analogy to the repair times entered in the table of degraded states at Step 11, these two parameters provide clues about the resources required and the likely costs each time the task is performed. Of course, the clock hours the component is out of service is a very indirect indication of downtime costs, if any. It is more likely to be useful during work planning and scheduling.

Step 17. Develop Task Intervals for Each Column in the PM Template.

Having completed the list of PM tasks and their scope and objectives, the expert panel next develops the PM task intervals. This involves the assignment of performance intervals to each task appropriate for the 8 combinations of functional importance, duty cycle, and service conditions addressed by the Template. To illustrate the format, the Template for a pump is shown in Table 2-1. During the workshop, the expert panel members rely mostly on their collective experience in assigning these intervals. However, they are strongly advised that they should not follow what is being done in their own plants if they have a sound technical basis for preferring a change. Part of their experience necessarily involves the cost of the tasks in relation to their perceived benefit. It is to be expected that these factors may be more closely aligned when the costs of failures are high, that is, for the critical columns of the Template.

Table 2-1
PM Template - for Pump - Horizontal - Multistage - Split Case

Task Name	CHS	CLS	CHM	CLM	NHS	NLS	NHM	NLM
Vibration Analysis	1M	3M	1M	3M	3M	1Y	3M	1Y
Oil Analysis	3M	6M	3M	6M	2Y	2Y	2Y	2Y
Performance Trending	2Y	2Y	2Y	2Y	NR	NR	NR	NR
Oil Filter Change, Clean, Inspect	2Y	2Y	2Y	2Y	2Y	AR	2Y	AR
System Engineer Walkdown	3M	3M	3M	3M	3M	3M	3M	3M
Refurbishment	AR	AR	AR	AR	AR	AR	AR	AR
Functional Testing	NA	AR	NA	AR	NA	AR	NA	AR
Operator Rounds	1S	1S	1S	1S	1D	1D	1D	1D
Acoustic Monitoring	AR	AR	AR	AR	AR	AR	AR	AR
Packing/Seal Replacement	AR	AR	AR	AR	AR	AR	AR	AR

For FLEX Equipment and FLEX Support Equipment, the low duty cycle columns of the Template recognize that this equipment is consistently in standby. For this equipment, the high duty cycle columns are reserved for occasional interim usage for other purposes at the plant and for use as intended in emergency circumstances.

The most confident way for the panel to proceed is to first address task intervals for the column in the Template with which they are most familiar. After consensus is achieved, they should select each following column to differ by only one characteristic from one of those already completed. For example, if CHM is the first column, the second might be CLM.

It is obvious that all of the aspects the panel members have entered into the database, which affect the overall benefit of the tasks, cannot be accounted for explicitly while entering the task intervals in the PM Template. Subsequent analysis by project personnel before the data are finalized in the database reconciles the experts' experiential views with the more complete logical foundation that can be extracted from the tabular data.

Step 18. Risks of Performing Intrusive Maintenance.

The components vary greatly in the degree to which disassembly and reassembly can lead to additional problems that are not present before the maintenance is performed. In this step, the opinions of the expert panel are consulted as to the kinds of failures they have found to be caused by maintenance error during intrusive maintenance on this component type.

Step 19. List the Most Common Causes of Failure.

This list records the most common types of component failures for this component type from the experience of the panel members. As such, it can be expected to represent the failures found commonly in industry experience in general. These failures occur despite the existence of current PM programs and illustrate the fact that the recommendations for PM programs in the PMBD will not prevent all failures. The reason is by no means the prevalence of human error, although that is certainly an important factor. Managers must acknowledge that even the most excellent PM programs will not provide 100% mitigation of all causes of failure even for wearout mechanisms. Further, typically 30% to 50% of all degraded states of equipment develop randomly and provide few opportunities for effective detection and mitigation. Individually the random failures are fairly low-probability events, but they are numerous.

Step 20. Develop a List of Useful Industry References.

Finally, the panel provides a list of technical industry references they continue to find useful.

2.3 Post-Workshop Analysis

2.3.1 Internal Consistency and QA

After the meeting, project personnel analyze all of the information provided in the workshop using the software tools in the PMBD. The purpose is to complete editorial tasks and conduct a sanity check on the alignment of recommended task intervals with the time scales of wearout mechanisms. This also checks the consistency with which the information was entered, in keeping with the internal rules and constraints of a relational database, and the ability of the Vulnerability calculation to run properly and provide sensible results. Examples of where results may not be sensible are 1) a failure rate that is much too high or too low in relation to known behavior, 2) format errors in time codes, 3) inconsistent or mistaken use of stressor factors, 4) illogical relation of task intervals between template columns, 5) apparent gaps in PM coverage (for example, an inexplicable absence of H's, M's, or L's), and 6) inconsistent application of task effectiveness between related PM tasks. If the corrective actions for these problems are not evident, the expert panel members are consulted to resolve them.

2.3.2 As-Found Reportable Conditions

Project personnel then insert appropriate As-Found Reportable Conditions that align with each line item in the Task Content for each PM task. These as-found conditions indicate what the maintenance worker will likely find if the degraded condition is present when he performs the PM task.

2.3.3 PM Task Characteristics

Project personnel then develop the remaining three parts of the technical basis for each PM Task. These are described next.

Failure Locations and Causes

This section provides an expansion of the objective of the task in terms of the failure locations and degradation mechanisms that the task is designed to deal with. To be concise, these items may be grouped appropriately. They are listed with the largest contributions to failure rate mitigation at the top. They account for about 80% of the failure rate mitigation that the task provides if it is the only task used, compared to the Run-to-Failure case. For non-FLEX equipment, this information is provided for the CHM task interval and operating context. Results will likely be different for other template columns.

Progression of Degradation to Failure

This section summarizes the information on times of occurrence of the dominant failures listed previously. It shows the predominant time periods that are expected to be free of failures for wearout behavior and notes whether random behavior might also be common.

Fault Discovery and Intervention

This section explains remaining aspects of the choice of one task over another, significant interactions among tasks, and the degree to which the task interval is actually dependent on and determined by the time scale of the more important degraded states being addressed. Task intervals are often found to be not sensitive in this way, which can offer opportunities for improving cost effectiveness.

2.3.4 PM TIPS

The next items addressed in post-workshop analysis are the four PM TIPS. For non-FLEX component types, these are described next and are developed only for the CHS condition with all stressors "turned on." The analogous TIPS for FLEX equipment are described in Section 3.4. The TIPS for FLEX and non-FLEX equipment are developed with the same meanings and in the same way, so the following description is identical to that for FLEX equipment in Section 3.4.

TIP 1: These tasks, even in the complete PM program, individually have an important effect on reliability. Preserve these tasks.

TIP 1 means that if any one of these tasks is dropped from the full recommended program, the MTBF is likely to decrease by at least a third. Unless the PM program already produces significantly more reliability than required and the task is expensive, it is obviously not a good idea to delete such a task from the program. Attempts to extend the task intervals for these tasks should be cautious.

TIP 2: Omitting these tasks individually from the full PM program does not have a large effect on reliability.

TIP 2 means that if you drop any one of these tasks from the full recommended program, the MTBF is not likely to decrease by more than 20%, and often much less. Such a task could be explored to determine whether extending its task interval or dropping it altogether is possible. However, for standby equipment or for equipment that is rarely if ever actively used (as will be true for all FLEX equipment), it will be essential to perform some PM tasks (Failure Finding tasks) to verify the equipment's operational readiness (that is, its availability), even though the effect of the task on its failure rate in operation may be slight. Omitting such a Failure Finding task would usually be a mistake. Of course, omitting more than one task from this group would also compound the negative effect on MTBF, although the effects are often not completely additive. Therefore, tasks listed in this group may present good opportunities to become more cost-effective, but each case requires exploration using the tools and diagnostics available in the PMBD.

TIP 3: These tasks, when performed as a group, give good reliability.

TIP 3 means that if the PM program consists of just these tasks and no others, the MTBF is likely to remain higher than 80% of the MTBF of the complete program. However, even though this result includes the compounded effect of all of the omitted tasks, a Failure Finding task should not be omitted if its task interval is more important for its impact on availability than on MTBF.

TIP 4: A single one of these tasks can provide significant reliability benefit just by itself.

TIP 4 means that such a task, by itself, can improve the MTBF by a factor of at least 2, but only compared to running to failure. Therefore, this will not be an impressive improvement in most cases. Even if it is, important Failure Finding tasks may also need to be added.

Section 3: PMBD Modification for Flex Equipment

The recent addition of FLEX equipment to the PMBD has required a few changes to the way the format of the PM Template and the way in which duty cycles and PM task intervals are represented. The conduct of the elicitation workshop remains unchanged, using the same 20 steps as described previously. The conversations during the workshop are changed only to the degree that the new formats must be accommodated. However, the component types being addressed in the FLEX program are mostly combinations of two or three of the more usual non-FLEX equipment types: these represent skid combinations that must be addressed as a single unit because of the extensive integration of PM tasks that is required. In the past, combining different equipment types (for example, to make a small system) has often proved problematic due to inconsistencies in the definition of duty cycles across radically different types of equipment. In the case of FLEX equipment, these difficulties are not encountered because scenarios envisaged for standby and use of FLEX equipment result in a simplified approach to duty cycles.

3.1 Equipment Application

This data field was added to provide an opportunity to explain particular aspects of the equipment that may limit its range of applications or in some way differ from what might be expected for normal nuclear plant equipment. This is particularly important for FLEX equipment because it is purchased to commercial grade standards.

For FLEX equipment, the Nuclear Energy Institute's "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide," (NEI 12-06), explains the intended applicability of FLEX equipment:

> Extreme external events (for example, seismic events, external flooding, etc.) beyond those accounted for in the design basis are highly unlikely but could present challenges to nuclear power plants.
>
> … though unlikely, external events could exceed the assumptions used in the design and licensing of a plant…. Additional diverse and flexible strategies that address the potential consequences of these 'beyond-design basis external events' would enhance safety at each site.

> This document outlines an approach for adding diverse and flexible mitigation strategies—or FLEX—that will increase defense-in-depth for beyond-design-basis scenarios….

Therefore, portable equipment and earthmoving equipment will be involved, some in standby on-site and some at nearby off-site locations:

- Portable equipment that provides means of obtaining power and water to maintain or restore key safety functions for all reactors at a site....
- Reasonable staging and protection of portable equipment from BDBEEs applicable to a site: The equipment used for FLEX would be staged and reasonably protected from applicable site-specific severe external events to provide reasonable assurance that N sets of FLEX equipment will remain deployable following such an event.

As a result, an example of the text that could appear in this field is as follows:

> This equipment is intended for use in emergency conditions, essentially in disaster relief situations. In that role, it will be maintained in standby for long periods of time, with appropriate provisions for maintaining and testing it. The long standby periods are expected to be interrupted by regular or irregular operation outside in conditions that are not more severe than the ultimate intended usage in emergencies. The equipment will also experience regular short periods of operation required for functional tests or to perform other PM tasks. All operational periods must be included in an integrated count of run hours.
>
> It is assumed that all equipment commissioning and break-in requirements have been completed before the equipment is put into operation. These requirements are therefore not considered to be part of the PM program. However, they should be addressed in a separate process.

3.2 Operating Context

In the PMBD, the term *operating context* means duty cycle and service conditions. This field was added mainly to provide an opportunity to explain how the duty cycle of FLEX equipment will likely differ from that of normal plant equipment. For FLEX equipment, there are several issues affecting the duty cycle: 1) low duty cycle will obviously correspond to being maintained in standby, 2) if operated to perform some other function while in standby (for example, used for one week to pump water from a cooling pond), a higher duty cycle could be appropriate for that period, 3) high duty cycle usage in emergency conditions could be limited to a short mission time of a few hours, or it could extend over several months, and 4) such equipment is therefore likely to not have a unique duty cycle over its whole life. This means that the PM actions required could change from time to time, depending on interim high duty usages dispersed between (usually) longer periods of standby.

To be conservative, any period of usage that does not correspond to normal standby will be considered to have a high duty cycle for the purpose of deciding the appropriate PM actions during such a period. High duty cycle periods will have all PM task intervals depicted in terms of run hours instead of calendar time as used for non-FLEX equipment. The low duty cycle standby condition will continue to have task intervals in terms of calendar years.

The following is an example of the text that could appear in this field to explain how to proceed:

> Determining the PM tasks that should be done when the equipment is sometimes in standby and is sometimes used for other purposes requires a concept of duty cycle that is somewhat more constrained than for non-FLEX equipment. For FLEX equipment, the definition in the Duty Cycle Definition field includes both high and low duty cycle as usual for non-FLEX equipment. The low duty case will normally apply during standby, and the high duty cycle case will apply during the occasional non-standby high usage periods as well as emergency usage. It is unlikely that the high duty case will be used for calculating failure rates and other reliability analysis purposes in either of the high duty situations. This is because it is likely that such calculations will be deemed neither useful nor necessary. In contrast, Vulnerability analysis may well be a valuable tool for optimizing standby PM tasks.

3.2.1 Duty Cycle When Determining PM Tasks and Intervals

In determining required PM actions while FLEX equipment is in standby and operated only for maintaining and testing, the equipment will be considered to have a Low Duty Cycle determined by the passage of calendar time.

However, during periods when the equipment is operated to perform functions other than maintaining and testing it, the equipment will be considered to have a High Duty Cycle to determine required PM actions during this period of higher usage. These PM actions will be determined by the run time hours during high duty operation and the task interval (in run time hours) in the relevant High Duty column of the PM Template. A *higher usage period* is the period during which the equipment has been operated for any purpose other than maintaining or testing it. The high duty run time hours will be reset to zero by the special tasks required when returning the equipment to standby.

PM task intervals for high duty operation will thus be stated in run time hours for all FLEX PM tasks in the PM Template, whereas all task intervals for low duty operation will remain in calendar years.

If the equipment has been used for a period of higher usage, the Low Duty Cycle PM recommendations should not be re-implemented for standby purposes until the High Duty cycle does not apply and until all provisions (for example, special tasks, if any) for reentering standby have been completed.

3.2.2 Duty Cycle for a Calculation

The calculation that the PMBD performs to estimate the failure rate will always need to use a specific duty cycle. For FLEX equipment, the *Duty Cycle Definition* field will define the duty cycle to be used for calculations. For non-FLEX equipment, the field will continue to describe the Low Duty Cycle condition in terms of calendar time. However, it will describe the High Duty Cycle condition in terms of run time hours.

When in standby, the Low Duty Cycle should be used for Vulnerability calculations along with the PM intervals that it implies, regardless of intervening short periods of high usage. If a calculation is ever needed for the short periods of high usage during standby, it could indeed be done using the High Duty Cycle setting and corresponding PM program. However, this would definitely be a conservative calculation (that is, it would be equivalent to assuming that the high duty cycle applies over long periods of time). In practice, there should normally be little need for such a calculation. For calculations pertaining to ultimate use during emergency situations, such conservatism is likely to be more acceptable—and if mission times turn out to be quite long, it would also be more realistic.

In the FMEA table, time codes for wearout mechanisms will continue to be stated in calendar years. However, when a Vulnerability calculation compares time codes with High Duty Cycle task intervals in run time hours, it will automatically convert the latter—assuming that 1000 run time hours are equivalent to 1 calendar year. Failure rates, even for high duty scenarios, will continue to be stated in failures per year. These rates should be interpreted as failures per year or per 1000 run time hours, whichever occurs first.

3.3 Functional Importance and PM Template

According to INPO AP-913, Revision 4 (pending) [5], both the FLEX Equipment (defined in NEI 12-06 as required to support maintenance of the key safety functions and must be N+1 redundant, where N equals the number of nuclear units on the site) and the FLEX Support Equipment (which is not required for maintenance of the key safety functions and is N redundant) are classified as Non-Critical. The following passage from NEI 12-06 (Section 3.2.2, Minimum Baseline Capabilities, Item 15, page 23) differentiates the requirements for N and N+1 redundancy:

In order to assure reliability and availability of the FLEX equipment required to meet these capabilities, the site should have sufficient equipment to address all functions at all units on-site, plus one additional spare, that is, an N+1 capability, where "N" is the number of units on-site. Thus, a two-unit site would nominally have at least three portable pumps, three sets of portable ac/dc power supplies, three sets of hoses and cables, etc. It is also acceptable to have a single resource that is sized to support the required functions for multiple units at a site (for example, a single pump capable of all water supply functions for a dual unit site). In this case, the N+1 could simply involve a second pump of equivalent capability. In addition, it is also acceptable to have multiple strategies to accomplish a function (for example, two separate means to repower instrumentation). In this case the equipment associated with each strategy does not require N+1. The existing 50.54(hh)(2) pump and supplies can be counted toward the N+1, provided it meets the functional and storage requirements outlined in this guide. The N+1 capability applies to the portable FLEX equipment described in Tables 3-1 and 3-2 (that is, that equipment that directly supports maintenance of the key safety functions). Other FLEX support equipment only requires an N capability.

The FLEX Equipment and the FLEX Support Equipment may have different PM requirements. The issue of functional importance is thus still a binary choice between two categories, with the result that the existing PM Template table structure can remain unchanged for FLEX components. Instead of obliging PMBD users to adopt an alternative table structure for the FLEX PM Template and requiring them to ignore the time-honored non-FLEX PM Template, it is possible to avoid confusion by simply relabeling parts of the existing PM Template.

Therefore, in the PMBD, the "FLEX Equipment" will continue to use the existing Critical data fields although the software will display them as FHS, FLM, and so on (F for FLEX instead of C for Critical). The "FLEX Support Equipment" will use the non-critical columns and will be displayed as SHS, and so on (S for Support).

The relationship between the two formats for the PM Template table is shown in Table 3-1 (for example only).

Table 3-1
Format Changes to the PM Template for FLEX Components

Non-FLEX Headings	**CHS**	**CLS**	**CHM**	**CLM**	**NHS**	**NLS**	**NHM**	**NLM**
FLEX Headings	**FHS**	**FLS**	**FHM**	**FLM**	**SHS**	**SLS**	**SHM**	**SLM**
Calibration	100H	2Y	200H	3Y	200H	6Y	300H	10Y
Inspection	100H	6Y	200H	8Y	150H	10Y	300H	10Y

Equipment that would always be stored or operated as FLEX Equipment would have the four Support columns set to NA (Not Applicable), whereas equipment that would always be stored or operated as FLEX Support Equipment would have the four FLEX Equipment columns set to NA. If a component could be stored or operated as either FLEX Equipment or FLEX Support Equipment, any or all of the Columns 2 through 9 may be required.

As described in Section 1.3.2, task intervals for low duty cycles are stated in calendar time units while those for high duty cycles are in run time hours. PM Templates for non-FLEX components will continue to have all PM task intervals stated in calendar time units.

3.4 PM TIPS for FLEX Components

PM TIPS present information regarding the PM tasks that are very important in the overall PM program as well as those that are much less important. This information may be helpful when there is a need for further customization of the Template recommendations for specific site conditions. The TIPs are developed by consultants after the expert elicitation workshop by running PMBD algorithms for specific PM programs taken from the PM Template. However, before describing the four kinds of TIPS, the conditions under which they are determined need to be discussed.

By far, the most important operating context for FLEX N+1 type TIP development will be FLM, which will apply to FLEX Equipment during the long periods of inactivity during standby. Essentially the same comments apply to Flex Support Equipment, where SLM will be the most common and important case. PM TIPS will be developed for whichever case applies and for FLM if both FLM and SLM apply, because cost-effective PM that preserves reliability during standby will be a major goal in both cases. The required changes will be incorporated into Version 3.1 of the web version of the software.

In contrast, the other columns of the PM Template do not seem to warrant the development of TIPS. In operational disaster relief conditions for FLEX Equipment and Support Equipment (that is, FHS and SHS), the opportunities for customization of the Template program will most likely be very limited, and the alternative FHM and SHM conditions are not expected to occur often for either type of equipment in disaster relief mode. The FLS condition is not expected to be appropriate for FLEX Equipment in standby mode because exposure to severe conditions for long periods of time is not going to be a common occurrence for FLEX Equipment—if it occurs at all. FLM conditions may conceivably apply in disaster mode for equipment designed normally to operate in severe service conditions (that is, disaster conditions may still be "Mild" for equipment such as a dedicated tractor trailer), but this, too, is likely to be a special case.

Consequently, it was decided that TIPS would be developed only for the FLM and SLM cases. In general, FLM addresses "inside" standby conditions for FLEX Equipment, for which some degree of PM program customization may be appropriate. SLM addresses "inside" standby conditions for FLEX Support Equipment, for which a greater degree of PM program customization may be expected.

The following four TIPS are presented in the PMBD for both FLM and SLM cases:

- **TIP 1:** These tasks, even in the complete PM program, individually have an important effect on reliability. Preserve these tasks.

  TIP 1 means that if any one of these tasks is dropped from the full recommended program, the MTBF is likely to decrease by at least a third. Unless the PM program already produces significantly more reliability than required and the task is expensive, it is obviously not a good idea to delete such a task from the program. Attempts to extend the task intervals for these tasks should be cautious.

- **TIP 2:** Omitting these tasks individually from the full PM program does not have a large effect on reliability.

  TIP 2 means that if any one of these tasks is dropped from the full recommended program, the MTBF is not likely to decrease by more than 20%, often much less. Such a task could be explored to determine whether extending its task interval or dropping it altogether is possible. However, because this equipment is rarely if ever actively used, it will be essential to perform some PM tasks (Failure Finding tasks) to verify its operational readiness (that is, its availability), even though the effect of the task on its failure rate in operation may be slight. Omitting such a Failure Finding task would usually be a mistake. Of course, omitting more than one task from this group would also compound the negative effect on MTBF, although the effects are often not completely additive. Thus, tasks listed in this group may present good opportunities to become more cost-effective, but each case requires exploration using the tools and diagnostics available in the PMBD.

- **TIP 3:** These tasks, when performed as a group, give good reliability.

  TIP 3 means that if the PM program consists of just these tasks and no others, the MTBF is likely to remain higher than 80% of the MTBF of the complete program. However, although this result includes the compounded effect of all of the omitted tasks, a Failure Finding task should not be omitted if its task interval is more important for its impact on availability than on MTBF.

- **TIP 4:** A single one of these tasks can provide significant reliability benefit just by itself.

  TIP 4 means that such a task, by itself, can improve the MTBF by a factor of at least 2, but only compared to running to failure—so this will not be an impressive improvement in most cases. Even if it is, important Failure Finding tasks may also need to be added.

3.5 TIPS for Non-FLEX Components

Analogs of these four FLEX TIPS are produced for non-FLEX components and have the same meaning as TIPS for FLEX components, except that they are developed for different operating contexts. In non-FLEX cases, these TIPS are developed only for the CHS case and have all stressors activated.

3.6 Other Changes to the User Interface for FLEX Components

The modifications of the PMBD for FLEX equipment described so far require changes in the user interface of the existing version (Version 3.0). The format changes to the PM Template have already been noted. The new data fields for Equipment Application and Operating Context will appear on the same screen as the Equipment Boundary Description for both FLEX and non-FLEX components because they will sometimes also be useful for the latter. The two new sets of TIPS should be activated for FLEX components in the same way that non-FLEX TIPS are currently activated.

Section 4: Use of the EPRI PM Basis

Note: Until modifications to PMBD Version 3.0 are made (Version 3.1), Some of these analysis techniques may not be available. The information described in the previous sections will be accessible from the report tab of Version 3.0 of the PM basis Database.

4.1 PM Optimization

In the years leading up to this project, the majority of U.S. utilities were engaged in optimizing PM programs at nuclear power plants using various types of RCM approaches. This project was conceived as a response to requests for logically defensible PM tasks and intervals that had been found by the industry to be both technically applicable and cost-effective.

Today, PM optimization can be performed at several levels: 1) in the traditional way as a project-oriented activity in which a large part of the plant PM program is reviewed, 2) in a similar process whose main goal is to update previous optimization results and bring them into conformity with the plant's reliability objectives, 3) in a process that may be focused on special aspects such as task interval adjustment and/or improved use and integration of predictive maintenance, and 4) through a *living PM process*—a gradual optimization over a period of several years in response to equipment condition, maintenance experience, performance monitoring, and the evolution of maintenance technology.

The EPRI PM Basis reports can directly support all of these approaches in various ways. For example, the updating or selection of PM tasks for a large amount of equipment benefits from the use of a standard baseline of tasks such as the EPRI PM Basis, which also recommends variations to accommodate different duty cycles and service conditions. The EPRI PM Basis provides the necessary justification for moving from vendor-recommended tasks and intervals to technically sound and more cost-effective options. Access to the EPRI PM Basis will also promote consistent assignment of tasks to the same type of equipment in different systems, especially when these are selected by different analysts or system engineers.

Consistency with a nuclear power plant's equipment reliability program may involve integration with structure, system, or component (SSC) functions, risk significance, and performance criteria. For example, components whose failure would directly cause the failure of a risk-significant SSC with reliability performance criteria limited to only one or two failures in a period of several years would need to be protected by a level of PM aimed at preventing all failures; that is, it would be classed as a critical component.

A component whose failure has only an indirect effect on such performance criteria or whose failure would contribute to more relaxed performance criteria will need PM tasks to prevent just the most common failures, rather than all failures; that is, it would be classed as a non-critical component. Similar considerations would apply to preventing repetitive failures from the most common causes. The data tables in the EPRI PM Basis reports enable these choices to be made with some precision and with a clear technical basis.

A plant-specific PM Basis can be a de-facto requirement to support PM changes when these are the substance of corrective actions and goals for reverting to the normal PM program after a period of more intensive monitoring.

The most efficient way to establish a plant PM Basis is to define plant PM standards using the EPRI templates. Such plant PM standards speed the task selection process, encourage consistency in task and interval selection, and efficiently embody much of the plant PM Basis.

A focus on specific areas of improvement such as task intervals and predictive maintenance can make use of the time scales for the development of various degradation mechanisms and the specification of appropriate predictive techniques listed in the EPRI PM Basis data tables. For example, some PM task intervals on certain component types are fairly tightly constrained by known time scales of degradation. These are not worth the expenditure of plant resources in attempts to extend the task intervals. Other task intervals invite extension, with potential limits that can also be determined from the EPRI data.

Continuous monitoring using installed sensors, automatic alarms and alerts, and compilation of these histories in the plant computer or historian are becoming more common. The expense of making this transition away from selected periodic predictive maintenance tasks demands careful appraisal, before the expense is incurred. As described in Section 2.3, the PMBD can be quite useful in making such investigations as well as evaluating consequent changes required in the remaining periodic tasks after continuous monitoring has been introduced.

The PMBD will also assist in finding cost-effective PM programs for equipment and operating contexts with which the nuclear power industry has hitherto had little experience, such as in the new FLEX program requirements. Here the value will lie especially in making the real-world operating experience of other industries available to power plant personnel in a manner independent of vendor requirements.

4.2 Technological Evaluation of the Benefit of PM Changes

The PMBD is the only methodology and data available to utilities to enable the most important benefits of performing a PM task to be assessed and compared to alternatives. The benefits of PM changes are too often evaluated solely on the basis of PM cost reduction, simply from the change in the amount of PM performed, and not at all in terms of a reduction in the number of failures. But the latter is the only reason that PM resources are deployed at all in any industrial plant.

The PMBD contains all of the information needed to assess the reliability benefit of performing a specific PM task at a given interval in the context of the other PM tasks being performed. This information is contained in the breakdown of failure locations, degradation mechanisms, and the times to first failure, combined with the effectiveness of the particular tasks that address each mechanism. The software tool called Vulnerability that is provided within the PMBD automatically integrates all of this information to give simple evaluations of the marginal benefit of a PM change. To do this *Vulnerability* accurately gives an estimate of the relative contribution of each potential degraded state to the overall failure rate of the component. It also estimates, as a function of the task interval, the degree of mitigation offered by the PM tasks for the degraded states each task addresses. Simply sorting the degraded states by the size of these contributions immediately provides views of the most important PM tasks and the dependence of the failure rate on the task intervals.

This reliability evaluation alone is a valuable tool when selecting PM tasks and intervals because degraded states that are being inadequately addressed show up very clearly and easily expose gaps in PM coverage. However, the PMBD can compare two or more sets of PM tasks and intervals to give precise evaluations of the merit and demerits of one PM program over another.

To see how valuable this can be, consider the space of variables that enter such a comparison:

1. There can be 50 to 100 ways (that is, degraded states) by which a complex equipment item will degrade.
2. Some degraded states can develop randomly in time, others by a more measured and deliberate process known as *wearout*, where the wearout times vary greatly.
3. Each of possibly 10 or more PM tasks will address various degraded states with varying degrees of intrinsic effectiveness (*intrinsic* means even if each task is being done in the right way and at the right time).
4. If PM tasks are not done in the right way at the right time, their effectiveness can vary all the way down to being totally useless. Any realistic model must address this effect. Compromises are usually made in the task intervals even in the recommended PMBD PM programs, especially for the time-directed tasks. This is because not all degraded states can be addressed often enough to match their rates of development. Consequently, even task intervals

assigned by RCM are frequently "stretched" to meet real-world conditions. These effects are routinely ignored by RCM, which makes no attempt to characterize task effectiveness at all. For a quantitative perspective, these effects are properly accounted for in Vulnerability.

5. If more than one task addresses the same degraded state—which happens all the time—the effectiveness of each task will combine in ways that are not obvious. For example, each of two tasks might appear to provide strong mitigation if performed by itself in the absence of the other task, but their combined effects may appear to be much weaker than expected. This is due mainly to the fact that the scope of the two tasks may overlap; furthermore, once the contribution of the degraded state has been significantly mitigated by one task, the fact that it is further mitigated by the second task can be relatively unimportant in relation to the remaining contributions of all of the other degraded states. Second, there can be "common cause effects" between tasks stemming from sources such as imperfect training, skills, procedures, and plant culture so that they cannot be assumed to act as independent mitigating events.
6. The result of (5) is that the benefit derived from a given task is often a strong function of which other tasks are being performed, and when.
7. All of these effects (from Items 2 through 6) will also, for specific degraded states, depend quite strongly on the duty cycle and service stressors under which the equipment is applied and operated.

Care has been taken to ensure that the model algorithms employed by Vulnerability are not only simple but directly capture the essence of the many effects being addressed. These concepts are individually straightforward, but the bookkeeping complexity of actually applying them far exceeds what even the most experienced maintenance engineer (or anyone else) can compute mentally, although they can be easily handled by digital database technology.

Preventive maintenance must be carried out on a wide array of different kinds of equipment in a plant environment where over long stretches of time many other factors (for example, changes in design, operating mode, operational environment, management priorities, and failures of other equipment) obscure the impact of these effects. Indeed, most of this equipment is fairly reliable given even a modest degree of maintenance, so that learning by interpreting failures on any given kind of equipment is a difficult and relatively uncommon event. It is therefore not surprising that understanding optimal PM has remained elusive for so long.

The enduring value of using the PMBD is that an immense amount of this elusive industrial experience has been consistently captured laboriously and over a long period through the expert workshop process. In addition, the PMBD provides the technical basis for the validity of this experience, the limits of which can readily be assessed using the Vulnerability tools. These enable the user to better fit that experience to his or her own plant history and to gain additional insights that result in better risk management, correct levels of equipment reliability, reduced plant downtime, and appropriate direct expenditures that can sustain these benefits.

4.3 Integration of Continuous Monitoring

One of the principal benefits of introducing predictive PM tasks is to lessen the need for intrusive activities, which have a high cost and may also have a high chance of causing additional failures. Time-directed tasks such as internal inspections, overhauls, and scheduled replacements of components might thereby have their time intervals extended. The use of time-based predictive tasks such as oil sampling and vibration analysis has been very successful in achieving these goals over the last 30 years. The past 10 years or so have also seen the introduction of onboard sensors that send data quasi-continuously to a plant historian. For the most part, these data have at best been looked at and interpreted only periodically, so the mitigating value of this approach has scarcely exceeded that of the previous time-based predictive activities. However, emerging capabilities involve the continuous evaluation of this sensor data with various kinds of intelligent processing that have some ability to provide warning of impending equipment failure. These developments have real potential to change the way PM is done.

Continuous monitoring with correct diagnosis may have a better chance of detecting incipient failures while there is enough lead time to plan for corrective action at a time that avoids a plant outage. If this works well, the cost savings from reduced plant outages and from performing fewer time-directed tasks may outweigh the costs of installing sensors and high-tech monitoring.

One thing in its favor may be an improved opportunity to mitigate random failures for which time-based tasks are of little value. Random failures are likely to occur with little warning, but continuous monitoring may provide an opportunity to at least shut down equipment before further damage occurs. It is common for a third or more of degraded states to become manifest randomly, with at best a short time signature of impending failure. They are all listed in the PMBD. Thus the PMBD could be an invaluable tool in assessing the potential for improvements from this source.

Obviously, wearout mechanisms can also be better addressed by continuous monitoring because the intrinsic effectiveness of the task would never be diluted by performing the task too late. Nevertheless, the inclination to use PMBD Vulnerability calculations to evaluate the benefit of this advanced kind of continuous monitoring by simply increasing the task frequency of, for example, Vibration Analysis, runs into difficulties.

A fully informed decision on this topic would need to consider whether there are any failure mechanisms that the previous time-directed task (for example, monthly Vibration Analysis) addresses that might not be addressed by the new continuous monitoring and other time-directed tasks that remain in the program. It is not uncommon for such a periodic task to include observations, by the mere presence of the technician, of degraded conditions that are unconnected to vibration levels and that sensors would not be able to detect.

Furthermore, the sensors and associated diagnostic software may not have the same effectiveness at detecting a degraded state as the previous time-based task would have had; it may also have a different breadth of purview across many such states. The scope of mitigation across many degraded states, the task effectiveness in each case, and the role of "extraneous acts of mitigation" are all perfectly suited to evaluation by the PMBD.

When the PM Basis is used in this way, the relative benefit and risk of the new predictive task, whether by continuous monitoring or not, can be viewed in explicit relationship to the existing tasks.

Section 5: References

1. *Preventive Maintenance Basis: Project Overview Report.* EPRI, Palo Alto, CA: 1998. TR-106857-V40.
2. USNRC, "Japan Lessons-Learned Project Directorate, JLD-ISG-2012-01," USNRC Compliance with Order EA-12-049, Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events, Interim Staff Guidance, Revision 0, ADAMS Accession No.: ML12229A174, United States Nuclear Regulatory Commission, Washington D.C., USA, August 29, 2012.
3. NEI 12-06, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide," NEI 12-06 (Rev. 0), Nuclear Energy Institute, 1776 I Street N.W., Suite 400, Washington D.C. (202.739.8000), August 2012.
4. Institute of Nuclear Power Operations, Consolidated Events System (ICES), is a recent initiative to consolidate the three current major industry systems and databases: Plant Events, EPIX, and NPRDS. It will become the primary means for reporting, retrieving, and analyzing event-based nuclear power plant operating experience in the United States.
5. Institute of Nuclear Power Operations, Equipment Reliability Process INPO AP-913, Revision 4 (pending).

Appendix A: Example Flex Data Report

EPRI PM Basis Database

Flex Data Report

FLEX - Pump - Horizontal - Oil Bath Mechanical Seal - IT4 DPF/DOC Diesel Driven

Prepared by:
Asset Performance Technologies, Inc.
Corrales, NM 87048

1. Introduction

Purpose

This document provides a program of preventive maintenance (PM) tasks suitable for application to a trailer-mounted skid where the skid consists of a horizontal single-stage pump with an oil bath mechanical seal driven by an IT4 DPF/DOC diesel engine, suitable for use in the FLEX program at U.S. commercial nuclear power plants. The PM tasks that are recommended provide a cost-effective way to intercept the causes and mechanisms that lead to degradation and failure. They can be used, in conjunction with material from other sources, to develop a complete PM program or to improve an existing program. Users of this information will be utility managers, supervisors, craft technicians, and training instructors responsible for developing, optimizing, or fine-tuning PM programs.

Approach

A group of utility representatives provided overall direction to this project. The broad objective of the project was to develop a collection of "industry standard" maintenance and testing strategies for equipment used as part of the Diverse and Flexible Coping Strategies used to address beyond-design-basis events using information supplied by an industry expert group. These strategies are documented in a set of templates and data tables contained in the EPRI Preventive Maintenance Basis Database and a companion Basis Document. The PM Basis Database project uses a process through which the expert group reaches agreement on the details of the template and its supporting basis information. Major process steps are to 1) select and describe the equipment, 2) develop the mechanisms and causes of degradation, 3) list recommended PM tasks and map them to the degraded states they are able to detect, 4) develop additional information on each PM task, and 5) recommend the time intervals at which each task should be performed in a variety of operational contexts. Degraded states of the equipment are each represented by a *Failure Location*, which is the hardware item that degrades, a *Degradation Mechanism*, which is how it degrades, and a *Degradation Influence*, which is the cause, possibly including stressor factors that initiate or accelerate the mechanism. For complex equipment, there may be more than a hundred of these mechanisms. To provide some context for the remaining sections of this report, a few of them are shown in Table A-1. A more extended list of such mechanisms with additional information is provided in Section 6e.

Table A-1
Examples of Degraded States for This Equipment

Failure Location	Degradation Mechanism	Degradation Influence
Diesel - After Cooler	Fouled	Debris
Diesel -- After Cooler	Fouled	Water-side corrosion
Diesel - After Cooler	Leak	Air-side corrosion

Use of Vendor Manuals with the PMBD FLEX Templates

The information and recommendations contained in this report should be used in conjunction with recommendations provided in the appropriate vendor manuals.

The bases for departures from vendor recommendations and the program described in this report need to be carefully considered and documented. The information in this report should enable decisions involving departures from vendor recommendations to be made with a greater awareness of the specific failure causes involved and the indications of degradation that can show whether the decision was appropriate as time passes. It is recognized that a specific PM task may address many failure causes that are also addressed by other tasks. This may provide for overlapping between tasks that can make such decisions less critical by the adoption of compensating actions.

Determination of Task Intervals

Intervals are to be determined and adjusted by each utility based on individual plant experience, standby conditions, and OEM Information Notices. Intervals provided in the template are suggested starting points for this process, although in general, where the tasks are already being performed, the existing intervals could be used as the starting point as long as a basis exists. Such a basis could be constructed from past inspection data and failure history and from information in this document. A key point is that it is prudent to change task intervals in the search for intervals that are short enough to protect against unacceptable equipment deterioration, but not so short as to waste maintenance resources or to introduce unnecessary sources of maintenance error.

When selecting time intervals for intrusive maintenance, it is not necessarily conservative to select shorter rather than longer time intervals in a possible range. Shorter intervals expose the equipment to more opportunities for maintenance error and to the potential for non-optimal setup. Furthermore, the reliability data for other complex plant component types suggest that components receiving a higher proportion of intrusive PM tasks may experience more failures than those that receive predominantly non-intrusive maintenance.

As an example, in more normal service conditions for critical components, visual inspection can be combined in rotation with a more detailed inspection and overhaul to provide flexibility on when the overhaul is performed. That is, if the Template recommended an overhaul at 10 years, it may not be necessary to schedule it strictly at 10 years. A further reason for careful reflection on the Template intervals is that the Template will sometimes recommend a task interval because it is often required by some regulation or industry code. In these cases, the PM Basis text may explain circumstances in which a more flexible interpretation could be used.

The intervals in the template and the previous discussion on task scheduling assumes that after an overhaul, whenever it occurs, the schedule is repeated as if starting from time zero. Consequently, the schedules for particular time-directed tasks do not continuously repeat because they are closely related to the schedules of the other time-directed tasks. The occurrence of the overhaul in effect resets the schedule clock.

The task intervals are specific for the component in order to address the technical basis for the task. When the component has PM performed in conjunction with another component type (for example, motor and pump), some compromises on task intervals may be necessary to meet scheduling demands. Normally the compromise would choose the shorter interval. These decisions will depend on the particular combinations of components at each utility. It is recommended that separate "skid templates" be developed by the utility for these situations.

Equipment Definition and Boundary

Because many of the FLEX components are skids consisting of a collection of various components such as prime movers, driven components, controls, and other equipment that would normally be treated as separate component types, the listing of components covered and, more importantly, not covered, will need to be descriptive. If the data set describes a skid, the major component types that make up the skid are listed first:

> The boundary of this FLEX - emergency component, the FLEX - Pump - Horizontal - Oil Bath Mechanical Seal - IT4 DPF/DOC Diesel Driven, is a horizontal pump with an oil bath mechanical seal and greased rolling element bearings, driven by an (IT4) Interim Tier 4 diesel engine with only DPF/DOC (Diesel Particulate Filter - Diesel Oxidation Catalyst) emission controls on a towable trailer with electric and hydraulic brakes. Use of the term "FLEX" here refers only to the U.S. nuclear power industry's "Diverse and Flexible Coping Strategies - FLEX" program and not at all to the availability of non-current emission type diesel engines.

Following is a partial listing of the major or larger components.

Note: Each of the larger components and their sublevel components are listed below to aid in understanding the equipment, subcomponents, assemblies, and parts that have and have not been included as "in scope" for this FLEX component. This list is illustrative only and will not include all items treated in the degradation table.

1. Interim Tier 4 Diesel:
   - Engine (for example, pistons, rings, valves, and shaft)
   - Engine control unit
   - Local control panel
   - Combustion air system (Turbocharger, supply air filter, after-cooler)
   - Fuel system (priming [low pressure] and engine driven [high pressure] fuel pumps, primary and secondary filters, fuel-water separator, day tank, and fuel injectors)
   - Oil pump(s)
   - Coolant, radiator, pump, engine driven fan, and thermostat valve
   - Exhaust system (DPF, diesel oxidation catalyst - DOC, Selective Catalytic)
   - Starter
   - Battery
   - Battery charger
2. Coupling: Engine - Pump:
   - Spline coupling, if present
   - Elastomeric doughnut or block type, if present
3. Pump:
   - Impeller
   - Volute casing
   - Mechanical oil bath seal
   - Grease lubricated rolling element bearings
   - Suction and discharge flanges
   - Check valves
   - Pump mounts
   - Detectors, sensors, and alarms (for example, suction and discharge gauges)
   - Priming pump, for example, belt driven compressor and venturi or vacuum pump
4. Trailer:
   - Skid base plate or frame
   - Trailer bed
   - Suspension and levelers
   - Tires, wheels, brakes, lights
   - Hitch/coupler

Excluded are:

- External fuel supply standby tanks as well as fuel supply and transfer pumps, motors, and piping

Comments on Equipment Application

This equipment is intended for use in emergency conditions, essentially in disaster relief situations. In that role, it will be maintained in standby for long periods of time, with appropriate provisions for maintaining and testing it. The long standby periods are expected to be interrupted by regular or irregular operation in conditions that are not more severe than the ultimate intended usage. The equipment will also experience regular short periods of operation required for functional tests or to perform other PM tasks. All operational periods must be included in an integrated count of run hours.

For FLEX equipment, the Nuclear Energy Institute's "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide," (NEI 12-06), explains that:

> Extreme external events (for example, seismic events, external flooding, etc.) beyond those accounted for in the design basis are highly unlikely but could present challenges to nuclear power plants.
>
> … Though unlikely, external events could exceed the assumptions used in the design and licensing of a plant. Additional diverse and flexible strategies that address the potential consequences of these "beyond-design-basis external events" would enhance safety at each site.
>
> This document outlines an approach for adding diverse and flexible mitigation strategies, or FLEX, that will increase defense-in-depth for beyond-design-basis scenarios.
>
> Thus, portable equipment and earthmoving equipment will be involved, some with standby on-site and some at nearby off-site locations:
>
> Portable equipment that provides means of obtaining power and water to maintain or restore key safety functions for all reactors at a site: This could include equipment such as portable pumps, generators, batteries and battery chargers, compressors, hoses, couplings, tools, debris clearing equipment, temporary flood protection equipment, and other supporting equipment or tools.
>
> Reasonable staging and protection of portable equipment from BDBEEs applicable to a site: The equipment used for FLEX would be staged and reasonably protected from applicable site-specific severe external events to provide reasonable assurance that N sets of FLEX equipment will remain deployable following such an event.

Furthermore, the NEI guidance requires:

> Programmatic controls that assure the continued viability and reliability of the FLEX strategies: These controls would establish standards for quality, maintenance, testing of FLEX equipment, configuration management, and periodic training of personnel.

It is assumed that all equipment commissioning and break-in requirements will have been completed before the equipment is put into operation. These requirements are therefore not considered part of the PM program. However, they should be addressed in a separate process.

FLEX equipment is purchased to commercial grade standards. Consequently, *Replacement* is likely to be more common as a PM recommendation for FLEX equipment than it is elsewhere in the EPRI database for power plant equipment installed for non-FLEX purposes.

Reliability and Availability as Used in This Document

In this report, the failure rate and the mean time between failures (MTBF) are both used to indicate the reliability of the equipment. The failure rate is taken to be constant over time, and its reciprocal is the MTBF. The term *Reliability* in this document does not refer explicitly to its mathematical definition, which is the probability that the equipment will function properly throughout its mission time. Thus, equipment with a low failure rate (that is, a high MTBF) is said to reliable.

The term *Availability*, on the other hand, refers to the average period of time the equipment functions properly as a fraction of the period of time during which it is required to function properly. This is a measure of the probability that standby equipment will start and work as expected when it is demanded at some future random time. The required Availability can be important for setting performance intervals for Failure Finding tasks when equipment is in standby for long periods of time and is subject to PM tasks that contain failure finding activities, such as Functional Tests of various kinds. If the failure rate is F and the time between tests is T, the Availability is given by:

$$A = 1 - F \times T/2$$

The Unavailability is equal to 1-A.

Industry References

1. NEI 12-06, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide," NEI 12-06 (Rev. 0), Nuclear Energy Institute, 1776 I Street N.W., Suite 400, Washington D.C. (202.739.8000), August 2012.
2. USNRC, "Japan Lessons-Learned Project Directorate, JLD-ISG-2012-01," USNRC Compliance with Order EA-12-049, Order Modifying Licenses

with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events, Interim Staff Guidance, Revision 0, ADAMS Accession No.: ML12229A174, United States Nuclear Regulatory Commission, Washington D.C., USA, August 29, 2012.

3. Standard Connections, NEI Workshop, December 2, 2012.
4. INPO, "FLEX Integrated Plan," Institute for Nuclear Power Operations (INPO), Revision Blank 5a, December 12, 2012.
5. "Regional Response Center Generic and Site-Specific Equipment - Engineering Information Record," Document: 51 - 9199717 -000 Revision 0, AREVA NP, 20004-019, November 20, 2012.
6. "Off-Highway Diesel Engines - Tier 3/Stage III A" Brochure, John Deere, DSWT09 (11-12).
7. "Off-Highway Diesel Engines - Interim Tier 4/Stage III B" Brochure, John Deere, DSWT67 (11-03).
8. "Emissions Technology - Nonroad Diesel Engines" (Has a reference to the anticipated Final Tier 4 requirements) Brochure, John Deere, DSWT41 (12-03).
9. "Operator Handbook – DriPrime Bareshaft Pumps," Godwin Pumps, HL130M-CI-ACW-12, 6" ANSI 150 X 4" ANSI 300.
10. "Trailer Operations Manual," MSG Inc.

2. PM Task Template Format and Definitions

According to INPO AP-913, Revision 4 (pending), both the FLEX Equipment (which is N+1 redundant, where N equals the number of nuclear units on the site; see "Definition of Functional Importance" below) and other FLEX Support Equipment are classified as Non-Critical, but they may well have different PM requirements. Internally in the database, the FLEX Equipment continues to use the existing Critical data fields although the software displays them as FHS, FLM, etc., (F for FLEX). The FLEX Support category is displayed as SHS, etc. (S for Support). Thus, the relationship between the two formats for the PM Template table is as shown in Table A-2 (example only).

Table A-2
Relationship Between Standard Classifications and FLEX Classifications

Normal Headings	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
FLEX Headings	**FHS**	**FLS**	**FHM**	**FLM**	**SHS**	**SLS**	**SHM**	**SLM**
PM Task 1	NA	NA	NA	NA	2M	1Y	3Y	5Y
PM Task 2	NA	NA	NA	NA	1Y	1Y	5Y	8Y

Equipment that would always be stored or operated as FLEX Equipment (N+1) would have Columns 6–9 set to NA (Not Applicable), whereas equipment that would always be stored or operated as FLEX Support Equipment would have Columns 2–5 set to NA. If a component could be stored or operated as either FLEX Equipment or FLEX Support Equipment, any or all of Columns 2–9 may be required.

Definition of Functional Importance, Duty Cycle, and Service Conditions

Functional Importance

Because all FLEX component types have been classified as Non-Critical (INPO AP-913, Revision 4, pending), the PMBD treats Functional Importance for FLEX components as simply a placeholder that differentiates FLEX Equipment that has N+1 redundancy from FLEX SUPPORT Equipment. Internally in the database, the N+1 FLEX Equipment continues to use the existing Critical data fields although the software displays them as FHS, FLM, etc., (F for FLEX). The FLEX Support category is displayed as SHS, etc. (S for Support).

The following passage from NEI 12-06 (Section 3.2.2, Minimum Baseline Capabilities, Item 15, page 23) differentiates the requirements for N and N+1 redundancy:

> In order to assure reliability and availability of the FLEX equipment required to meet these capabilities, the site should have sufficient equipment to address all functions at all units on-site, plus one additional spare, that is, an N+1 capability, where "N" is the number of units on-site. Thus, a two-unit site would nominally have at least three portable pumps, three sets of portable ac/dc power supplies, three sets of hoses and cables, etc. It is also acceptable to have a single resource that is sized to support the required functions for multiple units at a site (for example, a single pump capable of all water supply functions for a dual unit site). In this case, the N+1 could simply involve a second pump of equivalent capability. In addition, it is also acceptable to have multiple strategies to accomplish a function (for example, two separate means to repower instrumentation). In this case the equipment associated with each strategy does not require N+1. The existing 50.54(hh)(2) pump and supplies can be counted toward the N+1, provided it meets the functional and storage requirements outlined in this guide. The N+1 capability applies to the portable FLEX equipment described in Tables 3-1 and 3-2 (that is, that equipment that directly supports maintenance of the key safety functions). Other FLEX support equipment only requires an N capability.

Critical (labeled "F"): Corresponds to the N+1 FLEX Equipment requirements as defined in NEI 12-06.

Minor (labeled "S"): Corresponds to the FLEX Support Equipment requirements as defined in NEI 12-06.

Duty Cycle

High: Operated (beyond what is needed for test and maintenance in standby) for any part of the year.

Low: In standby, with starts and run time for test and maintenance only.

Service Condition

Note: Normal plant equipment is mostly expected to be in mild conditions when stored inside a building, but severe conditions will apply for standby outside or in non-controlled environments. When used in disaster relief scenarios, the classification is likely to change. Transport and earth moving equipment, mobile cranes, and fire engines may see severe or mild service conditions in disaster, standby, or normal use modes, depending on regional climate and how they are used.

Severe: Outside operation, high or excessive humidity, excessive temperatures (high/low) or temperature variations, or excessive environmental conditions (for example, salt, corrosive, spray, or low quality suction air).

If the pump has the following severe conditional operating issues: 1) frequently operates off-BEP, that is, ±>10% of the BEP (best efficiency point, otherwise known as the design point), 2) experiences extended operation (for 1 or more hours) at minimum flow conditions, 3) low NPSHA (net positive suction head available), or 4) process fluids containing chemicals, silt, debris or exhibiting multiphase flow, it is possible that some test conditions may create these more severe environments.

Diesel engines that are operated at idle or low load for an extended time, are operated at elevations above 10,000 feet, or are situated on ground that is not relatively level should be considered to be in a severe environment.

Mild: Inside operation or standby, clean area (not necessarily air conditioned), temperatures within OEM specifications, normal environmental conditions.

Other Comments on Operating Context

While the equipment is in standby and operated only for the purpose of maintaining and testing, it will be considered to have a Low Duty cycle determined by the passage of calendar time.

Whenever the equipment is operated for purposes other than maintaining and testing it, the recommended PM actions will be determined, during the period of higher usage, by the integrated run hours. For FLEX equipment, these will always be listed under High Duty cycle. Thus, the equipment would not have a unique duty cycle.

The PM recommendations in the High Duty column should be implemented during any higher usage period. A *higher usage period* is one in which the equipment has been operated for any purpose other than maintaining or testing it.

If the equipment has been used for a period of higher usage, the Low Duty cycle PM recommendations cannot be re-implemented for standby purposes until the High Duty cycle does not apply and all provisions (for example, special tasks) for returning it to standby have been completed.

PM task intervals for high duty operation will be stated in run hours for all PM tasks in the PM Template, whereas all task intervals for low duty operation will remain in calendar years.

Nevertheless, a vulnerability calculation will still need to have a specific duty cycle assigned to it. The equipment duty cycle defined in the Definition of Duty Cycle should be used for Vulnerability calculations regardless of how that amount of run time occurred and regardless of whether run time is even contained in the definition.

Vulnerability will internally use a conversion factor of 1000 run hours to be equivalent to 1 year in order to convert the High Duty task intervals from run hours to calendar years. Failure rates calculated for high duty scenarios will continue to be stated in failures per year. These rates should be interpreted as failures per year or per 1000 run hours, whichever occurs first.

3. Building a PM Strategy

The recommendations provided in this report are the carefully considered judgments of utility personnel who have been identified by their industry peers as very knowledgeable and experienced with the specific type of equipment being addressed. However, these are generic recommendations. They should be interpreted as sound recommendations that provide a moderately conservative PM program that will be suitable for a variety of operating contexts, which have been approximately binned into the eight columns shown in the PM Template.

In particular, Service Conditions may be categorized as Severe for a variety of reasons, which may require the task intervals to be modified to suit plant-specific circumstances. In addition, the specific equipment design features and age, components that are not included in the equipment boundary description, plant history, equipment redundancy, and the availability of spares should all be taken into account when considering the actual task intervals to be used.

The generic recommendations in this report apply to equipment that is in nominally good condition. If the equipment being addressed has not been maintained adequately for a long period of time, consideration must be given to restoring the equipment to a nominally good condition before the recommendations take effect. This may involve performing a refurbishment.

Common Failure Causes

The expert group identified the most common (that is, dominant) failure locations for this equipment as follows.

For the diesel engine:

- Battery and battery charger problems
- Buildup of carbon deposits in the engine because of low-load operation and use of fuel with too high a sulfur content
- Dirty injector nozzles
- Contaminated fuel
- Fouled air, oil, and fuel filters

For the pump:

- Bearing grease failure

Risk of Performing Intrusive Maintenance

The expert panel noted the following ways in which failures are commonly introduced through the process of performing preventive maintenance.

For the diesel engine:

- Not completely purging all air after fuel system inspection or a fuel filter change
- Improper remounting of the fuel filter, leading to bypass
- Incorrect (backward) installation of air filters
- Using an incorrect fuel sampling procedure or making errors in following the sampling procedure, especially in the choice of the sampling location
- Handling of glycol as hazardous waste
- Errors in battery charging procedures that result in damage to the engine electronics, especially the ECU

For the pump:

- Over-greasing bearings

Bad Actors and Other Plant-Specific Factors

Equipment items of the same component type that share the same functional importance and operating context are usually assigned the same PM program. This is both for efficiency in analysis and implementation and to confer consistency in the application of industry experience across the plant systems. However, the generic application of PM decisions must also allow for the specific circumstances of individual equipment items and for the occurrence of "bad actors" that may require additional maintenance.

Effects of Stressor Factors

Because the PM recommendations for equipment in severe service conditions are given in a single column of the Template (the column depending on functional importance and duty cycle), it is not evident in this report that it is possible, through the database software, to modify the generic recommendations beyond what appears in the PM Template. This is done through the use of stressor factors, which can be selected by the user when using the software. The stressor factors cover the influences of extremes of temperature, high vibration, external sources of contamination, fluid quality, high moisture or condensation, high rotational speed, and biological agents. The action of a stressor factor, when "turned on" by the user, is to increase the rate of degradation of certain degraded states. This can affect the degree of mitigation provided by each PM task, the proportion of failures that come from the individual degraded states, and the resulting overall failure rate. In this way, the resulting recommendations more accurately reflect equipment-specific circumstances.

Task Effectiveness

Task effectiveness refers to the fact that a given PM task will mitigate some degraded states of the equipment much more than others even when the task is performed when recommended. The degree to which this mitigation occurs also depends on the task interval; if a task is done later than recommended, it may be less effective than if done on time. Thus, when a task interval is extended, some degraded conditions for which it might have provided significant mitigation may become more likely to result in failures. The degree to which this matters depends on whether the task would have been effective if done in time, whether another task also provides significant mitigation for that condition, and whether that degraded state would contribute significantly to the failure rate even if not mitigated at all. When a task interval is extended, it is very difficult to know whether it will have a significant effect on the failure rate unless the software that keeps track of these competing effects can be run.

Customizing PM Recommendations

It is unusual for a small to moderate change in a PM task interval to have a dramatic effect on the failure rate, especially when the PM program includes several tasks. However, this can happen, and it is more likely when more than one task interval is being adjusted. The database software gives the user the opportunity to modify the Template recommendations by changing task intervals. However, because of the many interacting effects described previously, it is not easy to find a combination of tasks and task intervals that is a better overall solution when considering reliability, availability, cost, practicality, and risk aversion. To provide some insight into potential improvements, PM TIPS are provided that attempt to inform the user which are the most value-added tasks solely from a reliability perspective and which are the least valuable. The sensitivity of the overall failure rate to each task interval is also given in the PM Objective statement. It is important to observe that statements about sensitivities and TIPS are dependent on the initial conditions, so these should be noted carefully.

Explanation of Most Likely Degraded Conditions

The overall failure rate is estimated by applying the model algorithms to each potential degraded state independently, after which the contributions are added together. This gives the user of the software the opportunity to sort the degraded states according to the size of these contributions: 1) the speed with which they degrade, that is, the contribution they would make to the failure rate in a run-to-failure or no-mitigation situation and 2) the degree to which each contributes to the overall failure rate when the PM program is applied. Users of the database are urged to consult these lists because they offer excellent insights into why the PM program is good or bad; they can also guide the user when trying to improve the program performance.

4. PM Program Basis

Table A-3 shows an example PM Template.

Table A-3
Example PM Template

Task Name	FHS	FLS	FHM	FLM	SHS	SLS	SHM	SLM
Functional Test and Inspection	NA	3M	NA	3M	NA	NA	NA	NA
Fluid Filter Replacement	2000H	2Y	NA	2Y	NA	NA	NA	NA
Fluid Analysis	NA	1Y	NA	1Y	NA	NA	NA	NA
In-Service Walkdown	1S	NA	NA	NA	NA	NA	NA	NA
Performance Test	3000H	3Y	NA	3Y	NA	NA	NA	NA
Standby Walkdown	NA	1M	NA	1M	NA	NA	NA	NA
Return to Standby	NA	AR	NA	AR	NA	NA	NA	NA
Component Operational Inspection and Performance Test	AR	AR	NA	AR	NA	NA	NA	NA
Component Operational Inspection	1000H	1Y	NA	1Y	NA	NA	NA	NA

Notes:
AR = As Required; NA = Not Applicable; NR = Not Recommended

Functional Test and Inspection

Task Objective

The objective of the Functional Test and Inspection task is to demonstrate the availability of the equipment, that is, that the diesel will start and run. For the short duration of this test, pumps with an oil bath type of seal may be run dry. In a full PM program for FLM conditions, the failure rate is not very sensitive to the task interval. This is not particularly relevant as this is primarily a failure finding task in which the task interval is important for other reasons.

Significant Degraded States

When the task acts alone under FLM conditions, the dominant degradation mechanisms it addresses are issues with normal oxidation and aging of the fuel from long-term standby, the buildup of biological contaminants from exposure to the environment, and age-related degradation of all oil and fuel filters. The following other issues may also present themselves: age-related loss of charge in the battery; insufficient antifreeze components in the coolant due to age; and various age and environmental exposure-related problems associated with hoses, tubing, belts, and block heaters.

Timing of Significant Degradation

The issues with normal oxidation and aging of the fuel from long-term standby occur after 1 to 3 years, while the buildup of biological contaminants from exposure to the environment is slightly longer—2 to 3 years—but will be shorter if maintained in dirty and or moisture-laden conditions. Age-related degradation of all oil and fuel filters should not be expected to occur before 2 to 3 years. The following issues should normally not be expected to present themselves much before 3 to 6 years in FLM conditions: age-related loss of charge in the battery; insufficient antifreeze components in the coolant due to age; and various age and environmental exposure-related problems associated with hoses, tubing, belts, and block heaters. Only the battery and belts exhibit earlier failures ranging from 1.5 to 2.5 years, respectively, if continually exposed to high temperatures.

Support for the Task Interval and Relation to Other Tasks

Failure rate sensitivity is for the task in the full PM program under FLM conditions, but this may be different for the task by itself. The failure rate is not very sensitive to the task interval. This is not particularly relevant as this is primarily a failure finding task in which the task interval is important for other reasons.

Recommended Task Content

The following rows consist of the Failure Locations and Degradation Mechanisms for which this task is expected to be reasonably effective. It is left up to the user to assemble these lists into a useful craft instruction.

- Should address: Diesel - After Cooler for: Fouled
- Should address: Diesel - After Cooler for: Leak
- Should address: Diesel - Air Box for: Accumulation of carbon deposits and oil
- Should address: Diesel - Alternator and Diodes for: Failed
- Should address: Diesel - Battery for: High resistance connections and cables
- Should address: Diesel - Battery for: Loss of Charge
- Should address: Diesel - Battery Charger for: Failed
- Should address: Diesel - Belts and Sheaves for: Worn
- Should address: Diesel - Coolant for: Insufficient antifreeze compound
- Should address: Diesel - Coolant for: Low level
- Should address: Diesel - Coolant or Block Heater for: Corroded or loose connections
- Should address: Diesel - Coolant or Block Heater for: Failed heater (shorted), may be leaking
- Should address: Diesel - Crankcase Air Breathers for: Clogged
- Should address: Diesel - Cylinder head for: Cracked
- Should address: Diesel - Digital Controls or ECU for: Failed, Improper control or display
- Should address: Diesel - Electrical Devices (for example, sensors, solenoids, relays, meters, switches, fuses, lights) for: High resistance, Poor contact
- Should address: Diesel - Emission Control - DPF/DOC (Diesel Particulate Filter - Diesel Oxidation Catalyst) for: Ash buildup (that is, requiring cleaning or replacement)
- Should address: Diesel - Emission Control - DPF/DOC (Diesel Particulate Filter - Diesel Oxidation Catalyst) for: Soot buildup (that is, requiring regeneration by increasing load for a period)
- Should address: Diesel - Engine Mounts for: Failed mount or loose bolting
- Should address: Diesel - Engine Valve Springs for: Broken
- Should address: Diesel - Engine Valve Stem for: Stuck
- Should address: Diesel - Engine Valve Train for: Wear
- Should address: Diesel - Exhaust Gas Recirculation (EGR) Cooler for: External leakage
- Should address: Diesel - Exhaust Gas Recirculation (EGR) Valve for: Sticking
- Should address: Diesel - Flywheel for: Damaged gear teeth
- Should address: Diesel - Fuel for: Biological growth in normal fuel
- Should address: Diesel - Fuel for: Contaminated
- Should address: Diesel - Fuel for: Fuel degradation products
- Should address: Diesel - Fuel for: Improper fuel
- Should address: Diesel - Fuel for: Improper sulfur content capable of causing engine damage
- Should address: Diesel - Fuel Filters for: Degraded filter materials
- Should address: Diesel - Fuel Filters for: Fouled
- Should address: Diesel - Fuel Hoses for: Leak
- Should address: Diesel - Fuel Lines for: Leak

- Should address: Diesel - Fuel Tank for: Wall corrosion and pitting
- Should address: Diesel - Fuel Tank Breather or Vent for: Clogged
- Should address: Diesel - Fuel Tank Strainer (if present) for: Clogged
- Should address: Diesel - Fuel-Water Separator Element for: Excessive water (water may carry over into fuel)
- Should address: Diesel - Gaskets, Seals, and O-Rings (Internal and External Elastomer Type) for: Leak
- Should address: Diesel - Head Gasket for: Leak-by
- Should address: Diesel - High Pressure Fuel Pump for: Loss of pressure
- Should address: Diesel - Hydraulic Lifter (if present) for: Stuck
- Should address: Diesel - Injector Tubing for: Cracked ferrule from over-torqued coupling
- Should address: Diesel - Injectors for: Leaking (fails to reseat)
- Should address: Diesel - Injectors for: Seized nozzles
- Should address: Diesel - Inlet Air Filters (Element Type) for: Fouled
- Should address: Diesel - Linkages and Controls for: Binding
- Should address: Diesel - Lube Oil for: Low level
- Should address: Diesel - Lube Oil Pressure Control Device for: Drift, Loss of setpoint
- Should address: Diesel - Lube Oil Pump for: Wear
- Should address: Diesel - Muffler and Silencer for: Internal damage
- Should address: Diesel - Oil Filters for: Degraded filter materials
- Should address: Diesel - Oil Filters for: Fouled
- Should address: Diesel - Oil Filters for: Leak
- Should address: Diesel - Pistons for: Piston seizure
- Should address: Diesel - Pistons for: Ring seizure caused by deposits
- Should address: Diesel - Push Rods for: Bent
- Should address: Diesel - Radiator for: Fouled, external
- Should address: Diesel - Radiator for: Fouled, internal
- Should address: Diesel - Radiator for: Leak
- Should address: Diesel - Radiator Cap for: Fails to seal
- Should address: Diesel - Radiator Fan for: Bearing failure
- Should address: Diesel - Radiator Fan for: Damaged blades
- Should address: Diesel - Radiator Fan Variable Clutch for: Failed
- Should address: Diesel - Radiator Hoses for: Leak
- Should address: Diesel - Radiator Tubing for: Leak
- Should address: Diesel - Starter for: Bearing Failure
- Should address: Diesel - Starter for: Damaged gear teeth
- Should address: Diesel - Starter for: Failure to engage
- Should address: Diesel - Thermostat for: Fails to operate
- Should address: Diesel - Turbocharger (All Types) for: Bearing failure
- Should address: Diesel - Turbocharger (All Types) for: Blade damage
- Should address: Diesel - Turbocharger (All Types) for: Shaft seal failure
- Should address: Diesel - Turbocharger (VGT Types) - Vane Angle Control and Linkage for: Failed actuator
- Should address: Diesel - Turbocharger (VGT Types) - Vane Angle Control and Linkage for: Sticking
- Should address: Diesel - Turbocharger (WGT Types) for: Stuck valve

- Should address: Diesel - Turbocharger Exhaust Flex Hoses for: Degrades and leaks
- Should address: Diesel - Turbocharger Exhaust Inlet Screen (if present) for: Fouled
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Degraded filter materials
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Fouled
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Leak
- Should address: Diesel - Vibration Damper or Harmonic Balancer for: Failed
- Should address: Diesel - Vibration Damper or Harmonic Balancer for: Loose bolts
- Should address: Diesel - Water Pump for: Leaking seal
- Should address: Diesel - Water Pump for: Loss of pressure
- Should address: Diesel - Wiring Harness for: Loose connections
- Should address: Pump - Bearing Seals - Lip for: Wear
- Should address: Pump - Bearings - Rolling Element (Radial and Thrust) for: Wear, fatigue
- Should address: Pump - Coupling - Elastomeric Element for: Cracking, tearing, or shearing
- Should address: Pump - Lubrication - Grease for: Housing leaks
- Should address: Trailer - Electric Brakes for: Failed end plug, poor connection, damaged cable
- Should address: Trailer - Electric Lights for: Failed bulb
- Should address: Trailer - Hitch or Coupling for: Cracked welds or loose bolting
- Should address: Trailer - Levelers for: Stuck
- Should address: Trailer - Tires for: Damaged - bulged, cracked
- Should address: Trailer - Tires for: Damaged - cut
- Should address: Trailer - Tires for: Incorrect pressure
- Should address: Trailer - Wheel Bearings for: Failed
- Should address: Trailer - Wheel Bearings for: Failed bearing grease
- Should address: Trailer - Wheels (Rims) for: Cracked, dented, bent, warped

Fluid Filter Replacement

Task Objective

The objective of the Filter Replacement task is to ensure that the filters have not exceeded their service life by avoiding excessive deterioration of the filter materials. In a full PM program for FLM conditions, the failure rate is not sensitive to the task interval.

Significant Degraded States

When the task acts alone under FLM conditions, the dominant degradation mechanisms it addresses are degradation of the oil and fuel filters from age and normal use.

Timing of Significant Degradation

The oil filters have an expected failure-free period of 2 to 3 years. In a full PM program for FLM conditions, the failure rate is not sensitive to the task interval.

The recommended interval for FHS conditions is every 2000 hours.

Support for the Task Interval and Relation to Other Tasks

Failure rate sensitivity is for the task in the full PM program under FLM SLM conditions, but this may be different for the task by itself. The failure rate is not sensitive to the task interval.

The recommended interval for FHS conditions is every 2000 hours.

Recommended Task Content

The following rows consist of the Failure Locations and Degradation Mechanisms for which this task is expected to be reasonably effective. It is left up to the user to assemble these lists into a useful craft instruction.

- Should address: Diesel - Crankshaft Bearings (Main, Thrust, and Connecting rod) for: Wear
- Should address: Diesel - Cylinder Liners for: Scuffing or surface wear
- Should address: Diesel - Fuel Filters for: Degraded filter materials
- Should address: Diesel - Fuel Filters for: Fouled
- Should address: Diesel - Hydraulic Lifter (if present) for: Stuck
- Should address: Diesel - Inlet Air Filters (Element Type) for: Fouled
- Should address: Diesel - Linkages and Controls for: Binding
- Should address: Diesel - Lube Oil for: Low level
- Should address: Diesel - Oil Filters for: Degraded filter materials
- Should address: Diesel - Oil Filters for: Fouled
- Should address: Diesel - Oil Filters for: Leak
- Should address: Diesel - Piston Wrist Pin Bearings for: Wear
- Should address: Diesel - Pistons for: Piston seizure
- Should address: Diesel - Pistons for: Ring seizure caused by deposits
- Should address: Diesel - Pistons for: Scuffing or surface wear
- Should address: Diesel - Timing Gears (if present) for: Wear
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Degraded filter materials
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Fouled
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Leak

- Should address: Diesel - Valve Train - Rocker Arms with Rollers for: Scuffing or surface wear of rollers

Fluid Analysis

Task Objective

The objective of the Fluid Analysis task is to non-intrusively and predicatively enable the inherent reliability of internal components to be attained and thereby to maximize equipment service life. In a full PM program for FLM conditions, the failure rate is not sensitive to the task interval. This task should also be an important element in returning the unit to standby mode.

Significant Degraded States

The dominant degradation mechanisms addressed by this task when acting alone under FLM conditions are age and contamination issues with the fuel, coolant, and lube oil. Although this task is primarily aimed at determining the continued usefulness of the diesel's lubricating, cooling, and fuel fluids, it may detect wear and degradation products from such sources as fuel tank corrosion, leaking gaskets, and worn engine internals.

Timing of Significant Degradation

The shortest of the fuel aging issues occurs after 1 to 3 years, and 2 to 3 years (or shorter if exposed to dirty or moist conditions) to observe biological growth in the fuel. The coolant should not be expected to lose its antifreeze protection or have excessive pH levels for at least 3 to 4 years. The lube oil, if properly maintained and not challenged by use, exposure to the elements, or hard internal engine wear, should last the expected life of the equipment.

Support for the Task Interval and Relation to Other Tasks

Failure rate sensitivity is for the task in the full PM program under FLM conditions, but this may be different for the task by itself. In a full PM program for FLM conditions, the failure rate is not sensitive to the task interval. This task should also be an important element in returning the unit to standby mode.

Recommended Task Content

This task is also an important element in returning the unit to standby mode.

The following rows consist of the Failure Locations and Degradation Mechanisms for which this task is expected to be reasonably effective. It is left up to the user to assemble these lists into a useful craft instruction.

- Should address: Diesel - Cam Follower Roller (if present) for: Scuffing or surface wear of rollers
- Should address: Diesel - Camshaft, Lobes, and Bushings for: Wear
- Should address: Diesel - Coolant for: Improper pH

- Should address: Diesel - Coolant for: Insufficient antifreeze compound
- Should address: Diesel - Coolant for: Low level
- Should address: Diesel - Crankshaft Bearings (Main, Thrust, and Connecting rod) for: Wear
- Should address: Diesel - Cylinder head for: Cracked
- Should address: Diesel - Cylinder Liners for: Scuffing or surface wear
- Should address: Diesel - Fuel for: Biological growth in normal fuel
- Should address: Diesel - Fuel for: Contaminated
- Should address: Diesel - Fuel for: Fuel degradation products
- Should address: Diesel - Fuel for: Improper fuel
- Should address: Diesel - Fuel for: Improper sulfur content capable of causing engine damage
- Should address: Diesel - Fuel Tank for: Wall corrosion and pitting
- Should address: Diesel - Gaskets, Seals, and O-Rings (Internal and External Elastomer Type) for: Leak
- Should address: Diesel - Lube Oil for: Contaminated
- Should address: Diesel - Lube Oil for: Incorrect oil
- Should address: Diesel - Lube Oil for: Loss of lubricating qualities, for example, TBN, viscosity
- Should address: Diesel - Lube Oil for: Low level
- Should address: Diesel - Piston Wrist Pin Bearings for: Wear
- Should address: Diesel - Pistons for: Piston ring and piston ring groove wear
- Should address: Diesel - Pistons for: Scuffing or surface wear
- Should address: Diesel - Timing Gears (if present) for: Wear
- Should address: Diesel - Turbocharger (All Types) for: Bearing failure

In-Service Walkdown

Task Objective

The objective of the In-Service Walkdown task is to visually verify that the unit is operating normally and is capable of continuing to be run. This task is not applicable to non-operational units in standby but should be employed when these units are placed in service.

Significant Degraded States

When the task acts alone under FLM conditions, the dominant degradation mechanisms addressed are those that can be discovered visually or audibly, such as leaks in hoses and tubing, leaking or loose radiator caps, and failed block heaters and their connections.

Timing of Significant Degradation

The shortest of these degraded states involves degradation of tubing and belts and can occur in a timeframe of 3 to 5 years.

Support for the Task Interval and Relation to Other Tasks

This task is not applicable to non-operational units in standby but should be employed during the time these units are in service.

Recommended Task Content

Depending on the installation, some of the following task items may not apply, or other task items that better describe the actual installation may require adjustment to the task list.

The following rows consist of the Failure Locations and Degradation Mechanisms for which this task is expected to be reasonably effective. It is left up to the user to assemble these lists into a useful craft instruction.

- Should address: Diesel - After Cooler for: Leak
- Should address: Diesel - Belts and Sheaves for: Worn
- Should address: Diesel - Coolant for: Low level
- Should address: Diesel - Coolant or Block Heater for: Corroded or loose connections
- Should address: Diesel - Coolant or Block Heater for: Failed heater (shorted), may be leaking
- Should address: Diesel - Digital Controls or ECU for: Failed, Improper control or display
- Should address: Diesel - Electrical Devices (for example, sensors, solenoids, relays, meters, switches, fuses, lights) for: High resistance, Poor contact
- Should address: Diesel - Engine Mounts for: Failed mount or loose bolting
- Should address: Diesel - Fuel Hoses for: Leak
- Should address: Diesel - Fuel Lines for: Leak
- Should address: Diesel - Gaskets, Seals, and O-Rings (Internal and External Elastomer Type) for: Leak
- Should address: Diesel - Injector Tubing for: Cracked ferrule from over-torqued coupling
- Should address: Diesel - Lube Oil for: Low level
- Should address: Diesel - Muffler and Silencer for: Internal damage
- Should address: Diesel - Oil Filters for: Leak
- Should address: Diesel - Radiator for: Fouled, external
- Should address: Diesel - Radiator for: Leak
- Should address: Diesel - Radiator Cap for: Fails to seal
- Should address: Diesel - Radiator Fan for: Damaged blades
- Should address: Diesel - Radiator Fan Variable Clutch for: Failed
- Should address: Diesel - Radiator Hoses for: Leak
- Should address: Diesel - Radiator Tubing for: Leak
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Leak
- Should address: Diesel - Water Pump for: Leaking seal
- Should address: Diesel - Wiring Harness for: Insulation breakdown
- Should address: Diesel - Wiring Harness for: Loose connections

- Should address: Pump - Connections and Piping for: Leaks
- Should address: Pump - Gaskets and O-Rings for: Leaks caused by degraded material properties
- Should address: Pump - Lubrication - Grease for: Housing leaks
- Should address: Pump - Seal - Mechanical Oil Bath Type for: Leaks
- Should address: Pump Casing for: Corrosion or rust or damage to externals and bolting
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Corrosion or rust or damage to bolting
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Loose fasteners
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Warped, cracked welds
- Should address: Trailer - Levelers for: Mispositioned or unlevel

Performance Test

Task Objective

The objective of the Performance Test is to ensure that the engine can run at full load for a sustained period of time and that the pump is able to provide its full capacity and pressure requirements. The scheduled period under FHS conditions addresses in-service usage in non-emergency conditions only. In a full PM program for FLM conditions, the failure rate is not sensitive to the task interval.

Significant Degraded States

For the task acting alone under FLM conditions, the dominant degradation mechanisms addressed are the pump and trailer wheel bearing lubrication issues, usually due to age and contamination, and normal wear and age issues associated with the pump's priming system, drive coupling, pump seals and bearings, bearing seals, check valves, and impeller.

Although the diesel must start and run at full load for a sustained period to test the pump, there are no dominant degraded states of the diesel that are addressed by this task when acting alone. Thus they are not listed previously.

Timing of Significant Degradation

The pump and trailer wheel bearing lubrication issues are usually due to age and contamination, which should not occur before 5 to 10 years, respectively, unless exposed to hot and dirty environmental conditions—which would essentially halve the expected failure-free periods. Normal wear and age issues associated with the pump's priming system, drive coupling, bearing seals, check valves, pump internals, and the pump's seals and bearings all exhibit expected failure-free periods of at least 7 to 10 years or greater, even if continually exposed to high temperature conditions.

The recommended interval for FHS conditions is every 3000 hours.

Support for the Task Interval and Relation to Other Tasks

The entry of 3000 hours in the FHS column in the PM Template refers only to temporary usage of the equipment in the high duty mode as it will not be practical to perform this task under emergency usage conditions. Whenever the Performance Test is performed, it is recommended that the Component Operational Inspection should be performed at the same time, if possible—that is, using the more comprehensive Component Operational Inspection and Performance Test. Failure rate sensitivity is for the Performance Test in the full PM program under FLM conditions, but this may be different for the task by itself. The failure rate is not sensitive to the task interval.

Recommended Task Content

While in standby mode, whenever the Performance Test is performed it is recommended that the Component Operational Inspection be performed at the same time, if possible—that is, using the more comprehensive Component Operational Inspection and Performance Test.

The following rows consist of the Failure Locations and Degradation Mechanisms for which this task is expected to be reasonably effective. It is left up to the user to assemble these lists into a useful craft instruction.

- Should address: Pump - Bearing Seals - Lip for: Wear
- Should address: Pump - Bearings - Rolling Element (Radial and Thrust) for: Wear, fatigue
- Should address: Pump - Check Valve - Disk Arm (if present) for: Bent
- Should address: Pump - Check Valve - Hinge Pin (if present) for: Binding
- Should address: Pump - Check Valve - Hinge Pin (if present) for: Wear
- Should address: Pump - Check Valve - Rubber Flapper (if present) for: Deteriorated, cracked
- Should address: Pump - Check Valve - Seat Failure (Body or Disk) for: Crud buildup
- Should address: Pump - Check Valve - Seat Failure (Body or Disk) for: Damaged seat
- Should address: Pump - Connections and Piping for: Leaks
- Should address: Pump - Coupling - Elastomeric Element for: Cracking, tearing, or shearing
- Should address: Pump - Discharge and Suction Connections for: Damaged
- Should address: Pump - Gaskets and O-Rings for: Leaks caused by degraded material properties
- Should address: Pump - Impeller for: Corrosion
- Should address: Pump - Impeller for: Loose
- Should address: Pump - Impeller for: Physical damage
- Should address: Pump - Impeller for: Wear
- Should address: Pump - Lubrication - Grease for: Degraded
- Should address: Pump - Priming System for: Failed air compressor
- Should address: Pump - Priming System for: Failed O-ring seals

- Should address: Pump - Priming System for: Stuck ejector ball
- Should address: Pump - Seal - Mechanical Oil Bath Type for: Leaks
- Should address: Pump - Shaft for: Cracked or damaged
- Should address: Pump Casing for: Corrosion or erosion or damage to Internals
- Should address: Pump Casing for: Corrosion or rust or damage to externals and bolting
- Should address: Pump Casing for: Wear
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Corrosion or rust or damage to bolting
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Loose fasteners
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Warped, cracked welds
- Should address: Trailer - Bed, Frame, and Lifting Lugs for: Cracked welds or loose bolting
- Should address: Trailer - Levelers for: Mispositioned or unlevel
- Should address: Trailer - Tires for: Incorrect pressure
- Should address: Trailer - Wheel Bearings for: Failed bearing grease

Standby Walkdown

Task Objective

The objective of the Standby Walkdown task is to visually verify, where possible, that the unit is ready for testing or in-service use. In a full PM program for FLM conditions, the failure rate is not sensitive to the task interval.

Significant Degraded States

For the task acting alone under FLM conditions, the dominant degradation mechanisms addressed can be discovered visually or audibly, such as failed battery chargers, batteries with low or no charge, or leaks emanating from hoses, tubing, or the radiator. If block heaters are used, this task should also discover problems with failed heaters and degraded connections.

Timing of Significant Degradation

The battery issues can occur under the best conditions after 3 to 4 years or much sooner in hot locations, while leaks should not be expected to occur before 3 to 6 years.

Support for the Task Interval and Relation to Other Tasks

Failure rate sensitivity is for the task in the full PM program under FLM conditions, but this may be different for the task by itself. The failure rate is not sensitive to the task interval.

Recommended Task Content

The following rows consist of the Failure Locations and Degradation Mechanisms for which this task is expected to be reasonably effective. It is left up to the user to assemble these lists into a useful craft instruction.

- Should address: Diesel - Battery for: Loss of Charge
- Should address: Diesel - Battery Charger for: Failed
- Should address: Diesel - Oil Filters for: Leak
- Should address: Diesel - Radiator for: Leak
- Should address: Diesel - Radiator Hoses for: Leak
- Should address: Diesel - Radiator Tubing for: Leak
- Should address: Pump Casing for: Corrosion or rust or damage to externals and bolting
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Corrosion or rust or damage to bolting
- Should address: Trailer - Levelers for: Mispositioned or unlevel
- Should address: Trailer - Tires for: Damaged - bulged, cracked
- Should address: Trailer - Tires for: Damaged - cut
- Should address: Trailer - Tires for: Incorrect pressure

Return to Standby

Task Objective

The objective of the Return to Standby task is to perform essential tasks such as fluid analysis or changing oil and flushing fuel systems so that the unit can be returned to a long-term standby condition. Therefore, in the template, this task is not given a definite interval (AR). However, in this context, this task is always recommended to be performed before returning the unit to the standby mode.

Significant Degraded States

For the task acting alone under FLM conditions, the dominant degradation mechanisms addressed mostly concern the diesel, such as leaking tubing, hoses, and radiator cap seals; worn belts and sheaves; failed block heaters; and radiator core leaks.

Timing of Significant Degradation

Leaking tubing, hoses, and radiator cap seals should not occur before at least 3 to 6 years. Worn belts and sheaves have a 5-year failure period unless subjected to high heat conditions. Block heaters are not expected to fail until around 7 years of operational use, and the radiator core should not build up enough corrosion to leak until after 8 to 10 years.

Support for the Task Interval and Relation to Other Tasks

This task is recommended to be performed only before returning the unit to the standby mode.

Recommended Task Content

This task, under all template conditions, is recommended to be performed before returning the unit to standby mode; therefore, no specific task interval applies.

The following rows consist of the Failure Locations and Degradation Mechanisms for which this task is expected to be reasonably effective. It is left up to the user to assemble these lists into a useful craft instruction.

- Should address: Diesel - After Cooler for: Leak
- Should address: Diesel - Belts and Sheaves for: Worn
- Should address: Diesel - Coolant for: Low level
- Should address: Diesel - Coolant or Block Heater for: Corroded or loose connections
- Should address: Diesel - Coolant or Block Heater for: Failed heater (shorted), may be leaking
- Should address: Diesel - Digital Controls or ECU for: Failed, Improper control or display
- Should address: Diesel - Electrical Devices (for example, sensors, solenoids, relays, meters, switches, fuses, lights) for: High resistance, Poor contact
- Should address: Diesel - Engine Mounts for: Failed mount or loose bolting
- Should address: Diesel - Fuel Hoses for: Leak
- Should address: Diesel - Fuel Lines for: Leak
- Should address: Diesel - Gaskets, Seals, and O-Rings (Internal and External Elastomer Type) for: Leak
- Should address: Diesel - Injector Tubing for: Cracked ferrule from over-torqued coupling
- Should address: Diesel - Lube Oil for: Low level
- Should address: Diesel - Muffler and Silencer for: Internal damage
- Should address: Diesel - Oil Filters for: Leak
- Should address: Diesel - Radiator for: Fouled, external
- Should address: Diesel - Radiator for: Leak
- Should address: Diesel - Radiator Cap for: Fails to seal
- Should address: Diesel - Radiator Fan for: Damaged blades
- Should address: Diesel - Radiator Fan Variable Clutch for: Failed
- Should address: Diesel - Radiator Hoses for: Leak
- Should address: Diesel - Radiator Tubing for: Leak
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Leak
- Should address: Diesel - Water Pump for: Leaking seal
- Should address: Diesel - Wiring Harness for: Insulation breakdown
- Should address: Diesel - Wiring Harness for: Loose connections
- Should address: Pump - Connections and Piping for: Leaks
- Should address: Pump - Gaskets and O-Rings for: Leaks caused by degraded material properties
- Should address: Pump - Lubrication - Grease for: Housing leaks
- Should address: Pump - Seal - Mechanical Oil Bath Type for: Leaks

- Should address: Pump Casing for: Corrosion or rust or damage to externals and bolting
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Corrosion or rust or damage to bolting
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Loose fasteners
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Warped, cracked welds
- Should address: Trailer - Levelers for: Mispositioned or unlevel

Component Operational Inspection and Performance Test

Task Objective

The objective of the Component Operational Inspection and Performance Test is to ensure that the engine will start and run at a sustained load of greater than 30% and that the pump can meet its expected capacity and pressure. *Operational* simply emphasizes that the engine and pump must be running to perform the task. This task is not given a specific interval in the PM Template because it is a combination of two separate tasks that are more likely to be performed at different intervals.

Significant Degraded States

The dominant degradation mechanisms addressed by this task when it acts alone under FLM conditions are aging and normal use issues affecting only the diesel, causing degradation of the fuel, all oil and fuel filters, and loss of antifreeze compounds in the coolant. Other degradations that are discovered during the execution of this task are battery issues (usually from loss of the ability to hold a charge), leaks from hoses and tubing as well as failed radiator cap seals, failed block heaters, worn belts and sheaves, and clogged crankcase air breathers.

The shortest pump and trailer degradations are those associated with the pump bearing and trailer wheel bearing lubrication issues due to age and contamination. However, these are not the dominant degradation mechanisms addressed by this task and thus are not listed previously.

Timing of Significant Degradation

Aging and degradation of the fuel caused by normal use should have a failure-free period of 1 to 3 years; however, biological growth contaminating the fuel oil can occur normally in the 2–3 year timeframe unless exposed to moisture and dirt, which will halve the expected time to early failure. All oil and fuel filters begin to exhibit loss of their ability to provide the proper levels of protection at 2 to 3 years. Loss of antifreeze compounds in the coolant should not occur much before 3 to 4 years. Battery issues, usually from loss of the ability to hold a charge, generally have a 3-4 year failure-free period unless exposed to constant high levels of heat, which shortens their failure-free period. Leaks from hoses and tubing as well as failed radiator cap seals have failure-free periods of 3 to 6 years; block heaters also exhibit the foregoing time to early failure. Worn belts and sheaves, clogged crankcase air breather, and failed thermostats should not occur much before 5 to 6 years in these nominally mild conditions.

Support for the Task Interval and Relation to Other Tasks

This combination of the Performance Test and the Component Operational Inspection tasks is recommended instead of scheduling the Inspection and only performing the Performance Test on-condition, that is, when a problem with the pump is suspected. However, when the two separate tasks are performed at significantly different intervals, there will not often be the opportunity to perform the combined task.

Recommended Task Content

The following rows consist of the Failure Locations and Degradation Mechanisms for which this task is expected to be reasonably effective. It is left up to the user to assemble these lists into a useful craft instruction.

- Should address: Diesel - After Cooler for: Fouled
- Should address: Diesel - After Cooler for: Leak
- Should address: Diesel - Air Box for: Accumulation of carbon deposits and oil
- Should address: Diesel - Alternator and Diodes for: Failed
- Should address: Diesel - Battery for: High resistance connections and cables
- Should address: Diesel - Battery for: Loss of Charge
- Should address: Diesel - Battery Charger for: Failed
- Should address: Diesel - Belts and Sheaves for: Worn
- Should address: Diesel - Coolant for: Insufficient antifreeze compound
- Should address: Diesel - Coolant for: Low level
- Should address: Diesel - Coolant or Block Heater for: Corroded or loose connections
- Should address: Diesel - Coolant or Block Heater for: Failed heater (shorted), may be leaking
- Should address: Diesel - Crankcase Air Breathers for: Clogged
- Should address: Diesel - Cylinder head for: Cracked
- Should address: Diesel - Digital Controls or ECU for: Failed, Improper control or display
- Should address: Diesel - Electrical Devices (for example, sensors, solenoids, relays, meters, switches, fuses, lights) for: High resistance, Poor contact
- Should address: Diesel - Emission Control - DPF/DOC (Diesel Particulate Filter - Diesel Oxidation Catalyst) for: Ash buildup (that is, requiring cleaning or replacement)
- Should address: Diesel - Emission Control - DPF/DOC (Diesel Particulate Filter - Diesel Oxidation Catalyst) for: Soot buildup (that is, requiring regeneration by increasing load for a period)
- Should address: Diesel - Engine Mounts for: Failed mount or loose bolting

- Should address: Diesel - Engine Valve Springs for: Broken
- Should address: Diesel - Engine Valve Stem for: Stuck
- Should address: Diesel - Engine Valve Train for: Wear
- Should address: Diesel - Exhaust Gas Recirculation (EGR) Cooler for: External leakage
- Should address: Diesel - Exhaust Gas Recirculation (EGR) Valve for: Sticking
- Should address: Diesel - Flywheel for: Damaged gear teeth
- Should address: Diesel - Fuel for: Biological growth in normal fuel
- Should address: Diesel - Fuel for: Contaminated
- Should address: Diesel - Fuel for: Fuel degradation products
- Should address: Diesel - Fuel for: Improper fuel
- Should address: Diesel - Fuel for: Improper sulfur content capable of causing engine damage
- Should address: Diesel - Fuel Filters for: Degraded filter materials
- Should address: Diesel - Fuel Filters for: Fouled
- Should address: Diesel - Fuel Hoses for: Leak
- Should address: Diesel - Fuel Lines for: Leak
- Should address: Diesel - Fuel Tank for: Wall corrosion and pitting
- Should address: Diesel - Fuel Tank Breather or Vent for: Clogged
- Should address: Diesel - Fuel Tank Strainer (if present) for: Clogged
- Should address: Diesel - Fuel-Water Separator Element for: Excessive water (water may carry over into fuel)
- Should address: Diesel - Gaskets, Seals, and O-Rings (Internal and External Elastomer Type) for: Leak
- Should address: Diesel - Head Gasket for: Leak-by
- Should address: Diesel - High Pressure Fuel Pump for: Loss of pressure
- Should address: Diesel - Hydraulic Lifter (if present) for: Stuck
- Should address: Diesel - Injector Tubing for: Cracked ferrule from over-torqued coupling
- Should address: Diesel - Injectors for: Leaking (fails to reseat)
- Should address: Diesel - Injectors for: Seized nozzles
- Should address: Diesel - Inlet Air Filters (Element Type) for: Fouled
- Should address: Diesel - Linkages and Controls for: Binding
- Should address: Diesel - Lube Oil for: Low level
- Should address: Diesel - Lube Oil Pressure Control Device for: Drift, Loss of setpoint
- Should address: Diesel - Lube Oil Pump for: Wear
- Should address: Diesel - Muffler and Silencer for: Internal damage
- Should address: Diesel - Oil Filters for: Degraded filter materials
- Should address: Diesel - Oil Filters for: Fouled
- Should address: Diesel - Oil Filters for: Leak
- Should address: Diesel - Pistons for: Piston seizure
- Should address: Diesel - Pistons for: Ring seizure caused by deposits
- Should address: Diesel - Push Rods for: Bent
- Should address: Diesel - Radiator for: Fouled, external
- Should address: Diesel - Radiator for: Fouled, internal
- Should address: Diesel - Radiator for: Leak
- Should address: Diesel - Radiator Cap for: Fails to seal

- Should address: Diesel - Radiator Fan for: Bearing failure
- Should address: Diesel - Radiator Fan for: Damaged blades
- Should address: Diesel - Radiator Fan Variable Clutch for: Failed
- Should address: Diesel - Radiator Hoses for: Leak
- Should address: Diesel - Radiator Tubing for: Leak
- Should address: Diesel - Starter for: Bearing failure
- Should address: Diesel - Starter for: Damaged gear teeth
- Should address: Diesel - Starter for: Failure to engage
- Should address: Diesel - Thermostat for: Fails to operate
- Should address: Diesel - Turbocharger (All Types) for: Bearing failure
- Should address: Diesel - Turbocharger (All Types) for: Blade damage
- Should address: Diesel - Turbocharger (All Types) for: Shaft seal failure
- Should address: Diesel - Turbocharger (VGT Types) - Vane Angle Control and Linkage for: Failed actuator
- Should address: Diesel - Turbocharger (VGT Types) - Vane Angle Control and Linkage for: Sticking
- Should address: Diesel - Turbocharger (WGT Types) for: Stuck valve
- Should address: Diesel - Turbocharger Exhaust Flex Hoses for: Degrades and leaks
- Should address: Diesel - Turbocharger Exhaust Inlet Screen (if present) for: Fouled
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Degraded filter materials
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Fouled
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Leak
- Should address: Diesel - Vibration Damper or Harmonic Balancer for: Failed
- Should address: Diesel - Vibration Damper or Harmonic Balancer for: Loose bolts
- Should address: Diesel - Water Pump for: Leaking seal
- Should address: Diesel - Water Pump for: Loss of pressure
- Should address: Diesel - Wiring Harness for: Loose connections
- Should address: Pump - Bearing Seals - Lip for: Wear
- Should address: Pump - Bearings - Rolling Element (Radial and Thrust) for: Wear, fatigue
- Should address: Pump - Check Valve - Disk Arm (if present) for: Bent
- Should address: Pump - Check Valve - Hinge Pin (if present) for: Binding
- Should address: Pump - Check Valve - Hinge Pin (if present) for: Wear
- Should address: Pump - Check Valve - Rubber Flapper (if present) for: Deteriorated, cracked
- Should address: Pump - Check Valve - Seat Failure (Body or Disk) for: Crud buildup
- Should address: Pump - Check Valve - Seat Failure (Body or Disk) for: Damaged seat
- Should address: Pump - Connections and Piping for: Leaks

- Should address: Pump - Coupling - Elastomeric Element for: Cracking, tearing, or shearing
- Should address: Pump - Discharge and Suction Connections for: Damaged
- Should address: Pump - Gaskets and O-Rings for: Leaks caused by degraded material properties
- Should address: Pump - Impeller for: Corrosion
- Should address: Pump - Impeller for: Loose
- Should address: Pump - Impeller for: Physical damage
- Should address: Pump - Impeller for: Wear
- Should address: Pump - Lubrication - Grease for: Degraded
- Should address: Pump - Lubrication - Grease for: Housing leaks
- Should address: Pump - Priming System for: Failed air compressor
- Should address: Pump - Priming System for: Failed O-ring seals
- Should address: Pump - Priming System for: Stuck ejector ball
- Should address: Pump - Seal - Mechanical Oil Bath Type for: Leaks
- Should address: Pump - Shaft for: Cracked or damaged
- Should address: Pump Casing for: Corrosion or erosion or damage to internals
- Should address: Pump Casing for: Corrosion or rust or damage to externals and bolting
- Should address: Pump Casing for: Wear
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Corrosion or rust or damage to bolting
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Loose fasteners
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Warped, cracked welds
- Should address: Trailer - Bed, Frame, and Lifting Lugs for: Cracked welds or loose bolting
- Should address: Trailer - Electric Brakes for: Failed controller
- Should address: Trailer - Electric Brakes for: Failed end plug, poor connection, damaged cable
- Should address: Trailer - Electric Lights for: Failed bulb
- Should address: Trailer - Electric Lights for: Failed end plug, poor connection, damaged cable
- Should address: Trailer - Hitch or Coupling for: Cracked welds or loose bolting
- Should address: Trailer - Hydraulic Brakes for: Leaking hydraulic hoses and brake cylinders
- Should address: Trailer - Levelers for: Mispositioned or unlevel
- Should address: Trailer - Levelers for: Stuck
- Should address: Trailer - Suspension for: Cracked welds, loose bolting, failed leaves
- Should address: Trailer - Tires for: Damaged - bulged, cracked
- Should address: Trailer - Tires for: Damaged - cut
- Should address: Trailer - Tires for: Incorrect pressure
- Should address: Trailer - Wheel Bearings for: Failed
- Should address: Trailer - Wheel Bearings for: Failed bearing grease

- Should address: Trailer - Wheels (Rims) for: Cracked, dented, bent, warped

Component Operational Inspection

Task Objective

The objective of the Component Operational Inspection (without performing the Performance Test) is to ensure that the engine will start and load to at least 30% and that the pump is at least capable of pumping water. Operational simply emphasizes that the engine and pump must be running to perform the task. The scheduled period under FHS conditions addresses in-service usage in emergency and non-emergency conditions. In a full PM program for FLM conditions, the failure rate is not sensitive to the task interval.

Significant Degraded States

For the task acting alone under FLM conditions, the dominant degradation mechanisms addressed by this task are aging and normal use issues causing degradation of the fuel, oil and fuel filters, and loss of antifreeze compounds in the coolant. Other degradations that are discovered during the execution of this task are battery issues (usually from loss of the ability to hold a charge), leaks from hoses and tubing as well as failed radiator cap seals, failed block heaters, worn belts and sheaves, and clogged crankcase air breathers.

Timing of Significant Degradation

Aging and normal use issues causing degradation of the fuel occur with a failure-free period of 1 to 3 years; however, biological growth contaminating the fuel oil can occur in a 2 to 3 year timeframe unless exposed to moisture and dirt, which will halve the expected time to early failure. Oil and fuel filters begin to exhibit loss of their ability to provide the proper levels of protection at 2 to 3 years. Loss of antifreeze compounds in the coolant should not occur much before 3 to 4 years. Battery issues, usually from loss of the ability to hold a charge, generally have a 3 to 4 year failure-free period unless exposed to constant high levels of heat, which shortens their failure-free period. Leaks from hoses and tubing as well as failed radiator cap seals have failure-free periods of 3 to 6 years; block heaters also exhibit the foregoing time to early failure. Worn belts and sheaves, a clogged crankcase air breather, and failed thermostats should not occur much before 5 to 6 years in nominally mild conditions.

The recommended interval for FHS conditions is every 1000 hours.

Support for the Task Interval and Relation to Other Tasks

It is recommended that this task be performed at the same time as the Performance Test whenever possible. Failure rate sensitivity is for the task in the full PM program under FLM conditions, but this may be different for the task by itself. The failure rate is not sensitive to the task interval.

The recommended interval for FHS conditions is every 1000 hours.

Recommended Task Content

The following rows consist of the Failure Locations and Degradation Mechanisms for which this task is expected to be reasonably effective. It is left up to the user to assemble these lists into a useful craft instruction.

- Should address: Diesel - After Cooler for: Fouled
- Should address: Diesel - After Cooler for: Leak
- Should address: Diesel - Air Box for: Accumulation of carbon deposits and oil
- Should address: Diesel - Alternator and Diodes for: Failed
- Should address: Diesel - Battery for: High resistance connections and cables
- Should address: Diesel - Battery for: Loss of charge
- Should address: Diesel - Battery Charger for: Failed
- Should address: Diesel - Belts and Sheaves for: Worn
- Should address: Diesel - Coolant for: Insufficient antifreeze compound
- Should address: Diesel - Coolant for: Low level
- Should address: Diesel - Coolant or Block Heater for: Corroded or loose connections
- Should address: Diesel - Coolant or Block Heater for: Failed heater (shorted), may be leaking
- Should address: Diesel - Crankcase Air Breathers for: Clogged
- Should address: Diesel - Cylinder head for: Cracked
- Should address: Diesel - Digital Controls or ECU for: Failed, Improper control or display
- Should address: Diesel - Electrical Devices (for example, sensors, solenoids, relays, meters, switches, fuses, lights) for: High resistance, Poor contact
- Should address: Diesel - Emission Control - DPF/DOC (Diesel Particulate Filter - Diesel Oxidation Catalyst) for: Ash buildup (that is, requiring cleaning or replacement)
- Should address: Diesel - Emission Control - DPF/DOC (Diesel Particulate Filter - Diesel Oxidation Catalyst) for: Soot buildup (that is, requiring regeneration by increasing load for a period)
- Should address: Diesel - Engine Mounts for: Failed mount or loose bolting
- Should address: Diesel - Engine Valve Springs for: Broken
- Should address: Diesel - Engine Valve Stem for: Stuck
- Should address: Diesel - Engine Valve Train for: Wear

- Should address: Diesel - Exhaust Gas Recirculation (EGR) Cooler for: External leakage
- Should address: Diesel - Exhaust Gas Recirculation (EGR) Valve for: Sticking
- Should address: Diesel - Flywheel for: Damaged gear teeth
- Should address: Diesel - Fuel for: Biological growth in normal fuel
- Should address: Diesel - Fuel for: Contaminated
- Should address: Diesel - Fuel for: Fuel degradation products
- Should address: Diesel - Fuel for: Improper fuel
- Should address: Diesel - Fuel for: Improper sulfur content capable of causing engine damage
- Should address: Diesel - Fuel Filters for: Degraded filter materials
- Should address: Diesel - Fuel Filters for: Fouled
- Should address: Diesel - Fuel Hoses for: Leak
- Should address: Diesel - Fuel Lines for: Leak
- Should address: Diesel - Fuel Tank for: Wall corrosion and pitting
- Should address: Diesel - Fuel Tank Breather or Vent for: Clogged
- Should address: Diesel - Fuel Tank Strainer (if present) for: Clogged
- Should address: Diesel - Fuel-Water Separator Element for: Excessive water (water may carry over into fuel)
- Should address: Diesel - Gaskets, Seals, and O-Rings (Internal and External Elastomer Type) for: Leak
- Should address: Diesel - Head Gasket for: Leak-by
- Should address: Diesel - High Pressure Fuel Pump for: Loss of pressure
- Should address: Diesel - Hydraulic Lifter (if present) for: Stuck
- Should address: Diesel - Injector Tubing for: Cracked ferrule from over-torqued coupling
- Should address: Diesel - Injectors for: Leaking (fails to reseat)
- Should address: Diesel - Injectors for: Seized nozzles
- Should address: Diesel - Inlet Air Filters (Element Type) for: Fouled
- Should address: Diesel - Linkages and Controls for: Binding
- Should address: Diesel - Muffler and Silencer for: Internal damage
- Should address: Diesel - Lube Oil for: Low level
- Should address: Diesel - Lube Oil Pressure Control Device for: Drift, Loss of set point
- Should address: Diesel - Lube Oil Pump for: Wear
- Should address: Diesel - Oil Filters for: Degraded filter materials
- Should address: Diesel - Oil Filters for: Fouled
- Should address: Diesel - Oil Filters for: Leak
- Should address: Diesel - Pistons for: Piston seizure
- Should address: Diesel - Pistons for: Ring seizure caused by deposits
- Should address: Diesel - Push Rods for: Bent
- Should address: Diesel - Radiator for: Fouled, external
- Should address: Diesel - Radiator for: Fouled, internal
- Should address: Diesel - Radiator for: Leak
- Should address: Diesel - Radiator Cap for: Fails to seal
- Should address: Diesel - Radiator Fan for: Bearing failure
- Should address: Diesel - Radiator Fan for: Damaged blades
- Should address: Diesel - Radiator Fan Variable Clutch for: Failed

- Should address: Diesel - Radiator Hoses for: Leak
- Should address: Diesel - Radiator Tubing for: Leak
- Should address: Diesel - Starter for: Bearing Failure
- Should address: Diesel - Starter for: Damaged gear teeth
- Should address: Diesel - Starter for: Failure to engage
- Should address: Diesel - Thermostat for: Fails to operate
- Should address: Diesel - Turbocharger (All Types) for: Bearing failure
- Should address: Diesel - Turbocharger (All Types) for: Blade damage
- Should address: Diesel - Turbocharger (All Types) for: Shaft seal failure
- Should address: Diesel - Turbocharger (VGT Types) - Vane Angle Control and Linkage for: Failed actuator
- Should address: Diesel - Turbocharger (VGT Types) - Vane Angle Control and Linkage for: Sticking
- Should address: Diesel - Turbocharger (WGT Types) for: Stuck valve
- Should address: Diesel - Turbocharger Exhaust Flex Hoses for: Degrades and leaks
- Should address: Diesel - Turbocharger Exhaust Inlet Screen (if present) for: Fouled
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Degraded filter materials
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Fouled
- Should address: Diesel - Turbocharger Lube Oil Filter (if present) for: Leak
- Should address: Diesel - Vibration Damper or Harmonic Balancer for: Failed
- Should address: Diesel - Vibration Damper or Harmonic Balancer for: Loose bolts
- Should address: Diesel - Water Pump for: Leaking seal
- Should address: Diesel - Water Pump for: Loss of pressure
- Should address: Diesel - Wiring Harness for: Loose connections
- Should address: Pump - Bearing Seals - Lip for: Wear
- Should address: Pump - Bearings - Rolling Element (Radial and Thrust) for: Wear - fatigue
- Should address: Pump - Check Valve - Disk Arm (if present) for: Bent
- Should address: Pump - Check Valve - Hinge Pin (if present) for: Binding
- Should address: Pump - Check Valve - Hinge Pin (if present) for: Wear
- Should address: Pump - Check Valve - Rubber Flapper (if present) for: Deteriorated, cracked
- Should address: Pump - Check Valve - Seat Failure (Body or Disk) for: Crud buildup
- Should address: Pump - Check Valve - Seat Failure (Body or Disk) for: Damaged seat
- Should address: Pump - Connections and Piping for: Leaks
- Should address: Pump - Coupling - Elastomeric Element for: Cracking, tearing, or shearing
- Should address: Pump - Discharge and Suction Connections for: Damaged

- Should address: Pump - Gaskets and O-Rings for: Leaks caused by degraded material properties
- Should address: Pump - Lubrication - Grease for: Housing leaks
- Should address: Pump - Priming System for: Failed air compressor
- Should address: Pump - Priming System for: Failed O-ring seals
- Should address: Pump - Priming System for: Stuck ejector ball
- Should address: Pump - Seal - Mechanical Oil Bath Type for: Leaks
- Should address: Pump - Shaft for: Cracked or damaged
- Should address: Pump Casing for: Corrosion or rust or damage to externals and bolting
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Corrosion or rust or damage to bolting
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Loose fasteners
- Should address: Skid - Diesel and Pump Base Plate or Frame for: Warped, cracked welds
- Should address: Trailer - Bed, Frame, and Lifting Lugs for: Cracked welds or loose bolting
- Should address: Trailer - Electric Brakes for: Failed Controller
- Should address: Trailer - Electric Brakes for: Failed End Plug, poor connection, damaged cable
- Should address: Trailer - Electric Lights for: Failed bulb
- Should address: Trailer - Electric Lights for: Failed End Plug, poor connection, damaged cable
- Should address: Trailer - Hitch or Coupling for: Cracked welds or loose bolting
- Should address: Trailer - Hydraulic Brakes for: Leaking hydraulic hoses and brake cylinders
- Should address: Trailer - Levelers for: Mispositioned or unlevel
- Should address: Trailer - Levelers for: Stuck
- Should address: Trailer - Suspension for: Cracked welds, loose bolting, failed leaves
- Should address: Trailer - Tires for: Damaged - bulged, cracked
- Should address: Trailer - Tires for: Damaged - cut
- Should address: Trailer - Tires for: Incorrect pressure
- Should address: Trailer - Wheel Bearings for: Failed
- Should address: Trailer - Wheel Bearings for: Failed bearing grease
- Should address: Trailer - Wheels (Rims) for: Cracked, dented, bent, warped

5. PM TIPS for FLM and SLM Conditions

PM TIPS present information regarding the PM tasks that are more or less important in the overall PM program. This information may be helpful when there is a need for further customization of the Template recommendations for specific site conditions.

By far the most important case for PM development for N+1 type equipment will be FLM, which will apply to most plant equipment during the long periods of inactivity during standby. Essentially the same comments apply to Flex Support (N) Equipment, where SLM will be the most common and important case. PM TIPS are developed for whichever case (of FLM or SLM) applies.

In contrast, for FLEX (N+1) Equipment, FHS addresses operational disaster relief conditions, where opportunities for customization are most likely very limited. FHM conditions are not expected to be relevant for normal plant type equipment in disaster relief mode. FLS is not expected to be appropriate for normal plant type equipment in standby mode. FLM conditions may conceivably apply in disaster mode for a dedicated tractor trailer, but TIPS are not developed specifically for such an unusual case.

Therefore, FLM addresses *inside* standby conditions for FLEX Equipment, for which some degree of PM Program customization may be appropriate. SLM addresses *inside* standby conditions for FLEX Support (N) Equipment, for which a somewhat greater degree of PM program customization may be appropriate. Further comments on the applicability of these conditions can be found in Sections 4(e) and 5.

The PM TIPS

TIP 1: Under FLM conditions, these tasks, even in the complete PM program, individually have an important effect on reliability. Preserve these tasks:

- Fluid Analysis
- Component Operational Inspection
- Functional Test and Inspection

TIP 1 means that if any one of these tasks is dropped from the full recommended program, the MTBF is likely to decrease by at least a third. Unless the PM program already produces significantly more reliability than required and the task is expensive, it is obviously not a good idea to delete such a task from the program.

TIP 2: Under FLM conditions, omitting these tasks individually from the full PM program does not have a large effect on reliability:

- Fluid Filter Replacement
- Standby Walkdown

TIP 2 means that if you drop any one of these tasks from the full recommended program, the MTBF is not likely to decrease by more than 20%, and often much less. However, because this equipment is rarely if ever actively used, it will be essential to perform some PM tasks to verify its operational readiness (that is, to verify its availability), even though the effect of the task on its failure rate in operation may be slight. Omitting such a Failure Finding task would usually be a mistake. Of course, omitting more than one such task would also compound the negative effect on MTBF, although the effects may not be completely additive.

TIP 3: Under FLM conditions, these tasks, when performed as a group, give good reliability benefit:

None

TIP 3 means that if the PM program consists of just these tasks, the MTBF will remain higher than 80% of the MTBF of the complete program. This includes the compounded effect of the omitted tasks; however, a Failure Finding task should not be omitted if it is more important for its impact on availability than on MTBF.

TIP 4: Under FLM conditions, a single one of these tasks can provide significant reliability benefit by itself:

- Functional Test and Inspection
- Component Operational Inspection

TIP 4 means that such a task, by itself, can improve the MTBF by a factor of at least 2, but only compared to running to failure—so this may not be an impressive improvement in many cases. Even if it is, important Failure Finding tasks may also be needed.

Why Other Tasks May Still Be Important

A less than highly effective task may still be cost-effective when the downside risk is high, and omitting more than one such task would compound the negative effect on MTBF, although the effects may not be completely additive. Further, in mitigating severe accident scenarios, the costs of an in-service failure may be extremely high, justifying the inclusion of otherwise marginal mitigation activities—especially when the mission times over which such tasks are required are quite short. Finally, lack of a task that narrowly targets a small set of degraded conditions may be an obvious deficiency that invites regulatory action even if its overall effect on reliability is small.

Caution: The PM TIPS are provided only as a starting point for customization. None of the PM recommendations provided in the PM Template should be weakened by customizing them for particular plant conditions without a full consideration of the PM Basis for the recommendations. At a minimum, this should include a careful comparison of the customized program with the recommended program using the Vulnerability algorithm.

6. Customization for High Duty Cycle and Severe Standby Conditions

TIPS are not specifically developed for these cases because customization will not normally be appropriate 1) for operational disaster conditions, which will normally experience high duty cycle or 2) for severe standby conditions, because plant equipment (for example, DG, pump, motor, HX, TX, and switchgear) sensitive to such conditions will always be stored inside a qualified building. When mobile cranes and earth moving equipment are used intensively for a long period in disaster relief mode, this will closely resemble normal usage for which much PM experience already exists. This experience will already be reflected in the Template recommendations for SHM without the need for significant customization.

Even in standby, the approach to PM recommendations for equipment such as trucks, trailers, earth moving equipment, and mobile cranes should recognize that it is designed specifically for the outside environment. Thus, SLS might be relevant for such equipment only in the limited circumstances in which severe climatic challenges are the norm, so that the SLS recommendations already represent the required customization.

Appendix B: Details of Key Data Fields

B.1 Failure Locations

Table 1-3 of this report shows a few rows of the component-focused portion of the degradation table for a Volute Casing Type of Single-Stage Horizontal Pump with Mechanical Seal and Rolling Element Greased Bearings. It shows the Failure Locations, Degradation Mechanisms, Degradation Influences, Discovery Opportunities, Stressor Factors, Time Codes, and Repair Times.

For some component types, it may be convenient to arrange the Failure Locations in sections, each denoting a major maintenance-oriented division of the equipment (for example, Actuator and Valve Body for a valve). More often, they are addressed starting from one end of the equipment and working systematically to the other. The order that the panel members find most convenient is the best. Working horizontally along the rows seems to produce the most consistent results and is better suited to keeping all panel members focused on the same topic at one time.

For a single-stage horizontal pump, the complete list of failure locations is quite limited, numbering 16 different subcomponents, shown in Table B-1.

Table B-1
Examples of Failure Locations

Bearing Seals - Lip	Impeller
Bearing Temperature RTDs, if present	Lubrication - Grease
Bearing Vibration Probes, if present	Pump Base Plate and Foundation
Bearings - Rolling Element (radial and thrust)	Pump Casing
Breather Caps and Sight Glass Vents	Seal - Mechanical
Connections and Piping	Shaft
Discharge and Suction Flanges	Stuffing or Seal Box
Gaskets and O-Rings	Wear Ring, if closed impeller

However, these have 21 different degradation mechanisms, caused by 58 different causes (Degradation Influences), totaling 72 different degraded states. It is important to include the causes because the cause can dramatically affect the statistical pattern of failure. For example, if the bearing seals wear from a normal high level of use, the development of wear would follow steady wearout behavior, and no failure would be expected during the first 5 years of use. However, if the cause is misalignment, improper installation, or material defect, seal failure could occur randomly, that is, at any time, including soon after installation. In addition, the cause can dramatically affect the time scale of wearout behavior. For example, pump rolling element bearings can wear to the point of failure because of normal continuous use, but failures would not be expected before an in-service period of 10 to 15 years at the earliest. If the cause is misalignment, the earliest failure might occur after only 1 to 2 years.

B.2 Degradation Mechanisms and Influences

*Degradation mechanism*s are the means by which the equipment is brought to the failure point at the specified failure location. Aspects of the environment, plant operations, maintenance, or design that cause the initiation of degradation processes or that can affect the rapidity with which they develop are simply referred to as *influences* on the degradation. Other sources may refer to these as *causes*.

A partial list of these degradation mechanisms and influences from mechanical equipment is reproduced in Tables B-2 and B-3 to illustrate their range and applicability. They are drawn from other equipment types not shown in Table B-1.

Table B-2
Examples of Degradation Mechanisms

Insulation breakdown	Misadjusted
Change of spring constant	Pinched insulation
Crud buildup on seat	Improper crimping
Sliding wear	Damaged seat
Sticking	Cracking
Incorrect lubricant	Low oil level
Low oil flow	Clogged water cooling ports
Wear	Inadequate clearances
Failed sensor	Loose connections
Failed gasket	Stuck

Table B-3
Examples of Degradation Influences

Moisture from gasket failure	Contamination
Vibration	Misalignment
Run time	Wear
Improper torqueing	Silt accumulation
Aging of pump	Age
Clogged air filter	Leaking sight glass
Clogged/crushed lines	Debris
Cleanliness of process medium	Number of cycles
High temperature	Moisture ingress

These items are only a very small fraction of the total number of degradation mechanisms and influences encountered. The lists in Tables B-2 and B-3 show that some of the degradations are themselves subcomponent failures (for example, failed sensor and failed gasket), while often they are an association of hardware and a mechanism, such as plugged orifices or damaged valve seat. The hardware in such cases is usually a piece-part of the failure location as in *burnt contacts* for the degradation mechanism in pressure switches on a rotary screw compressor. In that case, the influence could be misalignment of contacts or contamination. Similarly, what appears as a degradation in one place can appear as an influence in another—as in *wear* being the influence that causes sticking as the mechanism in a compressor unloader valve, but wear being the degradation mechanism for bearings, influenced by a variety of factors such as *lubrication failure*, *misalignment*, or *normal use*.

This discussion illustrates that a division of the failure process into hardware failure location, degradation process, and influences on the degradation is obliged to invalidate tight definitions if it is going to be reasonably realistic and efficient. For the purpose of understanding what a PM task is trying to achieve, this latitude in definitions does not have any serious consequences. It is more important to have a practical description of the degradation process that is familiar to others skilled in the craft.

One objective of describing the degradation mechanisms and the influences on them is to alert the user to conditions that might be particularly applicable in his or her plant. For example, when moisture ingress and contamination are known drivers of insulation breakdown, and the equipment is in a damp and dirty location, this could be recognized as a vulnerability. The vulnerability might be a consideration if a task interval is being extended. The degradation mechanisms and influences also provide information that might be significant for improving craft training by showing what most to look for. They could also be an indication of the value of adequate procedures and training, especially in cases in which equipment is subject to many kinds of personnel error across a wide range of failure locations. A particularly high or low potential for personnel error, manufacturing defects, or installation errors might also correlate with the risk of performing maintenance and affect decisions to reduce the amount of intrusive maintenance being performed in favor of condition monitoring. The description is also a starting point for designing information feedback processes from the crafts in a living program, because—in combination with history at the plant—it can indicate the particular aspects to look for when performing PM tasks.

B.3 Time Scales for Degradation and Failure

The type of timing information that is useful is that which may have a bearing on applicable task intervals. It has been found to be more productive to ask first for the failure pattern (that is, random or wearout) produced by the combination of degradation and influence and then for the associated failure time. The latter is interpreted as the point at which the condition would become unacceptable because of a high probability of imminent failure. The failure pattern and associated failure time is coded in a simple way in the data field *TimeCode*, recognized by the Vulnerability algorithm.

Two general possibilities of failure pattern are recognized. The first, *Wearout*, is typified by a predictable pattern of deterioration in which a period of time is expected to elapse after a new or refurbished item is placed in service, before the first failures appear. *Wearout* thus implies that the process of deterioration involves an accumulation of some kind of damage, which must reach a threshold before failure will follow. Two types of wearout are recognized. The first is a universally applicable process that will be experienced by every user of the equipment and cannot be avoided. Universal wearout is coded as a UW followed by the expected failure-free period in years or as a range of these values. The second type of wearout is dependent on some special condition that must be present. These *conditional wearouts* are coded simply as a W followed by the expected failure-free period in years or as a range of these values. Some examples of the time codes for wearout are UW5, UW8_12, W2, and W10_20.

When a failure-free period is expected, it is acknowledged that the failure times that follow will obey a bell-shaped distribution—but none is expected to occur before the stated failure-free period.

The second type of failure pattern is one in which there is no expectation of a failure-free period so that failures could conceivably occur soon after the equipment is placed in service or at any time after. In this case, it is supposed that the chance of a failure in any given time period is more or less the same whether the equipment has been in service a short time or a long time. This failure pattern is referred to as *Random* and is coded simply as R with no time scale implied. Some random failures may truly occur “out of the blue” with no prior indication of the existence of a degraded condition, but others are probably a somewhat pathological kind of wearout with a failure-free period that is too short to be usefully mitigated by periodically performed PM tasks.

Other failures could be of the wearout kind but have times to earliest failure that are very sensitive to operating conditions so that the expected range of failure-free period is very large, for example, UW0.1_20. Corrosion processes are sometimes examples of such extreme unpredictability of the process. These may also be coded as *Random*.

"Randoms" are difficult to mitigate using conventional periodic PM tasks, but fortunately almost all random degradation processes appear to have a very low probability of occurrence in a single calendar year. They therefore do not often amount to a significant contribution to the failure rate once those with the highest occurrence rates that constitute what is known as *infant mortality* have occurred early in service life and have been removed. Randoms are nevertheless worth documenting in the PMBD because 1) they do occur and are a recognized and important part of industry operating experience, 2) they are often of mysterious origin, 3) they can be quite numerous, and 4) they are frequently a consequence of human error and are therefore important to acknowledge in personnel training. Various types of operations and maintenance personnel error and manufacturing and installation errors are simply coded as *Random*. Figure B-1 shows the main characteristics of wearout and random failure patterns.

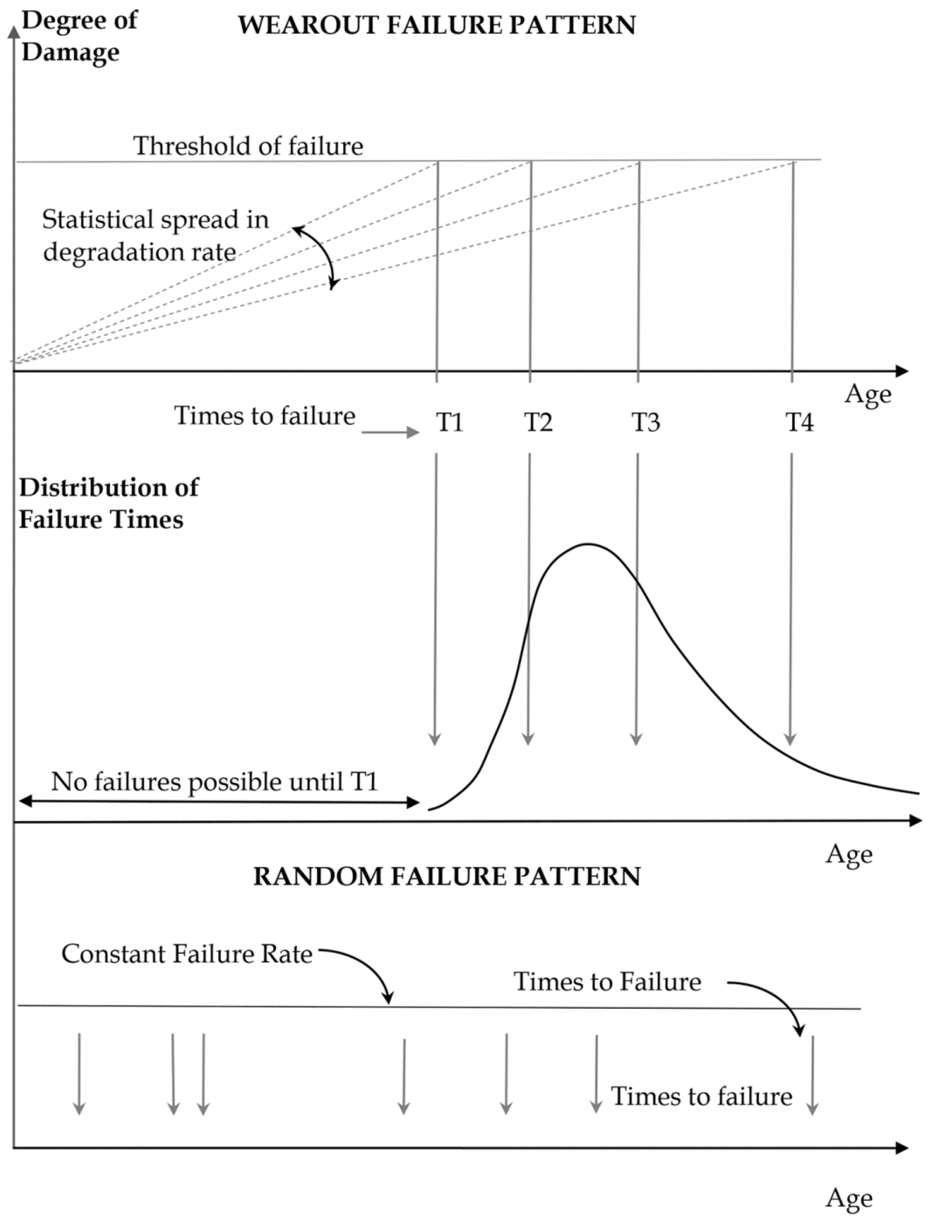

Figure B-1
Failure Time Characteristics Addressed by the PM Basis Database

B.4 Discovery Opportunities and PM Strategies

The Discovery and Prevention Opportunities field is used to denote opportunities for detecting the degradation or failure but not necessarily to identify the exact mechanism or even the exact failure location. The discovery opportunities are recorded only if they represent reasonably applicable possibilities for discovery. They do not have to reach the degree of universal applicability that usually accompanies an activity that is part of a recommended PM Strategy. They may be actions that could be applicable under certain circumstances or include actions that would not normally be considered cost-effective for regular scheduling. These, therefore, are a superset of the actions that are actually recommended.

It should also be remembered that PM Strategies are primarily thought of as preventing in-service failures, that is, reducing the failure rate. Thus, discovering a failure that has already occurred is not a mitigating activity from the perspective of reducing the failure rate. Nevertheless, a PM program should also include failure finding tasks when there are *hidden failures*. These are failures in which the equipment can be in a failed state that would lead to extended and unacknowledged equipment unavailability unless an action is taken to discover whether the equipment can still perform its functions. Actions that discover a failed condition can therefore legitimately be included in this field. Tasks that

qualify as Failure Finding tasks are often some kind of functional test, and these may also include activities that reduce the failure rate as well as discovering hidden failures.

A partial list of the discovery opportunities is shown in Table B-4. Each entry represents the observation, measurement, or test of the item shown.

Table B-4
Examples of Discovery Opportunities

Oil analysis	Diagnostic scans
Oil level and color	Leak rate test
Oil temperature	Reverse flow test
Bearing temperature	Radiography
Vibration analysis	Acoustic monitoring
Motor current	Timed stroke test
Insulation resistance	Minimum voltage test
Winding resistance	Trip load test
Alignment check	Timed stroke test
Inspection	Minimum voltage test
Chemistry sampling	Feel of manual operation
Pressure drop	Power factor loss test
Audible noise	Sounding
Flow	Determine spring constant
Eddy current testing	Manual operation
Thermography	Replace lubricant
Single-phase rotor test	ΔT trend

Discovery opportunities may be translated into more than one potential PM task, as in the case of Inspection, which could appear as *External Visual Inspection*, *Refurbishment*, or some other opportunity to visually examine the subcomponent. *Improper Operation* could be entered as a discovery opportunity, but because it is not a PM task it would obviously not appear as a recommended PM task.

Some of the entries may represent actions to be taken on another piece of equipment, for example, the measurement of motor current to indicate several problems in pump bearings. Such items would be labeled as applying to the other equipment.

Historically in the PMBD, lubrication tasks were not normally referenced as PM tasks when they were part of a plant lubrication program unless there was a specific PM task devoted to it. Consequently, routine filling up of oil reservoirs did not appear as a PM task, although the observation of oil level, color, and leaks appears frequently as discovery opportunities and is addressed by Operator

Rounds as the PM Strategy. Updates and new equipment data sets introduced in the past few years have been more explicit in stating Lubrication as a PM task, however it is accomplished.

Again, historically, parameters that are routinely monitored in the control room or by the plant computer were not described by a specific task on the PM Template, but they may have been mentioned as discovery opportunities and may have received separate treatment in the text describing the PM task rationale. This information can play a vital role in the PM program for a component. Utilities should therefore use all relevant data from these and other sources, such as parameter values from permanently installed equipment instrumentation, to support maintenance decisions. In recent years, the System Owner Walkdown Inspection has routinely included the instruction to examine and evaluate all such information to detect trends that indicate the health of the equipment. More recently, with the development of commercial hardware, software, and services that provide advanced diagnostic and predictive information using continuous monitoring of plant parameters, the PMBD has begun to directly reference Diagnostic Monitoring as a recommended PM strategy where appropriate.

The PM Strategy names have been assigned as recommended by the expert panel to closely match conventional usage for each component type, although the names also vary from one plant to another. This results in a variety of names for similar tasks on different component types, particularly for inspections and partial teardowns. Most of the time, each PM task is described by a task content list in each PM Basis report. Where this is not done, it is because the content is very focused and restricted, as in vibration analysis and oil analysis.

Finally, it should be clear that the extraction of information from the expert panel—and its classification—involved many judgment calls. It was constantly found that the nuances of why the entries are made in a certain way, or are often not made at all, could not be captured in the body of the table, or in the text, in a compact way within the resources of this project. However, the material was discussed extensively in the information elicitation workshops by the expert panel, checked by consultants after entry in the database tables, and subsequently reviewed by the members of the expert panel. In the past 12 years, purposely designed database tools have been used by the consultants to enter the information directly into the database during the workshop, eliminating the transcription of information and enabling the expert panel members to directly view the database tables. Some omissions and inconsistencies undoubtedly remain, but detecting them is not a straightforward task given the subtle and unstated reasoning that underlies many of the entries.

B.5 The PM Template

Each PM Basis data set includes a PM Template. The Template summarizes the program of tasks for the equipment type by presenting the name of each PM task on successive rows of a table. Adjacent is a reference to the section of text where the rationale for the task is described. Columns labeled 1 through 8 select one of the eight sets of conditions that correspond to the combined choices of critical or non-critical equipment, high or low duty cycle, and severe or mild service conditions. Time intervals for the performance of each task are entered at the intersections of the task rows and Columns 1 through 8. A sample Template is shown in Table 2-1 of this report.

When NR (Not Recommended) appears in the Template, it indicates that the expert panel recommended that the task not be applied for the indicated conditions. This was always done on a basis of cost-effectiveness. When AR (As Required) appears, it means either 1) that the task would not normally be performed at a regular interval but only in response to a trigger from another task or observation or 2) that the task would be performed only in response to a regulation. Variations in these regulatory requirements suggested that definite intervals should not be entered in the Template for tasks normally covered by regulations.

For some components, it was thought that there could be no instances in which the combination of criticality, duty cycle, and service condition corresponding to one or more columns in the Template could arise. In these cases, task intervals were replaced by NA (Not Applicable).

The Template shows a program of PM tasks and task intervals that the expert panel believes represents a technically sound and moderately conservative position. The task rationale provides a technical basis that demonstrates the coverage that each task provides for the degradation mechanisms identified in the degradation table, and it shows which of them is most responsible for the timing of the task. The program displayed in the Template is therefore a technically defensible PM program, but it may not be the optimum for a particular plant. Although each plant should take careful note of appropriate vendor recommendations, PM programs should also be informed by the technical basis presented in the PMBD and by their own history of preventive and corrective maintenance. For a plant that already has a PM program based on its own history, the Template can serve as a baseline for comparison, and the rationale section will probably indicate why their program is appropriate or whether it is not appropriate in some aspects. For a plant that does not have an extensive operating history with a particular component type, does not have confidence in its historical data, or does not have the current resources to develop information from its historical data, the Template can be used in concert with appropriate vendor recommendations directly as a default program, with gradual changes anticipated as information is fed back later from a living program.

The task intervals are shown on the Template in years or months. There is normally a level of uncertainty associated with these values that provides for some flexibility in scheduling tasks. The uncertainty has its origin in fundamental uncertainty in the data on failure times and their statistical characteristics and in the practical requirements of scheduling tasks at a refueling outage when they require off-line access to the equipment. When a task could be done only at a refueling outage, a 2-year operating cycle was normally assumed. However, some of the interval assignments were made to coincide with what the expert panel members believed were the correct intervals regardless of the length of an operating cycle. For example, "Replacement of Elastomers" was recommended at 5 years for critical solenoid valves in severe service conditions. This could be scheduled at 4.5 or 6 years for an 18-month cycle or at 4 or 6 years for a 24-month cycle. Obviously, plant experience will dictate the choice among these options.

Before the advent of the Vulnerability algorithm, in general, an increase of 25% in the stated intervals—up to a maximum of 2 years—was thought not to introduce a significant chance of failure in the absence of historical evidence to the contrary. This flexibility also provides the required latitude for exploring the effects of increases in the intervals. It was usually thought that interval extension could proceed in steps of 25% of the existing intervals at a plant, up to a maximum change of 2 years, as long as equipment condition had invariably been good at the existing intervals. This advice is probably still worth following if no other means are available for assessing the impact of PM task intervals on reliability. However, it is essentially a "go slow and wait and see" method. Users of the PMBD can obtain a better sense of this sensitivity by consulting the technical basis in the PMBD and by consulting the PM TIPS. Users should be aware, however, that the technical basis and PM TIPS in the PMBD are derived using specific assumptions about the operating context (that is, duty cycle and stressors) for critical components, which may not coincide with the user's application. Users of the PMBD are strongly advised to use the Vulnerability tools to establish the sensitivity of reliability and availability to changes in PM task intervals under their specific conditions. This will not only be user-specific, but it will also provide immediate input to the PM improvement effort using the result of actual analysis based on expert knowledge and judgment derived from industry experience.

B.6 Duty Cycles

Duty cycle is used in this work to provide an opportunity for PM requirements to depend on the degree to which the equipment is used. Wear of sliding or rolling surfaces; effects of thermal and mechanical transient stresses arising from normal operation and starting, stopping, and cycling; deterioration in material properties and chemical composition; and even the relocation and separation of lubricants that may result from prolonged inactivity are all aspects of the degradation that results from the different degrees of use. It was found that a simple binary choice of a High or Low duty cycle provides sufficient flexibility to describe the effects of duty cycle on PM tasks and intervals. High and Low duty cycles are not necessarily synonymous with continuous operation and standby operation, respectively, although sometimes it is indeed as simple as that (for example, for electric motors).

Equipment that is alternated between periods in standby and periods of continuous running, such as pumps and motors, is likely to be treated as high duty cycle because the equipment is still operated continuously for an appreciable fraction of the time. However, continuous operation does not always imply that there should be PM differences depending on the *amount* of usage. When the equipment is specifically designed for continuous duty, as in the case of most reciprocating compressors and rotary screw compressors, a more meaningful way to differentiate the maintenance effects of high and low duty cycles should include consideration of the degree of loading of the equipment when it is operating (partial loading equates to high duty cycle). Compressors are also differentiated in duty cycle according to whether they experience more than one start/stop cycle per hour. In addition, the non-lubricated types of reciprocating compressor also include consideration of the number of hours of continuous service per day.

Duty cycle for check valves included the degree of oscillation under flow conditions as well as the number of check cycles per year. The duty cycle definition for AOVs simply equated control functions (that is, modulating) with high duty cycle and isolation functions with low duty cycle.

Medium and Low Voltage Switchgear is not designed for a large number of operations or cycles without maintenance, and many of these components are scarcely operated at all. Therefore, a single value for cycles per year was used as the threshold between high and low duty cycles. Motor Control Centers (MCCs), in contrast, are not ever likely to challenge their design capabilities in terms of numbers of operations in nuclear power plants so that all MCCs were considered to have the same duty cycle (set as low, although whether high or low is of no interest). Pressure relief valves were also considered homogeneous in duty cycle (also low) because any operations at all represent a severe challenge to continued operation for a Safety Relief Valve, and the number of operations of Power-Operated Relief Valves before maintenance is required is relatively low.

These examples illustrate that the definition of *duty cycle* for the purpose of differentiating between levels of PM is extremely component-specific and needs to be approached with great care. It also demonstrates that there is a belief in the industry that the degree of usage of a component, however it is defined, may dictate the level of maintenance and might imply a dependence of reliability on duty cycle. In spite of this, about half of the component types covered had no differences at all between high and low duty cycles in the tasks and intervals recommended, even though the differentiation of the duty cycles themselves had been treated very carefully by the expert panel, as discussed previously. This may indicate that it is impractical in some cases to adjust maintenance to compensate for suspected duty cycle effects or that the experts were unclear about the changes needed. In this situation, exploring alternative task intervals using the Vulnerability algorithm will provide appropriate insight.

B.8 Service Conditions

Service conditions are used in the PM Basis to provide an opportunity for PM requirements to depend on a variety of process, environmental, and even design variables that appear to influence degradation rates and which could therefore require recommended maintenance to be modified according to these conditions. Once again, a binary choice was introduced between severe and mild service conditions. Overall, there tends to be a more or less standard set of severe service conditions, with mild conditions being the absence of the severe factors. Different equipment types may also have the severe conditions somewhat modified depending on the equipment.

Severe service conditions for Medium-Voltage Switchgear are typical of those representing a general sensitivity to humidity, heat, vibration, and contamination. The definitions in this case are as follows:

- **Severe:** High or excessive humidity, excessive temperatures (high or low) or temperature variations, excessive environmental conditions (for example, salt, corrosive materials, high radiation, spray, and steam), high vibration.
- **Mild:** Clean area (not necessarily air conditioned), temperatures within OEM specifications, normal environmental conditions.

In these definitions, *excessive* denotes a chronic exposure to conditions that exceed the original equipment manufacturer's recommendations. Often this can mean the difference between equipment located outside a building—exposed to the effects of weather and the local atmosphere—in relation to equipment located inside a building, regardless of whether the area is temperature controlled or air conditioned. Because the damage from severe conditions is normally cumulative, a few episodes of exposure may also be sufficient to qualify for severe conditions, such as exposure to dust and dirt during construction or cleaning.

Equipment exposed to an internal process environment, such as valves, should also have the internal environment considered. In some instances, such as check valves, the internal environment is by far the dominant consideration and includes important design aspects. These may partially duplicate factors more explicitly covered by the duty cycle definition, as the check valve case demonstrates. The duty cycle for check valves includes the number of check cycles per year and the degree of oscillation in flow conditions:

- **Check Valve - Severe:** One or more of the following conditions apply: flow conditions below maximum; subject to rapid opening or closing from the flow condition; installed in a non-recommended orientation; <10 pipe diameters from valve, pump, or pipe bend; turbulent or high velocity flow; corrosive fluids; debris-laden fluid.

Motor-Operated Valves include being cycled less than once per year as a qualification for severe service conditions. Electric Motors include high speed (>3600 rpm) as a reason to be considered as operating in severe service conditions because of the higher levels of vibration that tend to accompany high speed rotation. Pumps include consideration of speed, operation off the best efficiency point, frequent starts and stops, and extended operation at minimum flow conditions.

These examples show that it was sometimes necessary to include duty cycle or design aspects in statements about service conditions.

A reasonable level of consistency was the goal, but the definitions were intended only to provide guidance on the likely sensitivity of the task intervals to a broad range of considerations. Many plant-specific factors will come into play when adapting the Template intervals to a particular application. The definitions of *criticality, duty cycle, and service conditions* and the variation of recommended intervals across the columns in the Template provide a reasonably good picture of how significant the expert panel members thought the various effects should be. However, considerable variability may be introduced by the use of different service stressors when in severe service conditions. This is another reason for using the Vulnerability algorithm to detail the effect of the actual operating context as carefully as possible. The service stressors that can be turned on by the user at run time are intended for use only when there is a marked departure from mild conditions. Their effects are not additive because the algorithm does not know how to combine the effects of different stressors. Therefore, even when more than one stressor can influence a given degraded state, and more than one of them is turned on, the effect is limited to that of a single stressor.

B.9 Maintenance Risk

The term maintenance risk is used here to represent effects that accompany preventive maintenance that tend to increase failure rates rather than decrease them. If PM tasks are not performed correctly, if the wrong parts are used, or if the equipment is not properly adjusted and restored to operation after maintenance, this is a fairly direct way in which shortcomings in human factors can reverse the potential benefit of the task. Poor training, inadequate procedures, and poor supervision and management can be responsible. However, even when these factors are not above normal, there remains a finite probability of human error. There is also the chance that the PM task contains suboptimal practices such as over-greasing or subjecting electrical insulation to potential breakdown by using high-voltage tests. The act of removing switch covers, terminal blocks, lugs, and fasteners creates additional fatigue and mechanical stresses that can lead to deformation, leaks, and broken subcomponents.

The overall probability of maintenance error can be expected to be approximately proportional to the amount of maintenance performed. It would also seem likely that the more disassembly and reassembly required to perform a task, and the more complex the restoration of the equipment in terms of adjustment, setup, and realignment, the more opportunities there will be for errors to arise.

The risk of maintenance may therefore be high or low, depending on the equipment. For example, the expert panel members had the opinion that electric motors should not present significant maintenance risk because, other than alignment of the rotor on the magnetic and mechanical center, there are few other opportunities for serious errors. Switchgear and air-operated valves represent the other end of the spectrum, with multiple ways in which intrusive PM tasks can cause equipment reliability to be worse than it was before the tasks were performed. The point was demonstrated during the early years of this project when utility data from nuclear power plants on AOV reliability were correlated with the PM tasks being performed on them. A large and pervasive negative correlation was discovered between the frequency of intrusive PM (that is, internal inspections, parts replacement, and overhauls) and the reliability of the valves.

To provide further perspective on the importance of maintenance risk, it should be realized that the probability of an implementation error can be as high as 5–10% for some activities, and some equipment types have multiple items of this critical nature in a given PM task. Such numbers could thus lead to a probability of failure—from maintenance causes alone—of greater than 10%. This is a potentially large increase in the probability of subsequently failing to perform its function because target levels of reliability in the nuclear power industry are usually demanding (that is, a few percent or even less). Post-maintenance testing is likely to reveal only immediately lethal errors, not those that manifest themselves after a short time in service. Furthermore, there may be an amplification factor that operates because a PM task is often added as a corrective action to a whole population of components in a plant (sometimes ~100), whereas the problems that gave rise to the task additions may typically have affected only a very few components. A 20% chance of a maintenance error per task can then cause many more failures than it was intended to cure. This effect is enhanced if a task is performed many times in the life of a component.

Members of the expert panels were therefore routinely asked whether the component type being considered presented a significantly higher risk of further failures if intrusive PM was performed too frequently.

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