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Critical Equipment Maintenance Using EPRI Preventive Maintenance Basis Database (PMBD) Recommendations for a Combustion Turbine Plant

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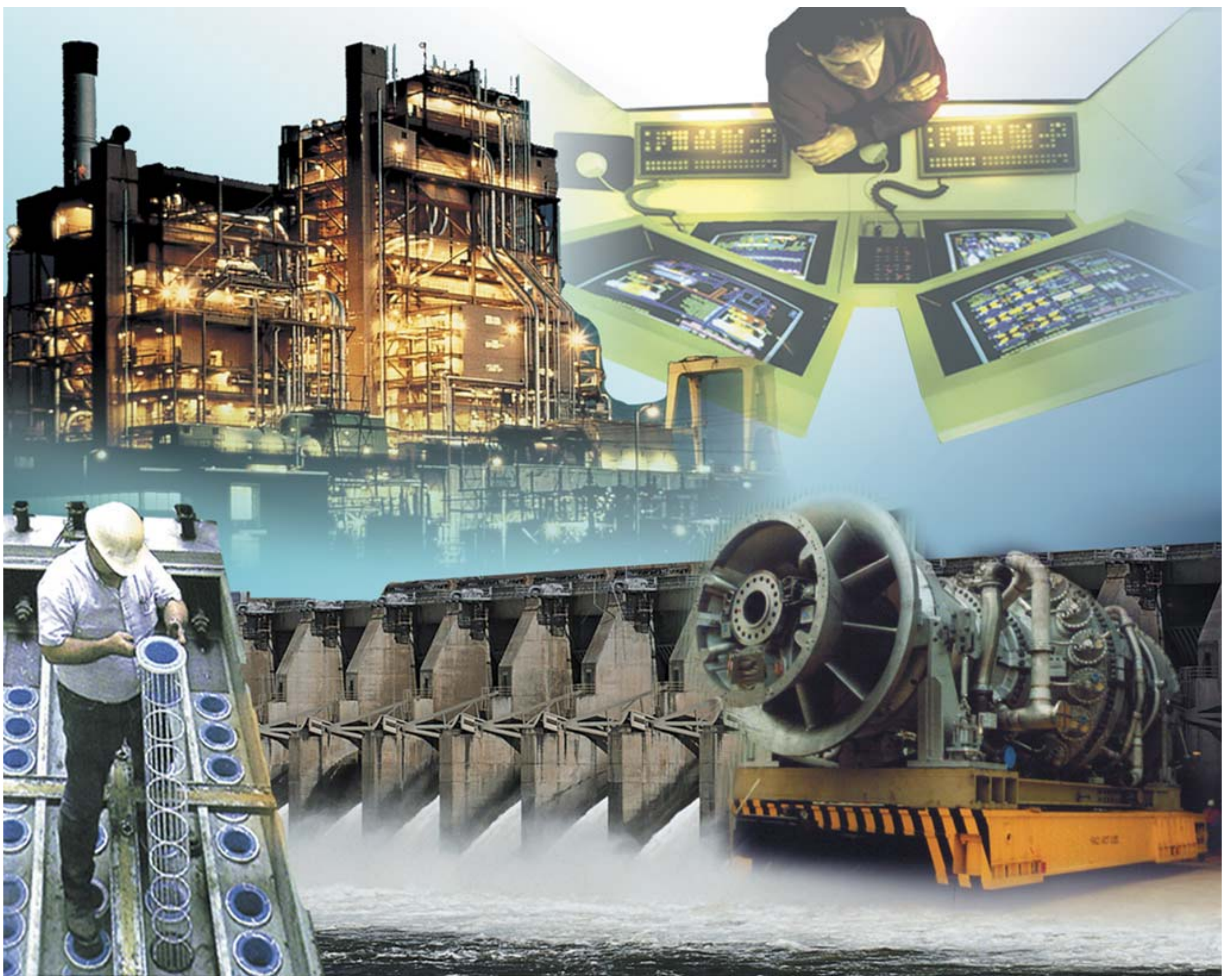

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Technical Update, November 2009

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PRODUCT DESCRIPTION

This technical update report covers specific component preventive maintenance strategies that were developed in cooperation with East Kentucky Power Cooperative's J.K. Smith plant personnel and EPRI's Generation Sector Fossil O&M group personnel. The EPRI Preventive Maintenance Basis Database (PMBD) 2.0 software tool was used to define preventive maintenance defense strategies for specific plant components. Many of the plant components were located in the balance-of-plant (BOP) areas at the station. The main combustion turbine (CT) and generator components related to combustion chamber, hot gas path, and major inspection areas were excluded from the EPRI recommendations.

Results and Findings

The results of the specific maintenance task decisions are quantified with regard to individual task content, frequency, and effectiveness in the appendix of the report.

Challenges and Objectives

This report can be used by management and the plant maintenance organization to better understand the value and effectiveness of their preventive maintenance decisions with regard to critical plant components and maintenance task optimization. The preventive maintenance decisions at most CT plants are usually centered around the use of on-site personnel and contract personnel to provide an adequate failure defense plan for plant equipment. Knowing the effectiveness of the plant component's failure defense plan can create substantial savings in nonfuel O&M maintenance costs by focusing resources where they are more effectively utilized.

Applications, Value, and Use

Maintenance task optimization can be used by any power generation sector to provide low-cost alternatives to large-scope condition based maintenance (CBM) programs, either by the individual utility or contracted maintenance service providers. Preventive maintenance (PM) task optimization can be easily accomplished using the EPRI PMBD software tool to direct the efficient use of utility preventive maintenance resources.

EPRI Perspective

Maintenance task optimization has historically been a strategic goal of reliability centered maintenance (RCM) initiatives. The EPRI PMBD tool provides the utility user with a way of measuring the intrinsic task effectiveness without undertaking the full rigor of a facilitated working group approach to RCM.

Approach

The member utility received assistance in classifying its plant equipment as to criticality, environment, and duty cycle along with the recommended preventive maintenance programs required to maintain the inherent reliability of those plant components. Selected equipment components were chosen by the utility power station so that a PM defense strategy could be developed using the EPRI PMBD software.

Keywords
Preventive maintenance
Condition based maintenance
Maintenance task optimization
Preventive Maintenance Basis Database (PMBD)
Reliability centered maintenance (RCM)

ACKNOWLEDGMENTS

Many thanks go to East Kentucky Power Cooperative's J.K. Smith plant personnel for their assistance in developing the critical equipment list and providing information regarding their specific equipment maintenance schemes.

Additionally, thanks are extended to Synterprise LLC for providing assistance with and offering solutions to the member utility's needs for actively capturing plant event data in their enterprise asset management system (EAMS). Synterprise LLC also helped train the member utility's site personnel in the use of their EAMS for event reporting and recording significant maintenance actions related to the plant maintenance hierarchy.

— Dan Flanigan, EPRI

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1 INTRODUCTION

Background – J.K. Smith Power Station

East Kentucky Power Cooperative’s (EKPC’s) J.K. Smith Power Station (Smith) is a 627 gross MW (summer) / 842 gross MW (winter), seven unit, #2 fuel oil or natural gas fired, simple-cycle combustion turbine power plant. It supplies 18–20% of EKPC’s peak power generating requirements. Three of the seven units (Units 1–3) are 110 gross MW (summer) / 150 gross MW (winter) units, model 11N2, manufactured by ABB and placed into service in 1995. Units 4, 5, 6, and 7 are 74 gross MW (summer) / 98 gross MW (winter) units, model 7-EA, manufactured by General Electric and placed into service in 2001 and 2004. Smith employs 7.5 full time equivalent employees (the plant manager position is a 50% split with another EKPC plant), with 1.5 management positions and 6 CT technicians.

Plant Maintenance Optimization

EKPC’s Smith Station, working with EPRI Solutions, completed an initial phase of a plant maintenance optimization (PMO) program in late 2003. The first phase included a PMO workshop held in September 2003, which most of the Smith Station personnel attended. The workshop introduced and educated management and the work force to the goals, processes, attributes, and technologies of PMO. Additionally, the workshop provided the opportunity for the plant work force to evaluate the performance attributes of their organization and identify the critical issues to be addressed and overcome during any future implementation of PMO. The workshop was followed by the PMO assessment. The assessment began with the review of requested data from the plant and was followed by two days of interviews conducted by the EPRI Solutions assessment team. Approximately seven personnel representing management and workers were interviewed. The purpose of the interviews was to gather data from plant personnel, at all levels, as to how work is currently being identified, planned, scheduled, and performed. The data collected during the interviews was evaluated, and a gap analysis of 20 key process elements was performed by the EPRI Solutions assessment team. This data was used to benchmark the plant against best practices and to tailor the assessment focus for Smith Station. Implementation of the PMO past the initial plant assessment was never begun by EKPC. Additionally, the Smith Station preventive maintenance (PM) basis consisted roughly of legacy PMs that were accomplished on an as-required basis.

Preventive Maintenance Basis

Preventive maintenance programs at electric power plants in the United States have evolved from strict compliance with the supplier’s general recommendations to more flexible tasks that are intended to accommodate plant-specific service conditions. During the 1990s, the industry, with support from the Electric Power Research Institute (EPRI), embarked on preventive maintenance optimization (PMO) programs. Most utilities either have implemented or are in the process of implementing these PMO programs.

The successful implementation of a PM program should result in the following:

- Identifying the optimum level of PM tasks necessary to achieve a balance between the equipment performance and the effective use of resources
- Providing a well-documented engineering basis for selecting PM strategies that can be the same as, different from, or in addition to the vendor's recommendations
- Addressing the component failure modes that could impact the plant's safety and availability
- Identifying the appropriate scope of the critical equipment for which PM activities are needed
- Identifying components that are not important to the plant's safety or availability but that can be removed from the PM program to make the maintenance resources available for other more important tasks

The information contained in this technical update represents a significant collection of human performance information, including techniques and good practices, related to the self-assessment of PM programs on specific power plant components. The assemblage of this information provides a single point of reference for the plant personnel who make up the PM organization. Through the use of this technical update, utilities should be able to significantly improve and consistently implement the processes associated with PM activities and their frequencies for specific critical plant components. This should help the user to achieve increased reliability and availability of the components on which the work activities are performed during outages and on-line maintenance opportunities.

PM Basis Analysis Process Flow

Developing a preventive maintenance basis for power plant components from scratch can be a very labor-intensive effort consuming large amounts of analysis resources. It is not recommended that standard power plant components—that is, motors, pumps, compressors, fans, valves, and so on—be analyzed using a labor-intensive process such as reliability centered maintenance (RCM) to determine specific PM strategies.

An alternative to PM analysis strategies like RCM includes the use of the EPRI Preventive Maintenance Basis Database (PMBD) software tool, which can be used by utility members to optimize PM strategies on over 150 specific standard power plant components. The EPRI PMBD can provide the utility member with specific task recommendations for preventive maintenance based upon the equipment classification and component type. Currently there are approximately 150 components in the EPRI PMBD that can be quickly referenced to determine the recommended PM strategies to maintain the inherent reliability of the component(s).

For power plant equipment that is not part of the EPRI PMBD software tool, the following multistep approach to developing a PM basis analysis effort can be used when analyzing specific system components or whole systems. These steps are shown here only as a guide and quick reference alternative to using the EPRI PMBD software tool.

1. Determine PM basis project goals and objectives. Goals should be aligned with plant upper tier goals for developing and maintaining a reliable PM basis.

2. Establish criticality criteria based upon project goals. Criticality criteria typically include safety, production, cost, and any regulatory attributes. Typical criteria are established using risk ranking methodologies.

3. Acquire a full set of plant system drawings (flow and control or process and instrument diagrams, instrument loop diagrams, and so on), system descriptions, design source documents (FSAR, DBD, and so on), maintenance history, vendor documents, and commitments.

4. Perform a detailed system walkdown (acquire component name plate information; make notations about component particulars).

5. Review drawings and identify system boundaries. Consider marking up drawings (P&ID) to show what is included and what is not included within boundaries.

6. Identify the system function or functions. Include engineering parameters such as pressure temperature, timing, voltage, flow, and so on.

7. Identify the system failure mode/s, failure effect/s, and failure cause/s.

8. Identify components within the system to be analyzed.

9. Identify each component's function or functions (include engineering parameters).

10. Determine each component's failure mode/s, failure effect/s, and failure cause/s for each failure mechanism.

11. Based on the component's function, failure mode, and failure effect, assign a criticality/priority for the component.

12. Compile component history, plant personnel interviews, CMMS history, preventive maintenance (PM) information (PMs already in place and open and closed work orders), vendor manuals, predictive maintenance (PdM) activities (vibration analysis, oil analysis, thermography, and so on), condition monitoring program activities (heat exchanger performance, motor-operated valve [MOV], air-operated valve [AOV], erosion/corrosion, and so on). It should be noted to document this information so the analyst can refer to facts if required to justify the recommendation made to the system owner (because the system owner will be referring to facts that they have on the component).

13. Interview plant personnel (maintenance, operations, system engineering, engineering programs, PdM group, planning, and so on) about component and system performance issues—what problems have been encountered in the past; whether there have been any repetitive problems; what preventive and/or predictive maintenance is being performed and at what frequencies; and what effect component failure/s would have on the system and on the plant. (It is recommended that different individuals from several functional plant organizations be interviewed. Everyone has different knowledge levels and opinions.)

14. Identify what preventive, predictive, and condition monitoring tasks should be performed and at what frequencies.

15. Compare the identified PM basis tasks to current plant practices, vendor recommendations, component history, plant personnel interviews, any commitments that have been made, and so on, and then make a PM basis recommendation.

    A PM basis recommendation should be a clear and concise statement as to:

    - What is to be performed
    - Who is performing the task
    - On what component
    - At what frequency

16. Develop a PM basis justification to support each PM basis recommendation.
    At a minimum, a PM basis justification should consist of:

    - The purpose of the task
    - The failure mechanism(s) addressed by the task
    - The maintenance history results
    - A comparison of the existing or recommended task and frequency with the EPRI PM basis template, if an EPRI PM basis template was used, and/or industry best practice, vendor recommendation, commitments, and so on
    - What effect a failure would have on the plant and/or system
    - Any references that are used

17. Provide a cost analysis, if that information is available, for any recommended changes or additions of tasks and identify which craft or group is affected by this recommendation.

18. Once **all** system components have been analyzed and recommendations made, inform the system owner that the PM basis recommendations are ready for review and approval. During the review process, if questions arise concerning any recommendation/s, be prepared to discuss the facts surrounding the recommendation/s made and resolve any questions.

19. After system owner review and approval, the system component PM basis recommendations are to be presented, by the system owner, to the plant management, maintenance, PdM group and operations for approval. Again, if questions arise concerning any recommendation/s, be prepared to discuss the facts surrounding the recommendation/s made and resolve any questions.

20. Once the system owner has received an approval for the system component PM basis recommendations, the recommendations should be turned over to the PM basis analyst for processing. The PM basis analyst should document the recommended changes in a PM change request (PMCR) for each affected component and submit the PMCR(s) to the PM basis coordinator for submittal. The PM basis coordinator should submit the PMCR(s) to Planning for implementation.

Equipment Classification

The station equipment list consisted of approximately 7000 components that were classified by the station personnel with assistance from EPRI. The following guideline was used to classify the equipment as critical, noncritical, or run-to-failure. Additional determinations were made as to each component's duty cycle (high or low) and service condition (severe or mild). Within the EPRI PMBD software tool, the following designations are used for equipment classification.

Using the PM Basis Database, a component designated "CHS" would be considered Critical, High duty cycle in a Severe service condition.

Classification Definitions

Criticality

Critical – Functionally important—for example, risk significant, required for power production, safety related, or addressed by other regulatory requirements.

Minor – Functionally not important, but economically important—for example, for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, or high potential to cause the failure of other critical or economically important equipment.

Run-to-Failure – Functionally and economically insignificant component not having an effect on plant maintenance or operation. These cases are excluded from the EPRI PMBD templates.

Duty Cycle

High – Continuous duty, including high cycling conditions

Low – Standby duty: started, brought up to stable system conditions, and returned to standby

Service Condition

Severe – High or excessive humidity, excessive temperatures (high/low) or temperature variations, excessive environmental conditions (for example, salt, corrosive, high radiation, coal dust, spray, steam), high vibration

Mild – Clean area (not necessarily air-conditioned), temperatures within OEM specifications, normal environmental conditions

EPRI PMBD Component Template Tables

The PM basis template tables are designed as shown below in Table 1-1. PM tasks range from simple visual inspections to labor-intensive rebuilds and restorations. Condition monitoring tasks largely include infrared thermography, vibration analysis, and lube oil analysis. Task frequency abbreviations include the following:

S – Shift
D – Day
W – Week
M – Month
Y – Year
BO – Boiler Outage
TO – Turbine Outage

Criticality
Critical – C
Minor – M

Duty Cycle
High – H
Low – L

Service Condition
Severe – S
Mild – M

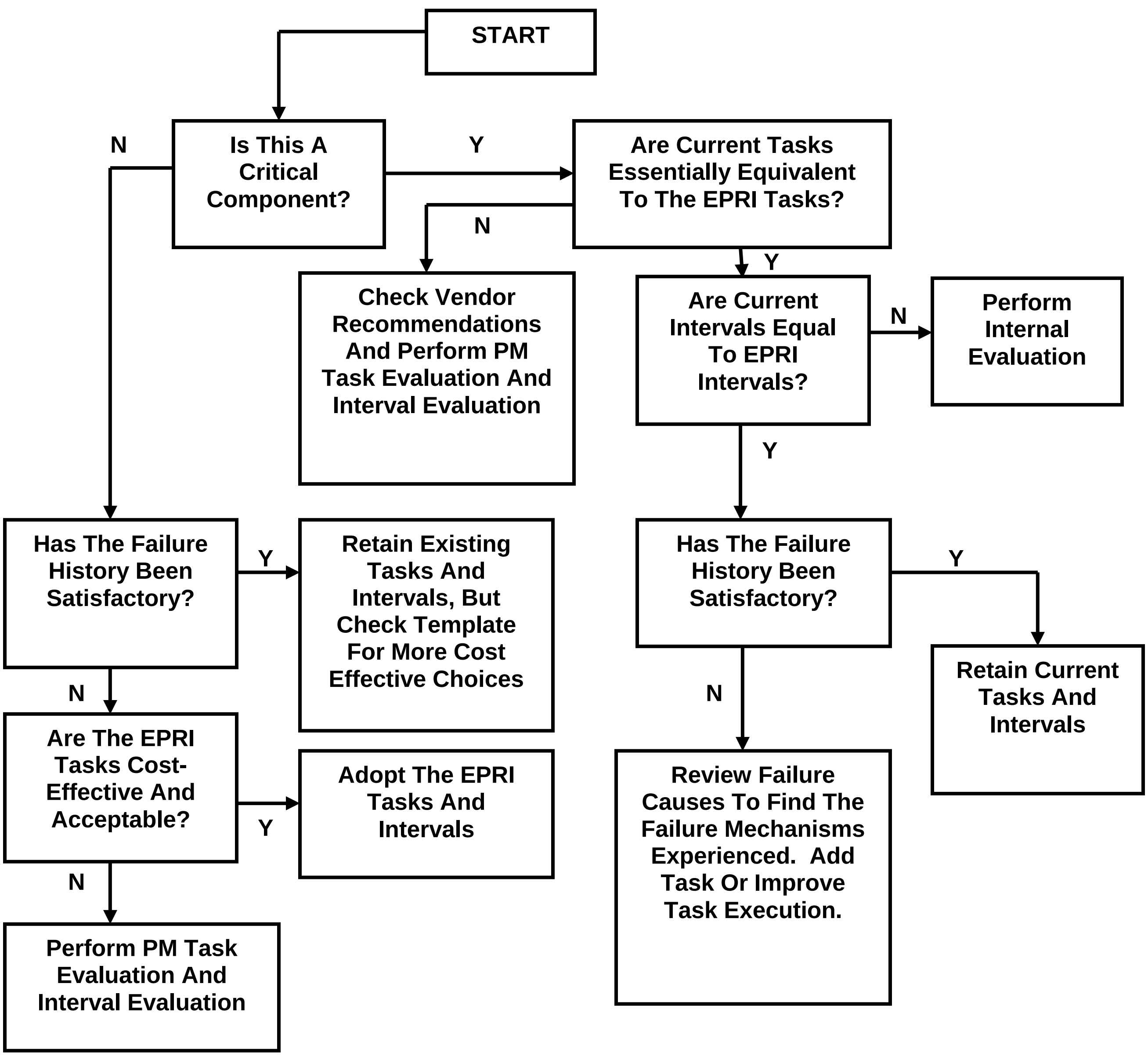
Table 1-1 PM Basis Template Design

	Criticality	**Critical**				**Minor**			
	Duty Cycle	**HI**	**LO**	**HI**	**LO**	**HI**	**LO**	**HI**	**LO**
	Service Condition	**Severe**		**Mild**		**Severe**		**Mild**	
	Abbreviation	**CHS**	**CLS**	**CHM**	**CLM**	**MHS**	**MLS**	**MHM**	**MLM**
PM Task1		Task 1 Freq CHS	Task 1 Freq CLS	Task 1 Freq CHM	Task 1 Freq CLM	Task 1 Freq MHS	Task 1 Freq MLS	Task 1 Freq MHM	Task 1 Freq MLM
PM Task2		Task 2 Freq CHS	Task 2 Freq CLS	Task 2 Freq CHM	Task 2 Freq CLM	Task 2 Freq MHS	Task 2 Freq MLS	Task 2 Freq MHM	Task 2 Freq MLM
PM Task3		Task 3 Freq CHS	Task 3 Freq CLS	Task 3 Freq CHM	Task 3 Freq CLM	Task 3 Freq MHS	Task 3 Freq MLS	Task 3 Freq MHM	Task 3 Freq MLM

Determining Critical Plant Components

An assessment of the Smith Station's balance-of-plant (BOP) equipment and components was made to determine their criticality. Individual components that had a direct relationship with the plant's ability to start on demand or were a requirement to run the CT units or support their safe operation were deemed critical by the assessment team. Additionally, components that had regulatory, safety, and/or environmental concerns and issues were also deemed critical. The criticality determinations were documented within a plant equipment spreadsheet. The station personnel were also encouraged to document the individual component criticality within their EAMS for future reference and failure review. The component failure review process shown in Figure 1-1 can be used to adequately adjust PM frequencies and/or tasks when the failure defense for plant components has failed.

Figure 1-1
PM Basis Component Failure Review and Logic Diagram



PM Basis Process Development

Adopting a PM basis process strategy can be a very formal affair. The station must be cognizant of the execution cost of the PM tasks to be performed and aware of the component's failure history. Cost/benefits should be defined before large PM and PdM programs are implemented. Unacceptable component reliability or high failure repair costs often drive the PM basis development strategy to adopt more effective maintenance tasks. The EPRI PMBD software development was based upon a very detailed expert elicitation process involving industry component experts, end users, and manufacturers of the individual PM basis components.

Not all PM tasks are created equal. The effectiveness of one PM task over another at detecting a given failure mode is what sets the EPRI PMBD apart from other PM basis task optimization processes. The individual component PM optimization tables shown in the Appendix A results section define which tasks have a greater reliability effect in terms of detecting component failure modes. It is assumed that the tasks are done correctly and at the most effective time—that is, before the onset of a degraded component condition.

2
EQUIPMENT HIERARCHY

Discussion

The original equipment list for the plant was downloaded from the EAMS into an Excel spreadsheet. The equipment list included over 7000 components related to the CT station. The major components were divided into plant locations to help better define the specific pieces of equipment within plant locations and areas. Within the EAMS, locations were defined to describe the plant hierarchy by the specific CT location or BOP location for common systems. In this case, seven CTs and their ancillary systems and equipment were defined, as shown below in the seven-unit combustion turbine plant CT1 through CT7:

GAS TURBINE PLANT HIERARCHY

CT1 through CT7

- **CT Enclosure**
  - PROPANE
  - GT
    - TURBINE SECTION INSTRUMENTS
    - COMPRESSOR SECTION INSTRUMENTS
    - IGV’S
  - GENERATOR
    - SEAL OIL
    - EXCITER
    - NEUTRAL POINT CUBICLE
    - INSTRUMENTATION
    - COOLERS
    - STANDSTILL HEATERS
  - STARTING DEVICE
  - LUBE OIL BLOCK
    - HYDRAULIC
    - LUBE OIL
    - RACHET
  - HEATING AND VENTILATION
  - COMBUSTOR TOWER
  - STRUCTURE
- **Cool and Seal Air System**
  - ATOMIZING AIR
  - PURGE
- **Cooling Water**
- **PECC and AA**

Inlet and Exhaust

- BLEED HEAT AND ANTI ICING
- FILTERS
- INSTRUMENTATION
- SILENCERS
- STRUCTURES
- SHUTTERS AND DOORS

Auxiliary Skids

- WATER WASH AND DRAIN TANKS
- FIRE PROTECTION
- FUEL GAS
- FUEL OIL
- WATER INJECTION
- COMPRESSOR WASH
- GENERATOR ACCESSORY CUBICLE
- BB MODULE
- CC MODULE
- FUEL GAS FILTERS

Balance of Plant

- NOX FORWARDING BUILDING
- FUEL FORWARDING BUILDING
- FIRE AND SERVICE WATER BUILDING
- SWITCHYARDS
- FUEL FORWARDING BREAKER BUILDING
- RIVER INTAKE AREA
- OIL WATER SEPARATOR TANK AREA
- NEUTRALIZATION BASIN 1
- NEUTRALIZATION BASIN 2
- ELECTRICAL ROOM 1
- MICROWAVE TOWER AREA
- FUEL OIL STORAGE TANK AREA
- FUEL OIL SEPARATOR TANK
- DEMIN # 1
- DEMIN # 2
- WATER TREATMENT PLANT BUILDING
- WAREHOUSE
- MAINTENANCE GARAGE
- OLD BOP CONTROL ROOM
- OPERATIONS CENTER AREA
- FUEL FORWARD 6
- FUEL FORWARD 7
- PDC
- GAS HEATER 1
- GAS HEATER 2

DUKE GAS YARD
BLACKSTART BUILDING
SMITH HR LOCATION
GAS YARD
GAS VALVE STATION
VEHICLES

Specific CT Station Work Process Assessment

From interviews with the plant staff, the following characteristics were determined regarding the PM program at the station:

- No formal PM basis established—only major CT equipment PM basis exists
- Minimal work orders used to document maintenance performed at the station
- Work identification determined through nightly rounds
- Legacy PMs that are remembered
- Site-superintendent-identified work
- PMs performed mainly based on OEM recommendations; therefore, actual amount of required optimized work (PMs) is undetermined
- No site-specific PdM program or equipment and condition indicator (E&CI) matrix established
- Work prioritization maintained by both site superintendent and CT technicians
- No formal EAMS schedule maintained to perform PMs
- Limited documentation of corrective maintenance performed by CT technicians
- Instrumentation call-sheets do exist
- Major equipment maintenance history maintained by vendor, through warranty work, and available to station personnel

PdM Technologies

- EAMS not fully utilized at the CT station
- Lube oil sampling done monthly on turbines only, sent to central lab for analysis
- Results returned, via e-mail and hard copy, within 2 days
- Results only indicate specifications that were out of limits
- Never had a results report indication of lube oil problem, have had indication of dirty sample bottles
- On-line vibration monitoring on turbines; alarms occur for increased vibration
- No periodic vibration monitoring done on any other rotating equipment
- Substation crew performs infrared thermography (IRT) on switchyard equipment and transformer—frequency unknown, no other IRT performed at station
- No other PdM technologies performed, for example, acoustics, motor testing, and so on
- Central lab performs lube oil analysis
- Transformer insulating oil analysis (only provided to substation crew)
- Water sample analysis
- Fuel oil samples (only performed for state requirements)

- Environmental lab monitors stack emissions and spills
- Most data/information reporting is hard copy
- No PdM EAMS executed program in place
- No integration of data/information gathered from various sources

Management and Work Culture

- Reasonable accountability is maintained
- Overall concern that staffing levels are not adequate
- Utility is considering going strictly to fuel oil as primary fuel at the station due to price of natural gas. It is generally believed by most station staff that this change will significantly increase the amount of station maintenance required.
- Leadership at station is recognized as very good
- Chain of command communication within station is recognized as excellent
- Across discipline communication not applicable due to station supervision and technicians covering both the operations and maintenance sides of the house
- Only goal set and tracked is Availability to Start when Needed—this is done through tracking successful starts vs. total starts

Station People Skills

- Site management has good experience and is well qualified
- CT technicians exhibit good work habits and appear eager to learn new tools and processes
- Majority of technicians have limited power plant experience
- Formal training at station is adequately maintained
- Training budget exists
- OJT training is maintained through rotation of off-shift personnel to day-shift to work with experienced technician
- Most site personnel feel that the use of the EAMS will help to better document equipment corrective conditions and CT non-starts
- Hot gas path, combustor, and major inspections are now being performed by the station crew instead of the equipment vendor

EKPC – J.K. Smith Work Flow

The current maintenance work flow at the station takes on four distinct processes, as shown in Figure 2-1. The work flow process is initiated via operator rounds and informal equipment health reviews by the experienced CT station personnel. The four work processes can be categorized as show below.

1. Work identification
2. Work prioritization and review
3. Work execution
4. Archive work accomplished

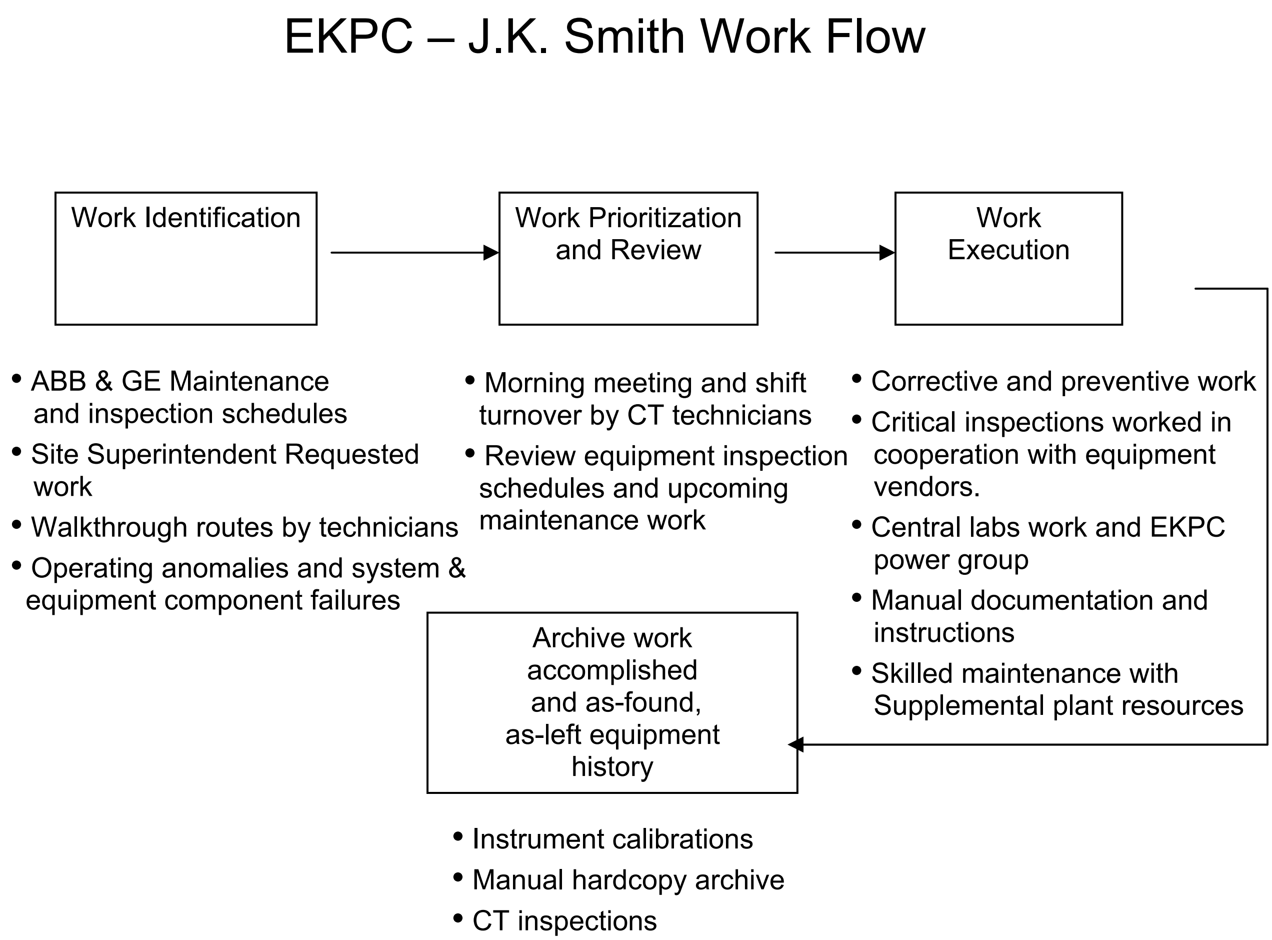


Figure 2-1
JK Smith Station Work Process Flow

3

PM BASIS CONCLUSIONS

Recommendations

The PM Basis Database tool can be used to optimize the preventive maintenance at almost any CT power station with very little analysis effort. The nineteen components that were analyzed and shown in Appendix A form the backbone of a station's component PM program.

The EPRI-recommended PM tasks have been identified by the PMBD 2.0 software as mitigating PM tasks to the failure modes identified within the software tool. The recommended task frequencies are based upon expert elicitation of the expert panels utilized to develop the component PM basis templates.

The following recommendations should be followed before implementing the PMBD tasks within this technical update:

1. A cursory comparison of the power station's PM tasks to the recommended EPRI PMBD tasks should be made before EAMS implementation. If task frequencies of the EPRI tasks represent a considerable increase in labor resource expenditure, then a cost-benefit analysis should be performed to justify added resource expenditures before implementation of the EPRI baseline frequencies and task recommendations. If component failure histories show unacceptable incidences of occurrence, then a frequency change may be justified.

2. Predictive maintenance (PdM) or condition based maintenance (CBM) on power station equipment can be a very viable PM strategy and is used extensively in the EPRI PMBD templates for failure mode detection. However, many PdM/CBM tasks require that the equipment be running to perform certain tasks (vibration analysis, IR thermography, on-line motor monitoring, and so on). The cyclic operation of a CT plant does not often allow for convenient periods of on-line inspection. Every opportunity to collect baseline PdM/CBM data should be taken advantage of to create adequate baseline condition-based data so anomalies can be identified and corrected.

3. Many times a system engineer walkdown or operator rounds will reveal incipient failure modes more effectively. These types of tasks should be considered first because of their relatively low execution cost. However, again the CT plant must be running to observe certain failure modes for individual plant components.

The nineteen PM optimization tables in Appendix A represent a cursory assessment of the intrinsic task effectiveness for the individual PMs shown. The two columns labeled 1) Task(s) to Perform to Obtain ≥ 50% Reliability Benefit and 2) Task(s) to Perform to Obtain ≥ 90% Reliability Benefit are based upon a PM program in which the station is not currently performing PMs on the component. An acceptable intrinsic reliability benefit can many times be obtained without performing numerous PM tasks. The key to an effective PM program is to perform more highly effective PM tasks, not just more PM tasks.

A

EKPC J.K. SMITH STATION – PM BASIS DATABASE RESULTS

Results Discussion

Categorization of the station equipment and components was accomplished with the help of EPRI personnel, based upon the equipment criticality, duty cycle, and service conditions. All component classifications were documented in an equipment database spreadsheet for reference and future equipment additions. A relatively large portion of the Smith Station equipment was classified as critical equipment based upon the assessments made by the team. Of the 7000 components classified, approximately 1000 were classified as critical, ~ 14.3% of the total. Run to failure equipment was also identified by the team, but not included in the team's assessment results.

Nineteen PM basis components were chosen by the plant to be included in the results of this Technical Update report. The following PM basis recommendations are included as a PM strategy and guide for station personnel. The PM basis task template tables, component PM assessments, PM optimization tables, and PM task descriptions form the results of this technical update.

Electric Motors – Medium Voltage (600V<15kV)

Table A-1 Electric Motors – Medium Voltage

Template Data Report:	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
Motor - Medium Voltage - <15kV	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Thermography	6M	6M	6M	6M	6M	6M	6M	6M
Vibration Monitoring	3M	3M	3M	3M	6M	6M	6M	6M
Oil Analysis And Lubrication	6M	6M	6M	6M	1Y	1Y	1Y	1Y
Electrical Tests - On-line	6M	1Y	6M	1Y	1Y	2Y	1Y	2Y
Mechanical Tests - On-line	3M	6M	3M	6M	6M	1Y	6M	1Y
Electrical Tests - Off-line	2Y	4Y	2Y	4Y	4Y	4Y	4Y	4Y
Mechanical Tests - Off-line	2Y	4Y	2Y	4Y	3Y	5Y	3Y	5Y
System Engineer Walkdown	3M	3M	3M	3M	3M	3M	3M	3M
Mechanical Refurbishment	AR	AR	AR	AR	AR	AR	AR	AR
Refurbishment	10Y	15Y	10Y	15Y	10Y	20Y	10Y	20Y
Operator Rounds	1S	1S	1S	1S	1D	1D	1D	1D

Component PM Assessment

For Electric Motors – Medium Voltage (660V<15kV) the EPRI PMBD recommends eleven tasks to maintain the inherent reliability of the component, as shown in Table A-1. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-2 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-2 has been included to show the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The addition of just one task, Mechanical Tests – On-Line, for medium-voltage electric motors will result in 50% greater reliability benefit than doing nothing. The execution of four PM tasks: Vibration Monitoring, Electrical Tests – On-Line, Mechanical Tests – Off-Line, and Operator Rounds will result in 90% greater reliability than doing no preventive maintenance at all.

Table A-2 Electric Motors – Medium Voltage PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Thermography	1.0		
Vibration Monitoring	1.0		√**
Oil Analysis And Lubrication	2.0		
Electrical Tests - On-line	2.0		√**
Mechanical Tests - On-line	2.0	√*	
Electrical Tests - Off-line	24.0		
Mechanical Tests - Off-line	10.0		√**
System Engineer Walkdown	1.0		
Mechanical Refurbishment	80.0		
Refurbishment	120.0		
Operator Rounds	0.25		√**

√* - Performing this one task will provide a 50% reliability benefit.
√** -Performing four PM tasks; Vibration Monitoring, Electrical Tests-On Line, Mechanical Tests-Off Line and Operator Rounds will result in 90% greater reliability

Infrared Thermography

Task Objective:

The main application of thermography is to provide an indication of the condition of exposed electrical connections, and to complement other indications of bearing wear, and the condition of air passages. Some flexibility is possible in the interval, although a few common wearout failure modes with short development times affecting bearings are addressed.

Task Content:

Thermography should include:
- Inspection for unusual and unbalanced heating of the connections at the main motor and motor heater leads and their respective power cable interfaces
- Unusual differences in exit air temperatures when compared to historical values
- Inspection for unusual heating in motor bearing and windings that cannot be attributed to normal thermal patterns and temperatures

Principle Failure Locations and Causes:

The main application of thermography is to provide indication of the condition of power cable connections, and to complement other indications of bearing wear from causes related to lubrication failure. Since the bearing temperature is directly measured by in-situ RTDs or thermocouples, thermography plays a backup role. Thermography can usually only give an indication of increased temperatures in the general surface region of the bearing casing, where this is accessible. Other indications of bearing wear are oil and vibration analysis, and motor current monitoring. Occasionally, thermography may also be useful in detecting blocked air passages.

Progression of Failure Mechanisms Over Time:

The lubrication related causes of bearing wear appear randomly over a period of many months up to 2 years. Blocked air passages and high resistance electrical connections have a similar time scale.

Task Interval Support:

None of the above causes is likely to fail the motor catastrophically on short time scales, so that a 6 month interval appears appropriate for thermography. This means that for safety related standby motors the thermography survey could be performed at the same time as surveillance testing. In the case of standby motors, thermography and the other on-line tests should be performed after the motor has been running at rated speed for four hours in order to reach a stable operating temperature and hence give valid measurements.

In some instances, e.g. the impairment of the oil pumping action caused by excessive oil in vertical configuration bearings, the degradation could be sufficiently rapid that thermography at a 6 month interval would not be an effective method of detection.

In any case, both direct bearing temperature indication and motor current are likely to be monitored continuously, i.e. observed every shift, and vibration and acoustic monitoring provide independent indications of bearing wear. Consequently, thermography is not a critical technology for detection of bearing wear in this class of motors.

Thermography scans on motors should be saved and trended for change.

Vibration Monitoring

Task Objective:

Vibration monitoring is very effective for addressing misalignment and wear in rotating components. There is essentially no latitude for interval extension because of the large number of random failure mechanisms involved, and a few very short term wearout modes.

Principle Failure Locations and Causes:

Vibration monitoring is very effective for addressing all causes of wear in bearings of all types. Additionally, vibration monitoring addresses all causes of failures originating in the shaft, in the rotor, including wound rotor windings, and in the frame, enclosure and mounting, including loose air baffles.

Progression of Failure Mechanisms Over Time:

Most of the causes of bearing failure appear randomly over a period of several months up to 2 years. The appearance of cracks, wear, and bowing in the shaft, and all degradation mechanisms in the rotor, although random in occurrence times, are not expected within a few years. The onset of degradation in the frame, such as deformation, weld failures, cracking, and soft foot share similar timing characteristics as for the shaft and rotor, although the progression to failure could be rapid if the vibration is close to a structural resonance.

Task Interval Support:

The suggested interval of 3 months for critical motors should be sufficiently frequent to make vibration monitoring an effective detection method for a wide range of failure causes. This interval has been recommended by the EPRI Maintenance and Diagnostic Center for inclusion in V3.0, instead of the original 6 month interval for all conditions. The new recommendation is more in line with the failure mode data.

Additionally, the frequency of vibration can provide specific diagnosis or focus further investigation in many instances.

Vibration monitoring spectrums on motors should be saved and trended for change.

Oil Analysis and Lubrication

Task Objective:

Oil sampling and analysis is particularly directed at causes of bearing and bearing seal wear for all types of bearings, and bearing cooling water leaks. There is essentially no latitude for interval extension because of the large number of random failure mechanisms involved, and a few very short term wearout modes.

Principle Failure Locations and Causes:

Oil sampling and analysis is particularly directed at causes of bearing wear for all types of bearings. Also covered are all sources of wear for bearing seals. Other failure causes that affect oil quality are failed cooling coils in the oil distribution system, and all the causes of wear on the shaft (including cracks and bowing). Oil temperature above the rated limit can lead to degradation. Typical anti-friction bearing temperatures usually will not exceed 45° C above ambient; 2-pole motors usually will not exceed 50° C above ambient.

Lubrication should follow the plant specific lubrication program. The regreasing of greased bearings should follow intervals stated in EPRI Report NP-7502.

Progression of Failure Mechanisms Over Time:

All the above degradation mechanisms are random in time of onset but in most circumstances are expected to appear over periods of many months or years, and are not expected to lead to failures on short time scales.

Task Interval Support:

The suggested interval of 6 months for critical motors should be sufficiently frequent to make oil analysis an effective detection method for a wide range of failure causes. This interval has been recommended by the EPRI Maintenance and Diagnostic Center for inclusion in V3.0, instead of the original 1 year interval for all conditions. The new recommendation is more in line with the failure mode data.

The sampling timeframe should only apply to those bearings with clean cavities and lubricant.

Lube oil analysis results on motors should be saved and trended for change with an industry accepted software analysis tool.

Electrical Testing – On-Line

Task Objective:

This task addresses degradation of rotor components, and degraded wound rotor winding connections. The interval is not strongly determined by the failure mode data but a significant number of common random failure mechanisms are addressed.

Task Content:

Electrical Tests – On-Line could include some or all of the following; these tests should be trended and compared to historical data to derive their maximum benefit:
· Motor current and power signature analysis
· Applied voltage and running current testing
· Flux monitoring

Principle Failure Locations and Causes:

The electrical on-line tests include a series of tests that are directed at detecting degraded or cracked rotor bars and shorting rings, loose connections on wound rotor windings, and a loose rotor cage. Motor current signature analysis may also detect defective insulation on stator laminations.

Progression of Failure Mechanisms Over Time:

Degraded wound rotor connections, and cracked rotor bars and shorting rings have random occurrence times and occur commonly.

Insulation on stator laminations continuously degrades and is expected to provide a failure free period that may approach 40 years although the degradation depends markedly on the degree of contamination, the temperature, vibration levels, and the quality and type of the stator lamination material and insulation (i.e. M19 steel and C5 insulation).

Task Interval Support:

Most of the degradations addressed by this task produce measurable effects before failure, and many are commonly encountered. There is a large difference between the intervals of 6 months to 1 year included in V3.0, which were recommended by the EPRI Maintenance and Diagnostic Center, and the original intervals of 3 years to 4 years. Because several of the failure mechanisms addressed are found commonly, the failure mode data suggest intervals less than those originally proposed.

In the case of standby motors, the electrical on-line tests should be performed after the motor has been running at rated speed for four hours in order to be at a stable operating temperature.

On-line electrical testing on motors should be saved and trended for change.

Mechanical Tests – On-Line

Task Objective:

This task addresses practically all sources of bearing degradation for all types of bearings, and many other failures in the oil distribution and bearing systems, as well as failed cooling coils and overheated windings. The interval is constrained by large numbers of random failure modes and a few short term wearout modes which are addressed.

Task Content:

Mechanical Tests - On-Line might include:
· Verification of name plate motor speed
· Acoustic monitoring
· Bearing temperature monitoring (continuous in most cases) and trending
· Winding temperature monitoring and trending
· Inspection of motor slip ring and brushes for abnormal wear, if present
· Monitor oil temperature and flow
· Monitor cooling water pressure, temperature, and flow
· Inspect for: damaged, loose, missing or vibrating parts, externally visible oil leaks around bearings and bearing seals, external water leaks around water bearing and stator cooling interfaces, broken or loose grounding cables, damaged conduits and seal flex, damaged wiring and insulators, damaged junction boxes and their gaskets, blocked / clogged / plugged air filters and inlet air screens
· Inspect bearing slinger rings for proper operation and movement
· Verify proper oil level; oil should not be discolored
· Inspect for plugged oil sight glass vent
· Verify proper motor strip heater status indication
· Listen for unusual noises
· Could also include percent load, duty cycle, and number of starts where appropriate and measurable.
· It would also be useful to include other periodic monitoring data such as vibration and thermography results into the trends.

Principle Failure Locations and Causes:

This task is essentially Performance Monitoring and utilizes installed plant instrumentation where available. The measurement of bearing temperatures and acoustic monitoring are very effective means of detection of practically all sources of bearing degradation for all types of bearings. Additionally, bearing temperature can be the means of detection of other failures or degradation in the oil distribution and bearing systems such as a blocked oil metering orifice, failed slinger rings, or a failed cooling coil, or failed seals. Consequently, the mechanical on-line task is focused principally on bearing systems and oil degradation through the measurement of bearing temperature. Bearing temperature may also detect wear on the shaft, deformation of the frame, or a loose rotor cage.

Measurement of cooling water flow and pressure is an additional means to detect failed cooling coils, and is a part of the mechanical on-line measurements.

Measurement of stator winding temperature provides detection of overheated windings, whether from local winding hotspots, increased mechanical load, or from clogged air filters, blocked air passages and screens, additional to what can be observed in the external visual inspection where all of these parts may not be accessible.

Progression of Failure Mechanisms Over Time:

The causes of bearing wear appear randomly over a period of many months up to 2 years, but in some cases can produce rapid deterioration depending, for example, on the degree of mechanical loading.

Frequent or continuous monitoring of bearing temperature can provide adequate coverage of even the rapidly developing degradation mechanisms, including damage to bearing seals. Less frequent degradations consisting of or leading to wear on the shaft, deformation of the frame, or a loose rotor cage are also covered by frequent bearing temperature monitoring.

Winding temperatures are also likely to be monitored continuously or at least more frequently than the performance of the mechanical on-line task because of the simplicity of the measurement. Winding temperature measurement also covers the clogging of air filters, screens, and air passages which can degrade significantly over a period of a few months. High winding temperatures above rated values from high temperature environments provide early indication of the likelihood of premature winding failure. Although the effect of elevated temperature on winding life is said to be well understood, predictable, and severe, winding failures from this source are expected only on a time scale of several years.

Task Interval Support:

Frequent bearing temperature and winding temperature measurements provide effective coverage of all the degradation modes mentioned above. Providing these are performed frequently, the other parts of the mechanical on-line task may be performed at intervals of one or two years. For V3.0, the EPRI Maintenance and Diagnostics Center has recommended shifting the emphasis in the Template to these more frequently performed activities and showing the intervals as 3 months to 6 months for this task. However, bearing temperature, motor current, and winding temperature may either be continuously recorded or observed every shift during operator rounds, which would permit the Mechanical on-line task to be performed at the one or two year intervals.

The mechanical on-line tests include visual observation of arcing at brushes and slip rings although more detailed inspection of brushes is included in the mechanical off-line task, or may even constitute a more frequent separate task if there is a history of brush problems.

In the case of standby motors, the mechanical on-line tests should be performed after the motor has been running at rated speed for four hours in order to be at a stable operating temperature.

On-line Mechanical testing on motors is basically a series of performance monitoring tasks that should be monitored and trended for significant physical changes.

Electrical Testing – Off-Line

Task Objective:

The task focuses on detecting degraded insulation, degraded electrical connections, and high resistance shorts and grounds in electrical components. The interval is not strongly determined by the failure mode data.

Task Content:

Electrical off-line tests can only be conducted meaningfully when all parts of the motor are within 10° F of ambient temperature. The tests should include some or all of the following; these tests should be trended and compared to historical data to derive their maximum benefit:

· Winding resistance
· Insulation resistance
· Polarization indexing
· Motor circuit evaluation
· AC High Pot.
· DC Step voltage

· Surge testing
· Power factor tip-up testing

Principle Failure Locations and Causes:

This task contains four main ingredients: measurements of winding resistance, insulation resistance, polarization index, and motor circuit evaluation. The task focuses primarily on detecting degraded insulation, whether associated with windings, bearings, feeder cables, or motor leads, the integrity of all electrical connections, and the detection of high resistance shorts and grounds in electrical components such as switches and surge capacitors.

Progression of Failure Mechanisms Over Time:

Electrical insulation is subject to continuous degradation. The main causes of insulation degradation are excessive heat above the rated limit, excessive starts within a short period, winding movement and vibration, age, and contamination (which may be e.g. oil, moisture or salt).

Although the initiation of these influences may be random, the degradation progresses relatively slowly and is expected to give a trouble free period of at least several years (exception could be high temperatures from excessive starts within a short period, which should be controlled by operational procedures). Insulation on stator laminations also degrades continuously and is expected to provide a failure free period that may approach 40 years.

Problems with feeder cables, motor leads, connections, lugs, switches and electrical devices such as surge capacitors are likely to occur randomly on various time scales, shorter than those above making these quite common occurrences. Measurement of winding resistance can detect shorts between turns, and ductor tests can be performed to evaluate the resistance of connections.

Task Interval Support:

The off-line tests could be performed every 2 to 4 years to provide effective coverage for the degradation modes discussed above. The interval recommendations in V3.0 and V3.1 are only slightly modified from the original intervals, on suggestions from the EPRI Maintenance and Diagnostics Center.

It is likely that only the first four items listed below would be included in every scheduled electrical off-line test. The remaining tasks could be included every other time.

Electrical testing – Off line on motors is basically a series of off line tests designed to address insulation degradation and wearout. Not all listed tasks need to be performed to maintain component reliability.

Mechanical Tests – Off-Line

Task Objective:

This task addresses a wide range and large number of common and random failure modes. However, these do not strongly constrain the task interval.

Task Content:

Mechanical Tests - Off-Line might include:
· Borescope of all accessible motor internals, air passages, and air gap
· Verification for proper alignment
· Inspect motor mountings for indications of soft-foot

· Inspect the slip ring and brushes for abnormal wear and proper alignment
· Hand rotate to determine presence of any shaft run-out, binding or rubbing noise
· Inspect for: damaged, loose, missing or vibrating parts, externally visible oil leaks around bearings and bearing seals, external water leaks around water bearing and stator cooling interfaces, broken or loose grounding cables, damaged conduits and seal flex, damaged wiring and insulators, damaged junction boxes and their gaskets, blocked / clogged / plugged air filters and inlet air screens.
· Inspect end windings for abrasion and tightness.
· Inspect bearing slinger rings for proper operation and movement
· Verify proper oil level; oil should not be discolored
· Inspect for plugged oil sight glass vent
· Verify proper motor strip heater status indication
· Listen for unusual noises

Principle Failure Locations and Causes:

The off-line mechanical task consists of an internal visual inspection combined with an alignment check. The alignment check, by dial indicator or laser, addresses soft-foot, as well as the degradation processes that affect the shaft (wear, sagging, and cracking). The off-line task also includes inspection of air passages, end windings, and bearing surface condition including Babbitt thickness. Soft-foot, and worn slip rings or brushes are other targets for inspection.

Additional inspection can be carried out by borescope. The objective then is to examine otherwise hidden areas of the rotor and stator for loose, damaged, or contaminated laminations, failed rotor bars or shorting rings, corona damage to insulation or fretting of insulation, broken surge rings or failed surge ring support brackets, broken ties or loose wedges, as well as loose windings, pole pieces or banding on wound rotors.

An additional test uses eddy current detection to examine the mechanical integrity of the cooling coil. This requires entry into the cooling coil and need not be performed at every mechanical off-line test.

Progression of Failure Mechanisms Over Time:

The most rapid degradation mechanisms addressed by this task are those involving wear of brushes for wound rotor motors where serious degradation can occur in weeks. Other rapid deterioration can occur from causes of misalignment. The remaining degradation mechanisms in this group occur randomly but on a time scale of many years.

Corrosion, erosion and fouling may act continuously or randomly and may result in cooling coil failures at random times. Eddy current testing provides the only effective means to detect such degradation before failure, since partial disassembly would otherwise be required in order to view the coil, and it is not a regularly scheduled task.

Task Interval Support:

If there is a history of rapid brush wear or deterioration there may be a need for a frequent brush inspection as a separate task. Vibration monitoring on a time scale of months should provide early warning of misalignment problems. The other sources of degradation in this group lead to a task interval in the range 2 to 3 years. The intervals in V3.0 have been modified slightly from the 2 year to 4 year recommendations of earlier versions at the suggestion of the EPRI Maintenance and Diagnostic Center.

Depending on the size of the motor, some consideration should be given to performing the mechanical off-line task only on condition indications from another task.

Off-line Mechanical testing on motors is basically a series of mechanical inspections that address multiple failure modes. Not all listed tasks need to be performed to maintain component reliability.

System Engineer Walkdown

Task Objective:

System Engineer Walkdown focuses mainly on visible indications of deterioration in oil quality, oil and grease leakage, low oil level, and air flow blockages. There is little opportunity to extend the interval because several common short term wearout failure mechanisms are addressed in addition to large numbers of random failure modes.

Task Content:

System Engineer Walkdown should include:

- Inspect for: damaged, loose, missing or vibrating parts, externally visible oil leaks around bearings and bearing seals, external water leaks around water bearing and stator cooling interfaces, broken or loose grounding cables, damaged conduits and seal flex, damaged wiring and insulators, damaged junction boxes and their gaskets, blocked / clogged / plugged air filters and inlet air screens
- Inspect bearing slinger rings for proper operation and movement
- Verify proper oil level; oil should not be discolored
- Inspect for plugged oil sight glass vent
- Verify proper motor strip heater status indication
- Listen for unusual noises

Principle Failure Locations and Causes:

System Engineer Walkdown focuses mainly on causes of visible indications of deterioration in oil quality, visible oil and grease leakage and low oil level, either from problems with wear of bearings or bearing seals, or from any failure in the oil distribution system. External visual inspection is also effective for detecting clogged air filters and blocked air passages or screens.

Bearing temperature, motor current and winding temperatures are all likely to be either continuously recorded or observed every shift during operator rounds. These frequent observations are included in the external visual inspection task, although plants will have a separate procedure, possibly a part of operator rounds, for how they are observed, recorded or trended. Bearing temperature is a key indication for all causes of bearing wear, failures in the oil distribution system, and other failures that can affect the wear of bearings. Motor current can also detect some bearing failures but usually at a later stage of development than bearing temperature. Winding temperature is a useful indicator for clogged air filters, air passages, and winding insulation failure.

Certain degradation processes in electrical circuits can also be observed, such as degraded insulation on feeder cables, and failed space heaters.

The inspection also includes general observation for loose, missing, or damaged parts, and listening for unusual noises or vibrations.

Progression of Failure Mechanisms Over Time:

Almost all the above degradation mechanisms are random in occurrence.

Task Interval Support:

The interval of 3 months is thought to be sufficient to detect the onset of most of the visible failure causes.

System engineer walkdown of motors is a visual inspection that addresses multiple random failure modes of the motor and its components. Since the failure modes are random in nature the omission of this task could lead to significant component failure issues.

Mechanical Refurbishment

Mechanical refurbishment of critical and non-critical motors is recommended on an "As Required" basis. The primary focus would be on worn mechanical parts, seals, bearings, etc… as determined by other PM tasks; Oil analysis, Vibration monitoring, On and Off-line mechanical and electrical tests, etc.

Task Objective:

The primary motivation for Mechanical Refurbishment is to change the bearings or other components when other diagnostic measurements indicate the need.

Task Content:

Mechanical Refurbishment should include:

- Replacement or reconditioning (Babbitt bearings only) of the bearings, bearing seals, gaskets, O-rings, and bearing insulation. After replacement, the bearing insulation should be tested to assure it provides the required degree of isolation from electrical currents that could damage the bearing.
- Ultrasonically test the bearing Babbitt for proper bond and the presence of voids
- Inspect and test for leaks in the oil cooling system
- Inspect and test for leaks in the stator cooling system
- Verify the operation, alarm action, general condition, and calibration of local bearing temperature indicators.
- Check for damaged, loose, or missing parts
- Removal of motor end covers and inspection plates and covers to allow access to motor bearings and windings without floating the rotor (i.e. rotor positioning and alignment are not to be affected by this inspection)
- Check for any damaged, loose, or missing parts
- Inspect bearings for abnormal wear, loss of Babbitt, pitting, and indications of lubrication problems such as discoloration and scorching
- Inspect the internal bearing insulation for integrity, damage, flashover, tracking, and proper insulation levels as recommended by the OEM
- Inspect and test the bearing RTDs for damage and proper temperature indication
- Perform a bearing journal and thrust runner inspection looking for indications of abnormal wear, proper RMS surface finish, proper alignment and positioning, and damage
- Inspect bearing seals for wear, alignment, and damage
- Inspect the oil cooler, reservoir, and oil piping for leaking, mechanical integrity, fouling, cleanliness, pitting, corrosion, erosion, and damage
- For horizontal motors remove and inspect the upper end turn air baffles for damage, electrical tracking, and cleanliness. With the air baffles removed inspect winding end turns for dusting, looseness, electrical tracking, mechanical integrity of the ties and blocking, and any damage to the windings.
- For vertical motors inspect for indication of loose coil wedges
- Inspect internal coating for integrity and damage
- Inspect internal motor leads for degradation of or damage to the lead wire insulation
- Motor rotor fans should be inspected for damaged, cracked, or missing blades, or loose hardware
- Inspect the pawls and ratchet plates of any anti-rotation devices for damage and abnormal wear. If possible perform an uncoupled break-away test on vertical motors employing an anti-rotation device.
- Remove covers and inspect all junction and termination boxes and contents for damage, grounded wiring indications of electrical arcing or tracking, and the condition and tightness of connections and insulation systems

· If present at the motor, inspect current transformers and or surge capacitors for leakage, damage and the proper tightness of the connections
· Inspect for: damaged, loose, missing or vibrating parts, externally visible oil leaks around bearings and bearing seals, external water leaks around water bearing and stator cooling interfaces, broken or loose grounding cables, damaged conduits and seal flex, damaged wiring and insulators, damaged junction boxes and their gaskets, blocked / clogged / plugged air filters and inlet air screens
· Inspect bearing slinger rings for proper operation and movement
· Verify proper oil level; oil should not be discolored
· Inspect for plugged oil sight glass vent
· Verify proper motor strip heater status indication
· Listen for unusual noises

Principle Failure Locations and Causes:

The primary motivation for mechanical refurbishment is to replace the bearings or other components as required, i.e. when other diagnostic measurements indicate the need.
Consequently, this task should be considered as an aspect of corrective maintenance, and not as a regularly scheduled PM task. A wide range of component locations is accessible during this task, and is evident in the task content below.

Progression of Failure Mechanisms Over Time:

This is an on-condition task.

Task Interval Support:

This is an on-condition task.

Mechanical refurbishment of motors is really considered to be a corrective maintenance task based upon results of PM inspections. The decision to refurbish should be based upon physical component criteria and executed on an "as required" basis.

Refurbishment

Task Objective:

Refurbishment covers a wide range and a large number of failure mechanisms but only about a dozen, concerning rotor bars and shorting rings, and rotor and stator laminations, are random failure modes not addressed by other tasks. However, there is not much opportunity for interval exploration because the intervals are long.

Task Content:

Refurbishment should include:
· Inspect for any damaged, loose, or missing parts
· Clean and inspect the rotor winding and core for: damaged or loose windings, end turns, ties, wedging, and rotor iron; missing end turns, ties and wedging; detached, loose or damaged shorting ring; test winding and insulation resistance
· Retreat rotor to restore proper insulation and mechanical rigidity
· Check the shaft for bowing and run-out
· Verify insulation and electrical connections of rotor slip rings, if present
· Resurface slip rings to proper micron finish
· Inspect and test oil and air coolers
· Inspect shaft bearing journals for wear, pitting, and damage; resurface, as required, to restore journals to proper micron finish

· Balance the rotor
· Clean and inspect the stator winding and core for: contamination, damaged or loose windings, end turns, blocking, wedging, ties, and stator iron; detached or loose surge ring; evidence of corona discharge damage, test winding and insulation resistance
· Verify proper operation of winding RTDs
· Clean air passages
· Tighten end windings and retreat stator to restore proper insulation and mechanical rigidity
· Inspect and test all supply cables, motor heaters, and alarms
· Inspect and refurbish the anti-rotation device, as required
· Replacement or reconditioning (Babbitt bearings only) of the bearings, bearing seals, gaskets, O-rings, and bearing insulation. After replacement, the bearing insulation should be tested to assure it provides the required degree of isolation from electrical currents that could damage the bearing.
· Ultrasonically test the bearing Babbitt for proper bond and the presence of voids
· Inspect and test for leaks in the oil cooling system
· Inspect and test for leaks in the stator cooling system
· Verify the operation, alarm action, general condition, and calibration of local bearing temperature indicators.
· Check for damaged, loose, or missing parts
· Removal of motor end covers and inspection plates and covers to allow access to motor bearings and windings without floating the rotor (i.e. rotor positioning and alignment are not to be affected by this inspection)
· Check for any damaged, loose, or missing parts
· Inspect bearings for abnormal wear, loss of Babbitt, pitting, and indications of lubrication problems such as discoloration and scorching
· Inspect the internal bearing insulation for integrity, damage, flashover, tracking, and proper insulation levels as recommended by the OEM
· Inspect and test the bearing RTDs for damage and proper temperature indication
· Perform a bearing journal and thrust runner inspection looking for indications of abnormal wear, proper RMS surface finish, proper alignment and positioning, and damage
· Inspect bearing seals for wear, alignment, and damage
· Inspect the oil cooler, reservoir, and oil piping for leaking, mechanical integrity, fouling, cleanliness, pitting, corrosion, erosion, and damage
· For horizontal motors remove and inspect the upper end turn air baffles for damage, electrical tracking, and cleanliness. With the air baffles removed inspect winding end turns for dusting, looseness, electrical tracking, mechanical integrity of the ties and blocking, and any damage to the windings.
· For vertical motors inspect for indication of loose coil wedges
· Inspect internal coating for integrity and damage
· Inspect internal motor leads for degradation of or damage to the lead wire insulation
· Motor rotor fans should be inspected for damaged, cracked, or missing blades, or loose hardware
· Inspect the pawls and ratchet plates of any anti-rotation devices for damage and abnormal wear. If possible perform an uncoupled break-away test on vertical motors employing an anti-rotation device.
· Remove covers and inspect all junction and termination boxes and contents for damage, grounded wiring indications of electrical arcing or tracking, and the condition and tightness of connections and insulation systems
· If present at the motor, inspect current transformers and or surge capacitors for leakage, damage and the proper tightness of the connections
· Inspect for: damaged, loose, missing or vibrating parts, externally visible oil leaks around bearings and bearing seals, external water leaks around water bearing and stator cooling interfaces, broken or loose grounding cables, damaged conduits and seal flex, damaged wiring and insulators, damaged junction boxes and their gaskets, blocked / clogged / plugged air filters and inlet air screens
· Inspect bearing slinger rings for proper operation and movement
· Verify proper oil level; oil should not be discolored
· Inspect for plugged oil sight glass vent
· Verify proper motor strip heater status indication
· Listen for unusual noises

Principle Failure Locations and Causes:

This task is focused on the condition of rotor laminations, rotor bars, and retaining rings, wound rotor windings, and stator laminations and windings. In addition, the task enables checks on the shaft, and on the frame, enclosure and mounting for deformation, cracks, and weld failures.

Frame and mounting degradations are also covered by vibration monitoring and by visual inspection. All the rotor degradations are also covered by vibration monitoring. Stator laminations and winding degradation might also be revealed by a borescope examination but can be more fully examined during refurbishment. Refurbishment should include inspection of corona damage to stator winding insulation because a few instances of damage from corona discharge have been noted in the industry. There do not appear to be any other degradation mechanisms that absolutely require a refurbishment to reveal the condition of the equipment, i.e. that are not also covered by one or more of the other tasks.

Progression of Failure Mechanisms Over Time:

The refurbishment task provides protection from a large number of degradation mechanisms that can cause failures over a period of many years.

Task Interval Support:

Although a significant number of these mechanisms are thought to initiate randomly or to progress erratically, the expert group thought that the combination of condition monitoring tasks described above, and other inspections (e.g. borescope), would lead to a minimum refurbishment interval of 10 years for the most critical motors, and up to 20 years for the least critical motors that are started infrequently. Exposure to heat, age, vibration and contamination should be a significant consideration when estimating these refurbishment intervals. It appears that refurbishment task intervals could benefit from adjustment based on multiple inputs about the condition and history of the equipment. However, the expert groups were reluctant to state that refurbishment could become a fully on-condition task (i.e. as required on the Template) because of the high cost of medium voltage motors.

Some utilities currently have the confidence in their condition monitoring programs and inspections to eliminate refurbishment as a regularly scheduled PM task. The foregoing analysis shows that all the failure causes should indeed be covered by condition monitoring and inspection.

Refurbishment of electrical motors is basically a condition directed task aimed at restoring the inherent reliability of the motor and associated components.

Operator Rounds

Task Objective:

Operator Rounds focuses mainly on visible indications of deterioration in oil quality, oil and grease leakage, low oil level, and air flow blockages. There is little opportunity to extend the interval because several common short term wearout failure mechanisms are addressed in addition to large numbers of random failure modes.

Task Content:

Operator Rounds should include:

- Inspect for: damaged, loose, missing or vibrating parts, externally visible oil leaks around bearings and bearing seals, external water leaks around water bearing and stator cooling interfaces, broken or loose grounding cables, damaged conduits and seal flex, damaged wiring and insulators, damaged junction boxes and their gaskets, blocked / clogged / plugged air filters and inlet air screens
- Inspect bearing slinger rings for proper operation and movement

· Verify proper oil level; oil should not be discolored
· Inspect for plugged oil sight glass vent
· Verify proper motor strip heater status indication
· Listen for unusual noises

Principle Failure Locations and Causes:

Operator Rounds focuses mainly on causes of visible indications of deterioration in oil quality, visible oil and grease leakage and low oil level, either from problems with wear of bearings or bearing seals, or from any failure in the oil distribution system. External visual inspection is also effective for detecting clogged air filters and blocked air passages or screens.

Bearing temperature, motor current and winding temperatures are all likely to be either continuously recorded or observed every shift during operator rounds. These frequent observations are included in the external visual inspection task, although plants will have a separate procedure, possibly a part of operator rounds, for how they are observed, recorded or trended. Bearing temperature is a key indication for all causes of bearing wear, failures in the oil distribution system, and other failures that can affect the wear of bearings. Motor current can also detect some bearing failures but usually at a later stage of development than bearing temperature. Winding temperature is a useful indicator for clogged air filters, air passages, and winding insulation failure.

Certain degradation processes in electrical circuits can also be observed, such as degraded insulation on feeder cables, and failed space heaters.

The inspection also includes general observation for loose, missing, or damaged parts, and listening for unusual noises or vibrations.

Progression of Failure Mechanisms Over Time:

Almost all the above degradation mechanisms are random in occurrence.

Task Interval Support:

In addition to the discussion of bearing temperature, motor current and winding temperature, some other items below are observable during normal operator rounds. Such items (e.g. oil level and color, unusual noises) are also assumed to be included as a formal part of operator rounds.

Operator rounds are considered to be a failure finding task and the main focus is on correcting as failed or incipient failure modes of motors.

Electric Motors – Low Voltage (<600V)

Table A-3 Electric Motors – Low Voltage

Template Data Report: Motor - Low Voltage - <600V	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Thermography	6M	6M	6M	6M	1Y	1Y	1Y	1Y
Vibration Monitoring	3M	3M	3M	3M	1Y	1Y	1Y	1Y
Oil Analysis And Lubrication	6M	6M	1Y	1Y	NR	NR	NR	NR
Bridge Test Over 20HP	3Y	3Y	3Y	3Y	NR	NR	NR	NR
Motor Performance Testing	3Y	3Y	3Y	3Y	NR	NR	NR	NR
System Engineer Walkdown	3M	3M	3M	3M	3M	3M	3M	3M
Refurbishment	AR	AR	AR	AR	AR	AR	AR	AR
Acoustic Monitoring	3M	3M	3M	3M	AR	AR	AR	AR
Operator Rounds	1S	1S	1S	1S	1S	1S	1S	1S

Component PM Assessment

For Electric Motors – Low Voltage (<600V) the EPRI PMBD recommends nine tasks to maintain the inherent reliability of the component, as shown in Table A-3. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-4 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-4 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The addition of just one task, Operator Rounds or System Engineer Walkdown, for low-voltage electric motors will result in a 50% greater reliability benefit than doing nothing. The execution of three PM tasks: Motor Performance Testing And (Operator Rounds or System Engineer Walkdown) And any one of Vibration Monitoring, Thermography, or Acoustic Monitoring will result in a 90% greater reliability than doing no preventive maintenance at all.

Table A-4 Electric Motors – Low Voltage PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Thermography	2.0		√**
Vibration Monitoring	1.0		√**
Oil Analysis And Lubrication	2.0		
Bridge Test Over 20 HP	8.0		
Motor Performance Testing	4.0		√**
System Engineer Walkdown	1.0	√*	√**
Refurbishment	40.0		
Acoustic Monitoring	1.0		√**
Operator Rounds	0.25	√*	√**

- *- Either perform System Engineer Walkdown or Operator Rounds.
- **- Perform three of the following tasks: Motor Performance Testing And (Operator Rounds or System Engineer Walkdown) And Any one of Vibration Monitoring, Thermography, or Acoustic Monitoring

Infrared Thermography

Task Objective:

The main application of thermography is to provide an indication of the condition of exposed electrical connections, and to complement other indications of bearing wear, and the condition of air passages. Some flexibility is possible in the interval, although a few common wearout failure modes with short development times affecting bearings are addressed.

Task Content:

Thermography should include:

- Inspection for unusual and unbalanced heating of the connections at the main motor and motor heater leads and their respective power cable interfaces
- Unusual differences in exit air temperatures when compared to historical values
- Inspection for unusual heating in motor bearing and windings that cannot be attributed to normal thermal patterns and temperatures

Principle Failure Locations and Causes:

The main application of thermography is to provide indication of the condition of power cable connections, and to complement other indications of bearing wear from causes related to lubrication failure. Since the bearing temperature is directly measured by in-situ RTDs or thermocouples, thermography plays a backup role. Thermography can usually only give an indication of increased temperatures in the general surface region of the bearing casing, where this is accessible. Other indications of bearing wear are oil and vibration analysis, and motor current monitoring. Occasionally, thermography may also be useful in detecting blocked air passages.

Progression of Failure Mechanisms Over Time:

The lubrication related causes of bearing wear appear randomly over a period of many months up to 2 years. Blocked air passages and high resistance electrical connections have a similar time scale.

Task Interval Support:

None of the above causes is likely to fail the motor catastrophically on short time scales, so that a 6 month interval appears appropriate for thermography. This means that for safety related standby motors the thermography survey could be performed at the same time as surveillance testing. In the case of standby motors, thermography and the other on-line tests should be performed after the motor has been running at rated speed for four hours in order to reach a stable operating temperature and hence give valid measurements.

In some instances, e.g. the impairment of the oil pumping action caused by excessive oil in vertical configuration bearings, the degradation could be sufficiently rapid that thermography at a 6 month interval would not be an effective method of detection.

In any case, both direct bearing temperature indication and motor current are likely to be monitored continuously, i.e. observed every shift, and vibration and acoustic monitoring provide independent indications of bearing wear. Consequently, thermography is not a critical technology for detection of bearing wear in this class of motors.

Thermography scans on motors should be saved and trended for change.

Vibration Monitoring

Task Objective:

Vibration monitoring is very effective for addressing misalignment and wear in rotating components. There is essentially no latitude for interval extension because of the large number of random failure mechanisms involved, and a few very short term wearout modes.

Task Content:

Task Content is not included in this release.

Principle Failure Locations and Causes:

Vibration monitoring is very effective for addressing all causes of wear in bearings of all types. Additionally, vibration monitoring addresses all causes of failures originating in the shaft, in the rotor, including wound rotor windings, and in the frame, enclosure and mounting, including loose air baffles.

Progression of Failure Mechanisms Over Time:

Most of the causes of bearing failure appear randomly over a period of several months up to 2 years. The appearance of cracks, wear, and bowing in the shaft, and all degradation mechanisms in the rotor, although random in occurrence times, are not expected within a few years. The onset of degradation in the frame, such as deformation, weld failures, cracking, and soft foot share similar timing characteristics as for the shaft and rotor, although the progression to failure could be rapid if the vibration is close to a structural resonance.

Task Interval Support:

The suggested interval of 3 months for critical motors should be sufficiently frequent to make vibration monitoring an effective detection method for a wide range of failure causes. This interval has been recommended by the EPRI Maintenance and Diagnostic Center for inclusion in V3.0, instead of the original 6 month interval for all conditions. The new recommendation is more in line with the failure mode data.

Additionally, the frequency of vibration can provide specific diagnosis or focus further investigation in many instances.

Vibration monitoring spectrums on motors should be saved and trended for change.

Oil Analysis and Lubrication

Task Objective:

Oil sampling and analysis is particularly directed at causes of bearing and bearing seal wear for all types of bearings, and bearing cooling water leaks. There is essentially no latitude for interval extension because of the large number of random failure mechanisms involved, and a few very short term wearout modes.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Oil sampling and analysis is particularly directed at causes of bearing wear for all types of bearings. Also covered are all sources of wear for bearing seals. Other failure causes that affect oil quality are failed cooling coils in the oil distribution system, and all the causes of wear on the shaft (including cracks and bowing). Oil temperature above the rated limit can lead to degradation. Typical anti-friction bearing temperatures usually will not exceed 45° C above ambient; 2-pole motors usually will not exceed 50° C above ambient.

Lubrication should follow the plant specific lubrication program. The regreasing of greased bearings should follow intervals stated in EPRI Report NP 7502.

Progression of Failure Mechanisms Over Time:

All the above degradation mechanisms are random in time of onset but in most circumstances are expected to appear over periods of many months or years, and are not expected to lead to failures on short time scales.

Task Interval Support:

The suggested interval of 6 months for critical motors should be sufficiently frequent to make oil analysis an effective detection method for a wide range of failure causes. This interval has been recommended by the EPRI Maintenance and Diagnostic Center for inclusion in V3.0, instead of the original 1 year interval for all conditions. The new recommendation is more in line with the failure mode data.

The sampling timeframe should only apply to those bearings with clean cavities and lubricant.

Lube oil analysis results on motors should be saved and trended for change with an industry accepted software analysis tool.

Bridge Test Over 20HP

Task Objective:

The task focuses on detecting high resistance electrical connections. The interval is not strongly determined by the failure mode data.

Task Content:

The results of Bridge Test should be compared between phases, rather than to a historical trend, in order to derive their maximum benefit. One scheme which has been used successfully is to take the following actions at the stated thresholds:

1. Require between-phase differences of <1% for a new motor which is not yet installed (i.e. no power cables connected).
2. Require between-phase differences of <1.5% for a used or older motor which is not yet installed (i.e. no power cables connected).
3. Require between-phase differences of <2% for a new motor which is installed (i.e. power cables are connected).
4. Schedule troubleshooting activities at a convenient time when between-phase differences are >3% for any motor which is installed (i.e. power cables are connected).
5. Take immediate troubleshooting actions when between-phase differences are >5% for any motor which is installed (i.e. power cables are connected).

Principle Failure Locations and Causes:

This task has been changed in Version 3.1 to focus on a bridge measurement of the resistance of connections and windings, phase by phase.

The Bridge Test is capable of an accurate measurement of the resistance of windings, feeder cables, and motor leads, looking particularly at the difference between results for each phase. Winding to winding shorts can be detected as well as poor connections.

Progression of Failure Mechanisms Over Time:

All the above degradation mechanisms are random in time of onset but in most circumstances are expected to appear over periods of many months or years, and are not expected to lead to failures on short time scales.

Task Interval Support:

On suggestions from the Large Electric Motors Users Group, LEMUG, the Bridge Test should be performed every second outage, say at 3 to 4 years, but only for critical motors with power above 20 HP.

If the Bridge Test is performed at all for critical motors below 20HP, the interval should be longer, for example, at 4.5 or 6 years.

Motor Performance Testing

Task Objective:

Motor Performance Testing is performed to ensure that the electrical characteristics of the motor, including performance, are within specifications, and to diagnose the source of many potential problems.

Task Content:

Task Content is not included in this release.

Principle Failure Locations and Causes:

Motor Performance Testing addresses a wide range of degraded electrical conditions. The best procedures and testing equipment provide information about motor performance as well as motor condition.

Progression of Failure Mechanisms Over Time:

The degradation mechanisms addressed by this task include a large number of random and wearout conditions covering a wide span of development time scales.

Task Interval Support:

Motor Performance Testing should be performed at every other outage, at 3 years, but only for critical motors with power above 20 HP. A more conservative position would be to perform the task annually.

If Motor Performance Testing is performed at all for critical motors below 20HP, the interval should be longer, for example, at 3 to 5 years.

System Engineer Walkdown

Task Objective:

System Engineer Walkdown focuses mainly on visible indications of deterioration in oil quality, oil and grease leakage, low oil level, and air flow blockages. There is little opportunity to extend the interval because several common short term wearout failure mechanisms are addressed in addition to large numbers of random failure modes.

Task Content:

System Engineer Walkdown should include:

- Inspect for: damaged, loose, missing or vibrating parts, externally visible oil leaks around bearings and bearing seals, external water leaks around water bearing and stator cooling interfaces, broken or loose grounding cables, damaged conduits and seal flex, damaged wiring and insulators, damaged junction boxes and their gaskets, blocked / clogged / plugged air filters and inlet air screens
- Inspect bearing slinger rings for proper operation and movement
- Verify proper oil level; oil should not be discolored
- Inspect for plugged oil sight glass vent
- Verify proper motor strip heater status indication
- Listen for unusual noises

Principle Failure Locations and Causes:

This inspection activity focuses mainly on causes of visible indications of deterioration in oil quality, visible oil and grease leakage and low oil level, either from problems with wear of bearings or bearing seals, or from failure in the oil distribution system. Visual inspection is also capable of detecting clogged air filters and blocked air passages or screens.

Bearing temperature, motor current, and winding temperature are all likely to be either continuously recorded or observed every shift during operator rounds. Bearing temperature is a key indication for all causes of bearing wear, failures in the oil distribution system, and other failures that can affect the wear of bearings. Motor current can also detect some bearing failures but usually at a later stage of development than bearing temperature. Winding temperature is a useful indicator for clogged air filters, air passages, and winding insulation failure.

Certain degradation processes in electrical circuits can also be observed, such as degraded insulation on feeder cables, and failed space heaters.

This task also includes general observation for loose, missing, or damaged parts, and listening for unusual noises or vibrations.

Progression of Failure Mechanisms Over Time:

Almost all the above degradation mechanisms are random in occurrence.

Task Interval Support:

The interval of 3 months is sufficient to detect the onset of most of the visible failure causes.

For particularly large and critical low voltage motors it will also be worth considering mechanical on-line tests analogous to those recommended for medium voltage motors. If these are considered to be cost-effective they could be performed at a 6 month interval for critical high duty motors, and at 12 months for standby motors.

Refurbishment

Task Objective:

Refurbishment is performed as a means to thoroughly check the condition of critical motors. It is mainly an on-condition task as the alternative interval of 10 to 15 years is not well supported by the failure data and can not provide very effective protection against a significant number of random failure mechanisms.

Task Content:

Task Content is not included in this release.

Principle Failure Locations and Causes:

This task is focused on the inspection and replacement of bearings, the condition of rotor laminations, rotor bars, retaining rings, wound rotor windings, and stator laminations and windings. In addition, the task enables checks on the shaft, and on the frame, enclosure and mounting for deformation, and cracks.

Progression of Failure Mechanisms Over Time:

The refurbishment task provides protection from a large number of degradation mechanisms that can cause failures over a period of many years.

Task Interval Support:

Although a significant number of these mechanisms are thought to initiate randomly or to progress erratically, the expert group thought that the combination of condition monitoring tasks described above would lead to full refurbishment being an on-condition task that does not require a regular schedule. Exposure to heat, age, vibration and contamination should be a significant consideration when estimating if and when to refurbish.

The condition of bearings is adequately addressed by vibration and acoustic monitoring and is likely the main trigger for a refurbishment. Frame and mounting degradations are also covered by vibration monitoring and by visual inspection. All the rotor degradations are also covered by vibration monitoring. The full condition of stator laminations and windings might only be revealed during refurbishment, although good indication of most of their degradation mechanisms can be obtained by motor analysis. Degradation of the winding and lamination insulation is not expected to occur for many years, perhaps for 40 years.

Refurbishment addresses essentially all the failure mechanisms, about 11% of which are not effectively addressed by other tasks. However, all of these are random occurrences for which Refurbishment at an interval of 10 years or more will not provide effective protection either. Nevertheless, some utilities may decide on an individual basis that a refurbishment is indeed necessary for very critical motors at 10 to 15 years.

Acoustic Monitoring

Task Objective:

Acoustic monitoring is focused on addressing grease-related causes of wear in bearings and other rotating components. There is little latitude for interval extension for critical motors because of the significant number of random failure mechanisms involved, and a few very short term wearout modes.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Acoustic monitoring should be effective for addressing some causes of wear in bearings of all types, especially those caused by a lack of grease, or an excess of grease. However, industry experience with this technology is limited, suggesting that information in the database on this technology may be subject to change.

Progression of Failure Mechanisms Over Time:

Most of the causes of bearing failure appear randomly over a period of several months up to 2 years.

Task Interval Support:
The suggested interval of 3 months is a conservative starting point with this new technology to make acoustic monitoring an effective detection method for a range of grease-related failure causes.

However, there may be dangers in applying the technology, e.g. if it promotes the addition of grease to bearings which are double shielded, or if it promotes over greasing. Consideration should be given to installing new grease fittings which prevent the addition of grease when the grease pressure in the bearing reaches 20 psi, and/or fittings which relieve internal grease pressure when it rises to a preset threshold.

Operator Rounds

Task Objective:

Operator Rounds focuses mainly on visible indications of deterioration in oil quality, oil and grease leakage, low oil level, and air flow blockages. There is little opportunity to extend the interval because several common short term wearout failure mechanisms are addressed in addition to large numbers of random failure modes.

Task Content:

Operator Rounds should include:
· Inspect for: damaged, loose, missing or vibrating parts, externally visible oil leaks around bearings and bearing seals, external water leaks around water bearing and stator cooling interfaces, broken or loose grounding cables, damaged conduits and seal flex, damaged wiring and insulators, damaged junction boxes and their gaskets, blocked / clogged / plugged air filters and inlet air screens
· Inspect bearing slinger rings for proper operation and movement
· Verify proper oil level; oil should not be discolored
· Inspect for plugged oil sight glass vent
· Verify proper motor strip heater status indication
· Listen for unusual noises

Principle Failure Locations and Causes:

Operator Rounds focuses mainly on causes of visible indications of deterioration in oil quality, visible oil and grease leakage and low oil level, either from problems with wear of bearings or bearing seals, or from failure in the oil distribution system. Visual inspection is also capable of detecting clogged air filters and blocked air passages or screens.

Bearing temperature, motor current, and winding temperature are all likely to be either continuously recorded or observed every shift during operator rounds. Bearing temperature is a key indication for all causes of bearing wear, failures in the oil distribution system, and other failures that can affect the wear of bearings. Motor current can also detect some bearing failures but usually at a later stage of development than bearing temperature. Winding temperature is a useful indicator for clogged air filters, air passages, and winding insulation failure.

Certain degradation processes in electrical circuits can also be observed, such as degraded insulation on feeder cables, and failed space heaters.

This task also includes general observation for loose, missing, or damaged parts, and listening for unusual noises or vibrations.

Progression of Failure Mechanisms Over Time:

Almost all the above degradation mechanisms are random in occurrence.

Task Interval Support:

In addition to the discussion of bearing temperature, motor current, and winding temperature, some other items below are observable during normal operator rounds. Such items (e.g. oil level and color, unusual noises) are also assumed to be included as a formal part of operator rounds.
For particularly large and critical low voltage motors it will also be worth considering mechanical on-line tests analogous to those recommended for medium voltage motors. If these are considered to be cost-effective they could be performed at a 6 month interval for critical high duty motors, and at 12 months for standby motors.

Air Dryer – Heated

Table A-5 Air Drier – Heated

Template Data Report: Air Dryer - Heated	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
System Engineer Walkdown	3M	3M	3M	3M	3M	3M	3M	3M
Performance Monitoring	1M	1M	1M	1M	1M	1M	1M	1M
Calibration	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Electrical Checks	4Y	4Y	4Y	4Y	4Y	4Y	4Y	4Y
Blower Inspection	3M	3M	6M	6M	3M	3M	6M	6M
Vibration Analysis	3M	3M	3M	3M	NR	NR	NR	NR
Blower Lubrication	AR	AR	AR	AR	AR	AR	AR	AR
Filter Inspection/ Replacement	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Desiccant Inspection/ Testing	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Drain Trap/ Strainer Inspection	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Valve Rebuild/ Replace	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Relief Valve Replacement	6Y	6Y	6Y	6Y	6Y	6Y	6Y	6Y
Operator Rounds	1S	1S	1S	1S	1D	1D	1D	1D

Component PM Assessment

For Air Drier – Heated the EPRI PMBD recommends thirteen tasks to maintain the inherent reliability of the component, as shown in Table A-5. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-6 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-6 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The addition of just one task, Operator Rounds or System Engineer Walkdown for Air Driers – Heated, will result in a 50% greater reliability benefit than doing nothing. The execution of three PM tasks: Operator Rounds or System Engineer Walkdown And Performance Monitoring And Blower Inspection will result in a 90% greater reliability than doing no preventive maintenance at all.

Table A-6 Air Drier – Heated PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
System Engineer Walkdown	1.0	√*	√**
Performance Monitoring	0.5		√**
Calibration	4.0		
Electrical Checks	4.0		
Blower Inspection	1.0		√**
Vibration Analysis	1.0		
Blower Lubrication	1.0		
Filter Inspection/Replacement	2.0		
Desiccant Inspection/Testing	2.0		
Drain Trap/Strainer Inspection	2.0		
Valve Rebuild/Replace	4.0		
Relief Valve Replacement	4.0		
Operator Rounds	0.25	√*	√**

- *- Either perform System Engineer Walkdown or Operator Rounds.
- **- Perform three of the following tasks: Operator Rounds or System Engineer Walkdown And Performance Monitoring And Blower Inspection

System Engineer Walkdown

Task Objective:

System Engineer Walkdown is intended to verify normal air system operation.

Task Content:

System Engineer Walkdown generally detects large leaks of air, water, or oil, as well as loose, damaged or missing fasteners, abnormal pressures, alarms, clogged filters, clogged or stuck drain traps, and dew point measurements.

Principle Failure Locations and Causes:

System Engineer Walkdown is well suited to detecting failed SOV's, clogged drain traps and mufflers, a mispositioned desiccant moisture isolation valve, and stuck cartridge valves. These are just a few among the large number of failure modes which can be addressed with this task.

Progression of Failure Mechanisms Over Time:

The failure modes listed in the Failure Location and Cause field are important because, except for the SOV failures, they occur commonly with short wearout periods or at random times, requiring a frequent task to detect them. The SOV failures are common wearout items after many years free of failure, but this task is the only good way to detect them quickly.

Task Interval Support:

This task is performed every shift when performed by operators, or approximately every week if performed by a system engineer. This frequency is sufficient to detect randomly occurring and short term wearout failure modes with high or medium effectiveness.

Performance Monitoring

Task Objective:

Performance Monitoring has the objective of measuring dryer performance and verifying its effective operation. The monthly interval is consistent with the significant number of random failure modes addressed, and is essentially determined by some of them.

Task Content:

Performance Monitoring includes recording the following parameter values:
· Purge pressure
· Tower pressure
· Drying time
In addition, record, and trend the following parameter values:
· Filter Delta P
· Dew Point
· Dryer Delta P

In addition, during this task, and with the purge turned off, feel for air exiting the purge outlet. If air is present, it indicates that valves are leaking.

Principle Failure Locations and Causes:

Performance Monitoring is important for effectively addressing failed electronic/electrical devices, clogged mufflers, and clogged or stuck prefilter drain traps. There is also a significant number of other failure modes which are addressed effectively by this frequently performed task. They are either not as common as the failure modes mentioned above, or Performance Monitoring is not relied on to the same extent or is not quite as well suited to the timing of the failure modes.

Progression of Failure Mechanisms Over Time:

Almost all the failure modes addressed occur with short development time scales or are expected to occur randomly. Many are also commonly encountered.

Task Interval Support:

Frequent (monthly) performance of this task guarantees adequate coverage of the many randomly occurring failure modes it addresses, especially the clogged muffler and drain trap problems.

Calibration

Task Objective:

The objective of this task is to verify proper operation and response of the specific instruments which are calibrated. The interval is consistent with the failure modes addressed but is not closely determined by them.

Task Content:

Calibration includes only temperature switches and pressure gauges used for delta P measurements at most utilities.

Principle Failure Locations and Causes:

Calibration is applied to pressure gauges used for differential pressure measurements, and to temperature switches. Most pressure switches get functionally tested via system operation and other functional tests, but are not good opportunities for Calibration.

Progression of Failure Mechanisms Over Time:

Pressure gauges can fail from contamination with oil or desiccant fines at random times. This failure mode is common, random, and relies heavily on the Calibration task to detect and correct it. Drift of pressure gauges and temperature switches also relies on this task but has a much longer development time scale than the interval recommended for the task.

Task Interval Support:

The one year interval is suitable for a random failure mode and not too frequent for the wearout mode of drift.

Electrical Checks

Task Objective:

The main objective of the Electrical Checks is to ensure that heater circuits and blower motor windings maintain their insulation integrity. The interval is closely determined by the underlying failure mode data.

Task Content:

Electrical Checks should include the following activities:
· Perform a resistance check/megger of the heater elements
· Perform a resistance check/megger of the heater contactor coil
· looking for loose connections or high resistance
· Perform a megger check to detect degradation of the blower motor winding insulation

Principle Failure Locations and Causes:

Electrical Checks address insulation integrity and loose connections of the heater elements, heater contactor coil, and blower motor winding insulation.

Progression of Failure Mechanisms Over Time:

The heater elements and heater contactor coil experience wearout failures at approaching 5 years and longer. The blower motor has a longer wearout period of 15 to 20 years.

Task Interval Support:

The 4 year interval is mainly determined by the failures of the heater elements and contactor coils.

Blower Inspection

Task Objective:

The main objective of this task is to keep the blower intake filters clean and in good condition. The interval is closely determined by the failure mode data.

Task Content:

The Blower Inspection should include the following activities:
· Inspect/clean/replace the blower intake filters as necessary.
· Inspect the blower seal for signs of leakage.
· Inspect the pulley sheaves and belts for wear, general condition, and proper belt tension.

Principle Failure Locations and Causes:

This task is focused on detecting clogged blower intake filters. Worn pulley sheaves, worn belts, and blower seal leaks are also addressed.

Progression of Failure Mechanisms Over Time:

Clogging of blower intake filters is a short term wearout phenomenon with an expected failure free interval of 3 months to one year. The other failure modes have time scales of quite a few years.

Task Interval Support:

The task has a recommended interval of 3 months for critical dryers in severe conditions to address the filter clogging failure mode.

Vibration Analysis

Task Objective:
The task objective is to detect signs of wear in rotating components before the dryer is forced out of service by a bearing or gear box failure. The interval is determined by the failure data.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Vibration analysis addresses worn pulleys and belts, and worn blower bearings and gears.

Progression of Failure Mechanisms Over Time:

Pulleys have primarily random failures, and blower bearings experience random and also extremely short term wearout failures.

Task Interval Support:

The 3 month interval for this task is appropriate for addressing the random and short term failure modes.

Blower Lubrication

Task Objective:

The objective of this task is to ensure the blower is properly lubricated at all times.

Task Content:

Blower Lubrication should include the following activities:
· Check the lubricant level and change the lubricant as necessary.
· Oil sampling and analysis could be included to establish the proper lubrication periodicity, as well as to verify good condition of the oil.

Principle Failure Locations and Causes:

Blower Lubrication is focused entirely on worn blower bearings and gears.

Progression of Failure Mechanisms Over Time:

These components have random and very short term wearout failure modes.

Task Interval Support:
The interval for this task could best be established by experience or by the use of oil sampling and analysis.

Filter Inspection/Replacement

Task Objective:

The objective of the task is to replace the filters at the right time. The typical 1 year interval is determined by the random nature and time scale of filter clogging; however, the delta P measurements can insure against premature clogging.

Task Content:

Filter Inspection/Replacement, in concert with filter delta P measurements made during the Performance Monitoring task, determines when the filters should be replaced.

The task should include inspecting the following filter components for clogging or collapse:
· Pre-filter cartridge
· After-filter
· Control/pilot air line filters
· Desiccant retention screens
· Also inspect the pre-filter and after-filter filter housings for corrosion and damage.

The actual pressure differential at which replacement is recommended is very dependent on filter size and capacity rating versus the actual operating cfm rating. A delta P of 5 to 7 psi is a typical for replacement. Note, however, that even a new filter (excepting very large ones) will show some delta P.

Principle Failure Locations and Causes:

This task primarily addresses clogging of the pre-filter cartridge, after-filter, control/pilot air line filters, desiccant retention screens, and also the inspection of the pre-filter and after-filter filter housings for corrosion and damage.

Progression of Failure Mechanisms Over Time:

Clogging of the filters is a short term wearout mode with a failure free period of about a year, or even less.

Task Interval Support:

The one year interval is suitable for these failure modes, provided severe service conditions do not cause premature clogging. The delta P measurements developed during the Performance Monitoring task can help to guard against this possibility.

Desiccant Inspection/Testing

Task Objective:

The objective of this task is to determine the condition of the dryer desiccant, and the dryer tower. The interval is essentially determined by the loss of the desiccant absorption capability.

Task Content:

Inspect and test the condition of the desiccant, and estimate its remaining useful life. Additionally, inspect the internal surface condition of the dryer tower for corrosion and wall thinning.

Principle Failure Locations and Causes:

This task addresses the condition of the dryer tower and the remaining ability of the desiccant to continue to absorb moisture. It is also worth noting that failure of pressure control valves is usually detected during post maintenance testing after this Desiccant Inspection task or the Valve Rebuild task.

Progression of Failure Mechanisms Over Time:

The loss of absorption of the desiccant is a wearout failure mode with a failure free period of a few years. Corrosion of the inside surface of the dryer tower has a much longer time scale but this task is the only opportunity to detect this condition.

Task Interval Support:

The one year interval is determined by the loss of absorption time-scale of the activated alumina desiccant. There is not much opportunity to extend this interval.

Drain Trap/Strainer Inspection

Task Objective:

The objective of this task is simply to ensure that the drain traps and strainer are clean, in good condition, and function as desired. The interval is consistent with the failure modes addressed but is not closely determined by them.

Task Content:

Drain Trap and Strainer Inspection should include the following:
- Inspect and clean the strainer and traps.
- Drain condensate out of all low points.

Principle Failure Locations and Causes:

This task addresses clogged or stuck pre-filter drain traps and deteriorated drain trap strainers.

Progression of Failure Mechanisms Over Time:

Clogging and sticking of the pre-filter drain traps is a common occurrence on a random time scale of a few months to a few years. Deterioration of the drain trap strainer screen has a failure free period which is on a much longer time scale; but this is the only task during which it would be discovered.

Task Interval Support:

The one year interval is associated with clogging and sticking of the drain traps, but is not completely determined by these failure modes because Operator Rounds and Performance Monitoring provide almost continuous monitoring of the drain trap condition. However, a one year interval does provide ultimate assurance of the condition of the traps, and provides relatively frequent opportunity to inspect the drain trap strainer.

Valve Rebuild/Replace

Task Objective:

This task has the objective of restoring the valves to an as new condition. The interval is clearly determined by the failure mode data.

Task Content:

Valve Rebuild/ Replace should include the following activities:

Inspect the pneumatic switching valves, check valves, pressure control valves, and cartridge valves (for PPC or PALL dryers with Mark 1 controllers) to determine if they should be rebuilt or replaced.
Use a rebuild kit if rebuilding the valves.

Principle Failure Locations and Causes:

Valve Rebuild/ Replace is focused on leakage and binding of pneumatic switching valves, purge and outlet check valves, and cartridge valves for PPC or PALL dryers with Mark 1 controllers. Wearout failures of pressure control valves over a much longer time period are also addressed.

Progression of Failure Mechanisms Over Time:

Leakage of the pneumatic switching valves, and leakage and binding of check valves can occur in a period of 1 to 2 years, although there are also random causes of these failures. The other failure modes are either wearout on a somewhat longer time scale or random in nature.

Task Interval Support:

Leakage of the pneumatic switching valves, and leakage and binding of check valves determine the 1 year interval for this task. Schedule this task to coincide with the Desiccant Inspection, Filter Replacement, or Relief Valve Replacement tasks, or when another suitable opportunity presents itself.

Relief Valve Replacement

Task Objective:

This task has the sole purpose of assuring that the safety relief valves will function as required. The interval is determined by the failure mode data.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Relief Valve Replacement addresses the weakening of springs in pressure relief valves, and their tendency to stick closed when not operated for long periods.

Progression of Failure Mechanisms Over Time:

Springs weaken over time in a wearout pattern with a failure free period of many years. Sticking is more random.

Task Interval Support:

The 6 year interval is suitable for the wearout failure mode, and has been found to be reasonable for the sticking shut failure mode. The valves are also recommended to be replaced after even a single lift in service.

Operator Rounds

Task Objective:

Operator Rounds are intended to verify normal air system operation.

Task Content:

Operator Rounds generally detects large leaks of air, water, or oil, as well as loose, damaged or missing fasteners, abnormal pressures, alarms, clogged filters, clogged or stuck drain traps, and dew point measurements.

Principle Failure Locations and Causes:

Operator Rounds are well suited to detecting failed SOV's, clogged drain traps and mufflers, a mispositioned desiccant moisture isolation valve, and stuck cartridge valves. These are just a few among the large number of failure modes which can be addressed with this task.

Progression of Failure Mechanisms Over Time:

The failure modes listed in the Failure Location and Cause field are important because, except for the SOV failures, they occur commonly with short wearout periods or at random times, requiring a frequent task to detect them. The SOV failures are common wearout items after many years free of failure, but this task is the only good way to detect them quickly.

Task Interval Support:

This task is performed every shift when performed by operators, or approximately every week if performed by a system engineer. This frequency is sufficient to detect randomly occurring and short term wearout failure modes with high or medium effectiveness.

Air Dryer – Unheated

Table A-7 Air Drier – Unheated

Template Data Report: Air Dryer - Unheated	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
System Engineer Walkdown	AR	AR	3M	3M	3M	3M	3M	3M
Performance Monitoring	1M	1M	1M	1M	1M	1M	1M	1M
Calibration	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Filter Inspection/ Replacement	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Desiccant Inspection/ Testing	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Drain Trap/ Strainer Inspection	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Valve Rebuild/ Replace	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Relief Valve Replacement	6Y	6Y	6Y	6Y	6Y	6Y	6Y	6Y
Operator Rounds	1S	1S	1S	1S	1D	1D	1D	1D

Component PM Assessment

For Air Drier – Unheated the EPRI PMBD recommends nine tasks to maintain the inherent reliability of the component, as shown in Table A-7. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM optimization strategy shown in Table A-8 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-8 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The addition of just one of three similar tasks, Operator Rounds Or System Engineer Walkdown Or Performance Monitoring for Air Driers – Unheated, will result in a 50% greater reliability benefit than doing nothing. The execution of two of three PM tasks: Operator Rounds Or System Engineer Walkdown And Performance Monitoring will result in a 90% greater reliability than doing no preventive maintenance at all.

Table A-8 Air Drier – Unheated PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
System Engineer Walkdown	1.0	√*	√**
Performance Monitoring	0.5	√*	√**
Calibration	4.0		
Filter Inspection/Replacement	2.0		
Desiccant Inspection/Testing	2.0		
Drain Trap/Strainer Inspection	2.0		
Valve Rebuild/Replace	4.0		
Relief Valve Replacement	4.0		
Operator Rounds	0.25	√*	√**

- *- Perform System Engineer Walkdown or Operator Rounds or Performance monitoring.
- **- Perform two of the three following tasks: Operator Rounds or System Engineer Walkdown And Performance Monitoring

System Engineer Walkdown

Task Objective:

System Engineer Walkdown is intended to verify normal air system operation.

Task Content:

System Engineer Walkdown generally detects large leaks of air, water, or oil, as well as loose, damaged or missing fasteners, abnormal pressures, alarms, clogged filters, clogged or stuck drain traps, and dew point measurements.

Principle Failure Locations and Causes:

System Engineer Walkdown is well suited to detecting leaking pneumatic switching valves, clogged filters, especially the small plastic housing kind, clogged mufflers and clogged or stuck prefilter drain traps, stuck cartridge valves, and leaking check valves. These are just a few among the large number of failure modes which can be addressed with this task.

Progression of Failure Mechanisms Over Time:

The failure modes listed in the Failure Location and Cause field are important because they occur commonly with short wearout periods or at random times, requiring a frequent task to detect them.

Task Interval Support:
This task is performed every shift when performed by operators, or approximately every week if performed by a system engineer. This frequency is sufficient to detect randomly occurring and short term wearout failure modes with high or medium effectiveness.

Performance Monitoring

Task Objective:

Performance Monitoring has the objective of measuring dryer performance and verifying its effective operation. The monthly interval is consistent with the significant number of random failure modes addressed, and is essentially determined by some of them.

Task Content:

Performance Monitoring includes recording the following parameter values:
· Purge pressure
· Tower pressure
· Drying time

In addition, record, and trend the following parameter values:
· Filter Delta P
· Dew Point
· Dryer Delta P

In addition, during this task, and with the purge turned off, feel for air exiting the purge outlet. If air is present, it indicates that valves are leaking.

Principle Failure Locations and Causes:

Performance Monitoring is important for effectively addressing mispositioned manual purge adjustment valves, leaking pneumatic switches, check valves and manual bypass isolation valves, failed electronic/electrical devices, clogged mufflers and desiccant retention screens, and clogged or stuck prefilter drain traps. There is also a significant number of other failure modes which are addressed effectively by this frequently performed task. They are either not as common as the failure modes mentioned above, or Performance Monitoring is not relied on to the same extent or is not quite as well suited to the timing of the failure modes.

Progression of Failure Mechanisms Over Time:

The failure modes listed in the Failure Location and Cause field are important because they are almost all commonly occurring with short development time scales or are expected to occur randomly. In the case of misadjusted purge adjustment valves, clogged desiccant retention screens, and leaking manual bypass isolation valves, this task is heavily relied on to detect the degraded conditions.

Task Interval Support:

Frequent (monthly) performance of this task guarantees adequate coverage of the many randomly occurring failure modes it addresses, especially the clogged muffler and drain trap problems.

Calibration

Task Objective:

The objective of this task is to verify proper operation and response of the specific gauges which are calibrated. The interval is consistent with the failure modes addressed but is not closely determined by them.

Task Content:

Calibration includes only pressure gauges used for delta P measurements at most utilities.

Principle Failure Locations and Causes:

Calibration is applied to pressure gauges used for differential pressure measurements. Most pressure switches get functionally tested via system operation and other functional tests, but are not good opportunities for Calibration.

Progression of Failure Mechanisms Over Time:

Pressure gauges can fail from contamination with oil or desiccant fines at random times. This failure mode is common, random, and relies heavily on the Calibration task to detect and correct it. Drift of the gauges also relies on this task but drift is not a common failure mode, and has a much longer development time scale than the interval recommended for the task.

Task Interval Support:

The one year interval is suitable for a random failure mode and not too frequent for the wearout mode of drift.

Filter Inspection/Replacement

Task Objective:

The objective of the task is to replace the filters at the right time. The typical 1 year interval is determined by the random nature and time scale of filter clogging; however, the delta P measurements can insure against premature clogging.

Task Content:

Filter Inspection/Replacement, in concert with filter delta P measurements made during the Performance Monitoring task, determines when the filters should be replaced.

The task should include inspecting the following filter components for clogging or collapse:
· Pre-filter cartridge
· After-filter
· Control/pilot air line filters
· Desiccant retention screens
· Also inspect the pre-filter and after-filter filter housings for corrosion and damage.

The actual pressure differential at which replacement is recommended is very dependent on filter size and capacity rating versus the actual operating cfm rating. A delta P of 5 to 7 psi is a typical for replacement. Note, however, that even a new filter (excepting very large ones) will show some delta P.

Principle Failure Locations and Causes:

This task primarily addresses clogging of the pre-filter cartridge, after-filter, control/pilot air line filters, desiccant retention screens, and also the inspection of the pre-filter and after-filter filter housings for corrosion and damage.

Progression of Failure Mechanisms Over Time:

Clogging of the filters is a short term wearout mode with a failure free period of about a year, or even less.

Task Interval Support:

The one year interval is suitable for these failure modes, provided severe service conditions do not cause premature clogging. The delta P measurements developed during the Performance Monitoring task can help to guard against this possibility.

Desiccant Inspection/Testing

Task Objective:

The objective of this task is to determine the condition of the dryer desiccant, and the dryer tower. The interval is essentially determined by the loss of the desiccant absorption capability.

Task Content:

Inspect and test the condition of the desiccant, and estimate its remaining useful life. Additionally, inspect the internal surface condition of the dryer tower for corrosion and wall thinning.

Principle Failure Locations and Causes:

This task addresses the condition of the dryer tower and the remaining ability of the desiccant to continue to absorb moisture. It is also worth noting that failure of pressure control valves is usually detected during post maintenance testing after this Desiccant Inspection task or the Valve Rebuild task.

Progression of Failure Mechanisms Over Time:

The loss of absorption of the desiccant is a wearout failure mode with a failure free period of a few years. Corrosion of the inside surface of the dryer tower has a much longer time scale but this task is the only opportunity to detect this condition.

Task Interval Support:

The one year interval is determined by the loss of absorption time-scale of the activated alumina desiccant. There is not much opportunity to extend this interval.

Drain Trap/Strainer Inspection

Task Objective:

The objective of this task is simply to ensure that the drain traps and strainer are clean, in good condition, and function as desired. The interval is consistent with the failure modes addressed but is not closely determined by them.

Task Content:

Drain Trap and Strainer Inspection should include the following:
- Inspect and clean the strainer and traps.
- Drain condensate out of all low points.

Principle Failure Locations and Causes:

This task addresses clogged or stuck pre-filter drain traps and deteriorated drain trap strainers.

Progression of Failure Mechanisms Over Time:

Clogging and sticking of the pre-filter drain traps is a common occurrence on a random time scale of a few months to a year or two. Deterioration of the drain trap strainer screen has a failure free period which is on a much longer time scale; but this is the only task during which it would be discovered.

Task Interval Support:

The one year interval is associated with clogging and sticking of the drain traps, but is not completely determined by these failure modes because Operator Rounds and Performance Monitoring provide almost continuous monitoring of the drain trap condition. However, a one year interval does provide ultimate assurance of the condition of the traps, and provides relatively frequent opportunity to inspect the drain trap strainer.

Valve Rebuild/Replacement

Task Objective:

This task has the objective of restoring the valves to an as new condition. The interval is clearly determined by the failure mode data.

Task Content:

Valve Rebuild/ Replace should include the following activities:
· Inspect the pneumatic switching valves, check valves, pressure control valves, and cartridge valves (for PPC or PALL dryers with PSA controllers) to determine if they should be rebuilt or replaced.
· Use a rebuild kit if rebuilding the valves.

Principle Failure Locations and Causes:

Valve Rebuild/ Replace is focused on leakage and binding of pneumatic switching valves, check valves, and cartridge valves for PPC or PALL dryers with PSA controllers. Wearout failures of pressure control valves over a much longer time period are also addressed.

Progression of Failure Mechanisms Over Time:

Leakage of the pneumatic switching valves, and leakage and binding of check valves can occur in a period of 1 to 2 years, although there are also random causes of these failures. The other failure modes are either wearout on a somewhat longer time scale or random in nature.

Task Interval Support:

Leakage of the pneumatic switching valves, and leakage and binding of check valves determine the 1 year interval for this task. Schedule this task to coincide with the Desiccant Inspection, Filter Replacement, or Relief Valve Replacement tasks, or when another suitable opportunity presents itself.

Relief Valve Replacement

Task Objective:

This task has the sole purpose of assuring that the safety relief valves will function as required. The interval is determined by the failure mode data.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Relief Valve Replacement addresses the weakening of springs in pressure relief valves, and their tendency to stick closed when not operated for long periods.

Progression of Failure Mechanisms Over Time:

Springs weaken over time in a wearout pattern with a failure free period of many years. Sticking is more random.

Task Interval Support:

The 6 year interval is suitable for the wearout failure mode, and has been found to be reasonable for the sticking shut failure mode. The valves are also recommended to be replaced after even a single lift in service.

Operator Rounds

Task Objective:

Operator Rounds are intended to verify normal air system operation.

Task Content:

Operator Rounds generally detects large leaks of air, water, or oil, as well as loose, damaged or missing fasteners, abnormal pressures, alarms, clogged filters, clogged or stuck drain traps, and dew point measurements.

Principle Failure Locations and Causes:

Operator Rounds are well suited to detecting leaking pneumatic switching valves, clogged filters, especially the small plastic housing kind, clogged mufflers and clogged or stuck prefilter drain traps, stuck cartridge valves, and leaking check valves. These are just a few among the large number of failure modes which can be addressed with this task.

Progression of Failure Mechanisms Over Time:

The failure modes listed in the Failure Location and Cause field are important because they occur commonly with short wearout periods or at random times, requiring a frequent task to detect them.

Task Interval Support:

This task is performed every shift when performed by operators, or approximately every week if performed by a system engineer. This frequency is sufficient to detect randomly occurring and short term wearout failure modes with high or medium effectiveness.

Battery – Flooded Lead Acid – Lead Calcium/Antimony

Table A-9 Battery – Flooded Lead Acid – Lead Calcium/Antimony

Template Data Report: Battery - Flooded Lead Acid - Lead Calcium/Antimony	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Cell Inspection	NA	3M	NA	3M	NA	3M	NA	3M
Battery Monitoring	NA	1M	NA	1M	NA	3M	NA	3M
Detailed Inspection	NA	1Y	NA	1Y	NA	1Y	NA	1Y
Battery Capacity Test	NA	5Y	NA	5Y	NA	5Y	NA	5Y
Battery Service Test	NA	NR	NA	2Y	NA	NR	NA	NR

Component PM Assessment

For Battery – Flooded Lead Acid – Lead Calcium/Antimony the EPRI PMBD recommends five tasks to maintain the inherent reliability of the component, as shown in Table A-9. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM optimization strategy shown in Table A-10 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-10 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. Executing any one of the five listed PM Tasks for Battery – Flooded Lead Acid will result in a 50% greater reliability benefit than doing nothing. The execution of one of two PM tasks, Cell Inspection Or Detailed Inspection, will result in a 90% greater reliability than doing no preventive maintenance at all.

Table A-10 Battery – Flooded Lead Acid – Lead Calcium/Antimony PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Cell Inspection	1.0	√*	√**
Battery Monitoring	0.5	√*	
Detailed Inspection	4.0	√*	√**
Battery Capacity Test	2.0	√*	
Battery Service test	2.0	√*	

- *- Perform any one of five of the PM Tasks listed. Note: If the one of the following two tasks are implemented, Cell Inspection or Detailed Inspection, that will result in greater reliability benefit than the other three tasks.
- **- Perform one of the two following tasks: Cell Inspection Or Detailed Inspection

Cell Inspection

Task Objective:

This task looks for gross defects at the level of individual cells, and serious deficiencies in the overall battery charging conditions. Intervals are strongly constrained by failure mode data.

Task Content:

Cell Inspection should include:

- Ensure electrolyte is clear, not discolored, and is at the proper level especially on lead-antimony type batteries towards the end of life.
- Should include a visual observation of the battery rack for evidence of corrosion, mechanical damage, and that the ground cable is properly connected.
- Inspect the battery for cracked jars and evidence of leaking electrolyte.
- Measure and record individual cell voltages.
- Ensure the room is clean and free of debris.
- On a 10% sampling basis, measure and record the specific gravity and electrolyte temperatures of the sampled cells, if not measuring the float charging current monthly.
- Inspect posts and connections for evidence of corrosion or damage.
- Inspect post seals for evidence of damage, deterioration, or leakage.
- Evaluate Internal Ohmic measurements for significant changes from past values.

Principle Failure Locations and Causes:

This task is directed at the detection of gross defects at the level of individual cells. It includes external visual inspection, and specific gravity and cell voltage measurements to address post corrosion, consequential plate contamination (copper plating), low level of the electrolyte, and plate shorting as a result of the buildup of shedding residue.

Progression of Failure Mechanisms Over Time:

Post corrosion can be rapid on a scale of a few months, with accompanying plate contamination if the corrosion is internal to the jar; a low level of electrolyte is essentially random from overcharging, or due to under-watering (maintenance error). The batteries with lead-antimony plates experience antimony poisoning on the negative plates which lead to a requirement frequent watering later in life. Plate shedding and shorting, and plate growth that crack the jar, do not drive the interval until late in the battery life.

Task Interval Support:

This task consists of visual inspection of the exterior of the cells (jars) and observing the general condition and level of the electrolyte. However, the only cell measurements are of all the individual cell voltages, plus sampling the specific gravity of the electrolyte in 10% of the cells, when not performing monthly monitoring of the float charging current. The above degradations are the most common, although there are many others that have less effect on the task interval, or are not dominant degradation mechanisms, or have additional effective means of detection or mitigation. Significant examples are over-watering or excessive equalization which can lead to a high level of electrolyte and consequent ground faults when overflow occurs, and also corroded, improperly connected, or damaged inter-cell connectors which can be observed when inspecting individual cells.

Battery Monitoring

Task Objective:

Focus is on the battery as a whole, ensuring that the battery is being charged at the correct float voltage, that environmental controls are working, and that there are no gross defects. The short intervals are constrained by rapidly developing random failure modes, and the consequences of charging at inappropriate conditions are extensive and severe.

Task Content:

Battery Monitoring should include:
· Measure and record the battery terminal voltage.
· Verify that the room cooling and ventilation is working and that temperatures are in specification.
· Measure and record the battery float current, if not performing quarterly sampling of battery electrolyte level and specific gravity. Float current is defined as the current drawn by the battery, not the charger output current. Investigate float current readings that are higher than previous readings.

Principle Failure Locations and Causes:

The focus of this task is on the battery as a whole. The main purpose is to ensure that the battery is being charged at the correct float voltage, the room temperature is appropriate, that the room ventilation system is operating, and that there are no gross defects such as leaks of electrolyte on the floor. The correct continuous charging conditions of temperature and float voltage are responsible for controlling many degradation mechanisms of the battery. Overcharging is a dominant underlying cause of industry battery failures.

In particular, terminal or post corrosion is influenced by both temperature and the float charging current. Plate corrosion and growth, and plate shedding are also key determinants of battery life, and are driven by overcharging, with plate corrosion and growth also sensitive to the temperature. Typically, life is reduced by 50% for every +15° F above the design temperature of 77° F. Consequently at 100° F, life is reduced by 60% to 70%.

A less common occurrence, hydration, is a condition due to chronic undercharging at low specific gravity over a period of several months. It can also occur over a period as short as a few days when a battery is left in a discharged condition. In either case hydration usually represents end of life for the battery. Inspection of the battery to detect the characteristic bath tub ring at the level of the electrolyte, or sampling of the electrolyte specific gravity, may not be performed quickly enough to prevent the fatal effects of hydration.

Because of the sensitive effect on these and other degradation mechanisms, and the effect on battery life, it is essential to be sure on a very frequent basis, that the correct charging conditions are being maintained.

Progression of Failure Mechanisms Over Time:

Post corrosion is a key degradation mechanism and proceeds sufficiently rapidly by overcharging to require attention on a scale of a few months. Hydration can also occur rapidly. On the other hand, plate corrosion and growth, and shedding proceed on a time scale of a few years, and thus do not directly influence the timing of this task.

Task Interval Support:

The interval of 1 month to 3 months for this task, depending on the functional importance of the battery, is chosen to provide assurance that the battery is constantly being charged under the right conditions to avoid sudden failures and to derive the maximum design lifetime. The best way to achieve this is to monitor the float charging current and voltage during this task. This provides a direct integrated measure of the charging status and avoids the need for sampling the specific gravity during the Cell Inspection, and for measuring the specific gravity of all cells at the Detailed Inspection.

Detailed Inspection

Task Objective:

This task addresses the condition of individual battery components, some of which are within the cells, e.g. the plates. The annual interval is not strongly constrained provided Cell Inspection and Battery Monitoring are performed to address the faster developing failure modes.

Task Content:

Detailed Inspection should include:
. Inspect the battery rack for evidence of corrosion, damage and that the ground is intact.
· Measure and record specific gravities and temperatures on all cells, if not monitoring or measuring the float charging current monthly.
· Inspect all cells for evidence of broken or deformed plates.
· Inspect plates for evidence of contamination (copper color), and the integrity of the separators.
· Inspect all cells for evidence of sulfation and mossing.
· Inspect all cell plates for evidence of hydration.
· Ensure that all battery posts are properly coated with corrosion inhibiting grease and there is no evidence of corrosion.
· Measure and record each cell's internal ohmic measurements and the inter-cell connector resistance; compare to previous valves.
· Inspect cell vents or flame arrestors for evidence of damage or blockage.
· Verify the integrity of all cable supports and that there is no evidence of cable damage.
· Ensure electrolyte is clear, not discolored, and is at the proper level especially on lead-antimony type batteries towards the end of life.
· Should include a visual observation of the battery rack for evidence of corrosion, mechanical damage, and that the ground cable is properly connected.
· Inspect the battery for cracked jars and evidence of leaking electrolyte.
· Measure and record individual cell voltages.
· Ensure the room is clean and free of debris.
· On a 10% sampling basis, measure and record the specific gravity and electrolyte temperatures of the sampled cells, if not measuring the float charging current monthly.
· Inspect posts and connections for evidence of corrosion or damage.
· Inspect post seals for evidence of damage, deterioration, or leakage.
· Evaluate Internal Ohmic measurements for significant changes from past values.

Principle Failure Locations and Causes:

The focus of this task is the condition of individual battery components, some of which are within the cells, e.g. the plates. Cell by cell measurements are made of
inter-cell connection resistance, cell internal resistance, and the specific gravity and temperature of the electrolyte in each cell (if not monitoring the float charging current and voltage), combined with a detailed internal and external inspection of each cell.

The task is most important for addressing post corrosion, plate growth, and the degree of plate shedding. Other important degradations that are addressed are the disintegration (aging) of plate separators, contamination of plates, and damage to or corrosion of the battery rack. Less common mechanisms are mechanical damage to the posts, sulfation and hydration, corroded or damaged inter-cell and inter-tier connections, and clogged flame arrestors.

Progression of Failure Mechanisms Over Time:

Poor seal design, improper installation, overcharging, lack of corrosion inhibiting grease, and other defects can lead to post corrosion at any time up to a few years. Post damage can also occur from maintenance error at any time. Plate separators may disintegrate after only a few years. Inter-cell and inter-tier connectors may deteriorate over a few months, or be damaged or incorrectly assembled at random times. Random failures of flame arrestors from clogging with foreign material or sulfate deposits also occurs randomly over a few years.

Task Interval Support:

The above timing considerations are the main reasons why this task is performed at an annual frequency.

Battery Capacity Test

Task Objective:

This task is focused on verifying design capacity. The interval is somewhat determined by the possibility of mechanical failure of the plates.

Task Content:

This task requires all the monitoring and inspection activities of the other tasks to be performed before the Capacity Test is started.

Principle Failure Locations and Causes:

Capacity testing by complete discharge of the battery is the only generally accepted way to verify that the battery is still capable of providing the design capacity. The dominant degradation mechanisms of post corrosion, plate growth, and plate shedding are all addressed by this task, along with many other mechanisms that are not so common. Some of these mechanisms appear to require this task to be performed within several years (such as plate growth), others progress on much shorter time scales but are effectively addressed more frequently by other tasks such as the Detailed Inspection at 1 year. In all cases the requirement for a demonstration of design capacity is only satisfied by a discharge test. Because battery life is shortened by too many deep discharges the frequency of this test is limited to once in 5 years. This is a suitable complement to the Detailed Inspection at 1 year.

Trending the battery capacity provides predictive information about the approach of end of life. Consequently, a capacity test on a Plante battery is a failure finding task to be performed every 10 years.

Thermographic scans of posts, and of inter-cell and inter-tier connections, during the discharge can reveal high resistance contacts and post corrosion beneath the seals. If the utility has already invested in a Thermography program, minimal additional resources are required to perform thermographic scans during the Capacity Discharge Test. This is cost-beneficial.

Progression of Failure Mechanisms Over Time:

Not provided.

Task Interval Support:

Not provided.

Battery Service Test

Task Objective:

This task verifies that the battery can still provide the minimum voltage at rated current for each part of a typical duty cycle. The interval is not strongly constrained by timing of failure modes.

Task Content:

This task requires all the monitoring and inspection activities of the other tasks to be performed before the Capacity Test is started.

Principle Failure Locations and Causes:

This test is similar to the discharge test but provides additional evidence that the battery can still provide the minimum voltage at rated current for each part of a typical duty cycle. This typically includes high current loads early in the duty cycle. This test will only be performed for the most critical batteries because it uses up useful life in terms of the number of available discharge cycles.

The Service Test is not recommended for batteries in severe service conditions because it was assumed there are no Class 1E batteries operated in these conditions. It is also not recommended for the Plante type of batteries because the capacity test is a sufficient failure finding task.

Progression of Failure Mechanisms Over Time:

Not provided.

Task Interval Support:

Not provided.

Battery – Inverter

Table A-11 Battery – Inverter

Template Data Report:	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
Battery - Inverter	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Thermography	1Y	NA	1Y	NA	2Y	NA	2Y	NA
Clean and Inspect	1Y	NA	1Y	NA	2Y	NA	2Y	NA
Component Replacement	5Y	NA	10Y	NA	5Y	NA	10Y	NA
Refer to Switchgear - Motor Control Centers	AR	AR	AR	AR	AR	AR	AR	AR
Refer to Battery - Charger	AR	AR	AR	AR	AR	AR	AR	AR
Operator Rounds	1S	1S	1S	1S	1D	1D	1D	1D

Component PM Assessment

For Battery – Inverter the EPRI PMBD recommends six tasks to maintain the inherent reliability of the component, as shown in Table A-11. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-12 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-12 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The addition of just one task, Operator Rounds or Clean and Inspect for Batteries – Inverter, will result in a 50% greater reliability benefit than doing nothing. The execution of two PM tasks: Clean And Inspect And Operator Rounds; Or Clean And Inspect And Component Replacement will result in a 90% greater reliability than doing no preventive maintenance at all.

Table A-12 Battery – Inverter PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Thermography	2.0		√**
Clean and Inspect	16.0	√*	√**
Component Replacement	16.0		√**
Circuit Breaker Testing	2.0		
Refer to Battery - Charger	4.0		
Operator Rounds	0.25	√*	√**

- *- Either perform Clean and Inspect or Operator Rounds.
- **- Perform two of the following tasks: Clean And Inspect And Operator Rounds; Or Clean And Inspect And Component Replacement.

Thermography

Task Objective:

This task focuses on a general temperature rise of the cabinet or, with access to the cabinet interior, of individual hot components. The intervals are consistent with failure mode timing.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

This task focuses on either a general temperature rise of the cabinet or, if access to the cabinet interior can be obtained, on individual hot components, typically on large input or output chokes, transformers, and loose connections, and may also indicate weak or loose fuse holders. The diagnostic indication is a temperature difference between two similar inverters with similar loads.

Progression of Failure Mechanisms Over Time:

Although winding degradation is not anticipated for many years, it frequently (but not always) results in rising temperatures for some time before failure occurs. Degradation caused by cooling system failures, e.g. restricted air flow, may occur more rapidly but will be dependent on the power rating of the inverter. Loose connections will mostly be random events.

Task Interval Support:

Thermography is most effective when the inverter cabinet doors can be opened during power operation. The effectiveness of thermography is in revealing differences in temperature between two similar inverters with similar loads. If the cabinet doors can not be opened only a general temperature indication can be obtained, and this will not be sensitive to small differences in individual component temperatures.

The task needs to be performed in the normal operating mode, but also taking opportunities, when possible, to perform it for the bypass mode, and when switched to the alternate source of power. These variations will generally sample different sets of connections, although only one such alignment can normally be addressed by any given thermography scan.

Thermography is not universally regarded as an effective PM task for chargers and inverters because the relatively high proportion of random failures, and the speed of their progression to failure, diminish its overall effectiveness.

When the cabinet doors can be opened, advantage should be taken of the opportunity to visually inspect the interior, in addition to performing the thermography scan. Typically, the visual inspection items listed under the "Clean and Inspect" task, should be performed each time the doors are opened.

Clean and Inspect

Task Objective:

This task is mainly intended to detect signs of overheated components, drift in circuit boards and metering instruments, and to cycle the static and maintenance bypass switches. The intervals are consistent with the drift and static switch failure modes and several other random failures.

Task Content:

Clean and Inspect should include:
· Verify proper operation of the maintenance bypass-switch
· Inspect for loose, missing, or damaged parts and foreign material
· Check all cables and connections for discoloration, cracks and other degradation
· Check high power connections for tightness
· Check that the silicon controlled rectifiers (SCR's) are properly torqued to their heat sinks and that the proper contact grease is used, if accessible
· Check for leakage or swelling of all electrolytic capacitors
· Check printed circuit boards and relays for signs of degradation; replace as necessary
· Clean and vacuum dust from cabinets and components
· Visually inspect transformers and chokes for damage, insulation breakdown, loose connections, and the presence of foreign material
· Clean ventilation filters; replace as necessary
· Verify accuracy of meters, calibrate if required
· Verify set points of alarm cards, adjust if necessary
· Verify the proper operation of all local and remote lamps, and annunciators
· Verify proper operation of static transfer switch, including timing test if desired
· Inspect contactors, if present
· Check the capacitance of the capacitor bank, if desired
· Verify free rotation of cooling fans and that they are not clogged or dirty
· Electrical Testing: Verify that output voltage, frequency, and waveform are within specification.

Principle Failure Locations and Causes:

The task addresses many items but is focused on the detection of overheating components that may be about to fail, on the calibration of printed circuit boards for metering and alarm functions, and on exercising the static switch and maintenance bypass switch.

Overheating may occur to power semiconductor devices because of insufficient torque or heat transfer material mating them to their heat sinks, because of blocked air filters, or because of the restriction of air flow by foreign material. Foreign magnetic or conducting material such as bolts or washers may also fail input or output chokes by vibrating against winding insulation if dropped inside large open windings. Electrolytic and oil-filled capacitors may show signs of overheating or leakage before failure.

Calibration of printed circuit boards and cycling of key switches are heavily relied on to address the expected failure modes of drift and aging, respectively.

Progression of Failure Mechanisms Over Time:

The most important influences on the timing of this task are random failures of power semiconductors, random occurrence of leakage from electrolytic and oil-filled capacitors, and the random occurrence of degraded windings and loose connections on power transformers. The main age related process for this task is the drift of circuit boards. The need to periodically cycle the maintenance bypass and static switches requires a task interval much shorter than the expected life of these switches.

Task Interval Support:

The recommended interval of 1 to 2 years appears to satisfy the above constraints while providing a reasonable interval between tasks. In V3.0 these intervals are shorter than the 2 years to 3 years originally proposed. The EPRI Maintenance and Diagnostic Center has proposed the shorter intervals, which are more in line with the failure mode data. Most of the random events addressed are quite common and a significant number of sub components are subject to them. Drift in circuit boards also requires a 1 year interval in order to be conservative.

Because overheating is a major factor in these component failures, the performance of thermography, and an accompanying visual inspection for signs of overheating or cooling obstruction, take on additional importance.

Component Replacement

Task Objective:

The aim of this task is the scheduled replacement of certain components. The intervals are strongly restricted by wearout failure modes.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Principle failure locations and causes text is not included for this release

Progression of Failure Mechanisms Over Time:

Progression of failure mechanisms over time text is not included for this release.

Task Interval Support:

Task interval support text is not included for this release

Operator Rounds

Task Objective:

Operator Rounds is intended to observe the system status via meter readings and indicator lights, to verify that the inverter is operating satisfactorily from its intended power source, and to detect obvious external signs of deterioration.

Task Content:

Operator Rounds should include:
· Read meters and check that they are indicating expected values
· Check indicator lights
· Verify system line-up and alarm status
· Check for audible noises and strange smells
· Check that the fan is running, if visible
· Verify that the room ventilation is operating properly and that area temperatures are within specification

If not included in regular operator rounds, the above external inspections should nevertheless be made regularly, i.e. on a weekly basis for critical inverters, and monthly for non-critical inverters.

Principle Failure Locations and Causes:

Operator Rounds provide an opportunity to observe the system status via meter readings and indicator lights, to verify that the inverter is operating satisfactorily from its intended power source, and to detect obvious external signs of deterioration such as unusual noises from worn fan bearings, or from vibration of damaged components, and to detect the smell of scorching or burning from overheated components such as degraded transformer windings.

Progression of Failure Mechanisms Over Time:

Progression of failure mechanisms is not included for this release

Task Interval Support:

Task interval support is not included for this release

Circuit Breaker – Substation – Oil Filled

Table A-13 Circuit Breaker – Substation – Oil Filled

Template Data Report: Circuit Breaker - Substation - Oil Filled	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Thermography	6M	6M	1Y	1Y	3Y	3Y	3Y	3Y
Substation Inspection	1M	1M	1M	1M	6M	6M	6M	6M
Ultrasonic Noise Analysis	1Y	1Y	1Y	1Y	3Y	3Y	3Y	3Y
Internal Inspection	5Y	5Y	5Y	5Y	AR	AR	AR	AR
Oil Analysis	5Y	5Y	5Y	5Y	8Y	8Y	8Y	8Y
Functional Testing	AR	AR	AR	AR	AR	AR	AR	AR
Compressor Inspection	2Y	4Y	2Y	4Y	2Y	4Y	2Y	4Y

Component PM Assessment

For Circuit Breaker – Substation – Oil Filled the EPRI PMBD recommends seven tasks to maintain the inherent reliability of the component, as shown in Table A-13. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-14 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-14 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The execution of just one task, Substation Inspection for the Oil Filled Circuit Breakers, will result in a 50% greater reliability benefit than doing nothing. The execution of two PM tasks: Internal Inspection And Substation Inspection will result in a 90% greater reliability than doing no preventive maintenance at all.

Table A-14 Circuit Breaker – Substation – Oil Filled PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Thermography	1.0		
Substation Inspection	1.0	√*	√**
Ultrasonic Noise Analysis	1.0		
Internal Inspection	32.0		√**
Oil Analysis	1.0		
Functional Testing	1.0		
Compressor Inspection	4.0		

- *- Performing this one task Substation Inspection will provide a 50% reliability benefit.
- **- Performing two of the following tasks: Substation Inspect And Internal Inspection will provide a 90% reliability benefit.

Thermography

Task Objective:

This task looks for thermal anomalies in the bushing connections and internal contacts. There is some support for the recommended intervals - mainly in high fault current situations.

Task Content:

Scan the bushings and connections.
Compare input and output temperatures of each phase.
Compare phase tank temperatures.
Ensure that the heater is working in the control cabinet.

Principle Failure Locations and Causes:

Thermography is focused on mechanisms such as failed cabinet heaters and thermostats, and misaligned, eroded, or coked interrupter contacts. None of these conditions normally occur frequently except in special circumstances.

Progression of Failure Mechanisms Over Time:

These mechanisms are generally of the long term wearout type. However, a high frequency of fault current interruptions can cause contact damage in only one or two years.

Task Interval Support:

This relatively inexpensive task could be performed quite frequently for critical breakers in severe service conditions or when there is a high frequency of fault current conditions.

Substation Inspection

Task Objective:

The Substation Inspection provides a level of confidence that the breaker is in nominal condition. There appears to be little support for monthly inspections from the underlying failure cause data.

Task Content:

Inspect bushings for cracks and chips, oil level, debris and contamination, evidence of flashover, broken strands or birdcaging in leads.
Inspect circuit breaker oil levels, observe evidence of oil leaks, discolored paint, condition and tightness of ground cable, condition of the concrete pad or foundation.
Look for evidence of rodent damage in the control cabinet, discolored wiring, alarm conditions or switches that have been pulled or tagged.
Check for oil leaks around the compressor or hydraulic pump, check and record operating pressure.
Observe general condition of belts and sheaves if present; listen for air leaks or other unusual noises.
Bleed water from compressor air receiver, depending on the season; check pressure at which the compressor starts.

Principle Failure Locations and Causes:

Substation Inspection is primarily important for finding water logging of pneumatic receiver tanks, external contamination of oil filled bushings, and hydraulic system leaks.

Progression of Failure Mechanisms Over Time:

Substation Inspection is primarily important for finding water logging of pneumatic receiver tanks, external contamination of oil filled bushings, and hydraulic system leaks.

Task Interval Support:

Water logging of the pneumatic receiver tank can occur on a time scale of 1 year or even less in high humidity conditions. Oil filled bushings will experience external contamination problems in a few years, or at much shorter times when subject to excessive dust and environmental contamination.

Ultrasonic Noise Analysis

Task Objective:

This task is mainly directed at finding air leaks and corona discharges. The task intervals are not directly supported by the failure cause data.

Task Content:

Airborne testing: Scan the entire breaker and the control cabinet, listening for evidence of leaks and other abnormal noises.

Contact testing: The condition of the air compressor reed valves on pneumatic mechanism type actuators may be discovered using the technique.

Principle Failure Locations and Causes:

Ultrasonic Noise Analysis mainly addresses worn or broken Reed valves on air compressors, external contamination of oil filled bushings, and pneumatic system leaks..

Progression of Failure Mechanisms Over Time:

Wear on Reed valves can degrade performance after about 10 years, and bushings can be significantly contaminated in a few years. However, these mechanisms can act in much shorter times on high cycle breakers or in dirty environmental conditions.

Task Interval Support:

This is an inexpensive task that can be performed quite frequently. There is little indication that the task should be performed more frequently than yearly.

Internal Inspection

Task Objective:

The purpose of this task is to renew the breaker to an as-new condition. The intervals are directly constrained by important wearout mechanisms.

Task Content:

Include all tasks from the Substation Inspection.
Remove and filter the oil.
Clean, inspect, and repair the:
· Tank
· Interrupter (main and arcing contacts, resistors)
· Bushings, including cleaning the outside surface
· Dashpot
Lubricate mechanism
Perform a slow close to check the alignment and contact wipe
Door gasket
Re-filter and refill with the same oil
Touch up the paint around the door
Perform a power factor and timing test
Change the air compressor oil, if present
Check tightness of all connections
Perform a Functional test which includes diagnostics of the "Capture the first trip" type

Principle Failure Locations and Causes:

Internal Inspection addresses a wide range of failure mechanisms, including contaminated compressor oil, plugged oil filters and breathers, and internal contamination in the main tank. It also addresses externally contaminated oil-filled bushings and the condition of the oil in the main tank, including (less effectively, especially under high fault current conditions) the causes of this oil contamination, such as wear or erosion of the explosion pots and arcing contacts.

Progression of Failure Mechanisms Over Time:

These are all wearout mechanisms with likely failure free intervals of about 5 years or more. However, these induction times will often be much shorter for high cycle breakers and/or those subject to dirt and humidity.

Task Interval Support:

For critical breakers with low duty cycles and mild service conditions, the 5 year interval may be adequate. However, under specific severe service conditions or very high duty cycles a shorter interval is likely to be beneficial but may not be cost-effective.

Oil Analysis

Task Objective:

Oil Analysis primarily provides information about condition of the contacts. The intervals are strongly constrained by important wearout processes.

Task Content:

This task includes DGA, oil quality, and particulates.

Principle Failure Locations and Causes:

Oil Analysis is focused on identifying contaminated oil caused by particulates from the erosion of arcing contacts and explosion pots.

Progression of Failure Mechanisms Over Time:

These are all wearout mechanisms with likely failure free intervals of about 5 years or more. However, these induction times will often be much shorter for high cycle breakers and/or those subject to dirt and humidity.

Task Interval Support:

For critical breakers, the 5 year interval may be adequate. The reliability does not respond markedly to this interval.

Functional Testing

Task Objective:

A Capture the first trip test ensures that the breaker integral performance is within specifications. This diagnostic test is recommended to be performed after each internal inspection but is otherwise an on-condition task.

Task Content:

This task consists of a "Capture the first trip" test. Additional tests (offline) could include power factor, main contact resistance, and timing tests on an on-condition basis. In addition, the breaker can be operated with the compressor motor shut off to assure that it will open 3 times.

Principle Failure Locations and Causes:

Functional Testing can discover worn or broken Reed valves on the air compressor and other failures in pneumatic and hydraulic mechanisms, as well as failures caused by a wide variety of other mechanisms.

Progression of Failure Mechanisms Over Time:

Some of these failure mechanisms can act at short times or randomly, making infrequent functional testing of limited value.

Task Interval Support:

Although some utilities perform trip tests as frequently as annually, they are of limited value unless the kind of diagnostic information that is indicated in this Functional Test is obtained. A practical and more useful alternative to frequent testing without diagnostics is to perform a diagnostic trip test when the breaker is installed, and after each internal inspection, and use the data as a baseline for comparison. Future diagnostic functional tests then become on-condition tasks and are performed only after other indications of a potential problem are discovered, and therefore have more of the character of troubleshooting. For this reason the Template interval for this task is shown as AR.

Compressor Inspection

Task Objective:

This task mainly ensures that the air compressors remain serviceable and that there are no leaks. The intervals are not strongly dependent on the failure cause data.

Task Content:

This task consists of the following:
· Record and compare the compressor start counter numbers.
· Change the compressor oil and visually inspect for evidence of water and grit which are indicative of internal wear.
· Change all filters.
· Check for oil leaks around the compressor, check and record operating pressure. Observe general condition of belts and sheaves if present; listen for air leaks or other unusual noises.
· Calibrate all I&C devices.
· Bleed water from compressor air receiver, depending on the season; check pressure at which the compressor starts.

Principle Failure Locations and Causes:

This task ensures that the compressor oil remains in good condition, prevents breathers from plugging, detects worn belts and sheaves, and detects signs of leakage from o-rings and gaskets.

Progression of Failure Mechanisms Over Time:

These are all wearout mechanisms operating over a time frame of a few years or much longer.

Task Interval Support:

An interval of 2 years to 4 years for this task appears to be reasonable depending on duty cycle and service conditions, provided the substation inspection task is performed much more frequently.

Switchgear – Low Voltage

Table A-15 Switchgear – Low Voltage

Template Data Report: Switchgear - Low Voltage	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Thermography - Cubicle (including bus)	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Breaker - Detailed Inspection	4Y	4Y	6Y	6Y	6Y	6Y	6Y	6Y
Breaker - Overhaul	8Y	8Y	12Y	12Y	12Y	12Y	12Y	12Y
Cubicle - Detailed Inspection	4Y	4Y	6Y	6Y	6Y	6Y	6Y	6Y
Functional Test	AR	AR	AR	AR	AR	AR	AR	AR

Component PM Assessment

For Switchgear – Low Voltage the EPRI PMBD recommends five tasks to maintain the inherent reliability of the component, as shown in Table A-15. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-16 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-16 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The execution of one of three tasks, Breaker – Detailed Inspection Or Breaker – Overhaul Or Cubicle – Detailed Inspection, will result in a 50% greater reliability benefit than doing nothing. The execution of two PM tasks, Breaker - Detailed Inspection And Cubicle - Detailed Inspection; Or Breaker - Overhaul And Cubicle - Detailed Inspection, will result in a 90% greater reliability than doing no preventive maintenance at all.

Table A-16 Switchgear – Low Voltage PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Thermography – Cubicle (Including Bus)	1.0		
Breaker - Detailed Inspection	8.0	√*	√**
Breaker Overhaul	24.0	√*	√**
Cubicle – Detailed Inspection	4.0	√*	√**
Functional Test	1.0		

- *- Performing one of three tasks; Breaker - Detailed Inspection Or Breaker - Overhaul Or Cubicle - Detailed Inspection will provide a 50% reliability benefit.
- **- Performing two of the following tasks: Breaker - Detailed Inspection And Cubicle - Detailed Inspection; Or Breaker - Overhaul And Cubicle - Detailed Inspection will provide a 90% reliability benefit.

Thermography – Cubicle (Including Bus)

Task Objective:

This task detects temperature increases, associated with main current carrying components, caused by degraded or loose connections, or contacts. The interval is not supported by the failure mode data so that some interval extension could be possible, even though the mechanisms are common.

Task Content:

Breaker and Cubicle Thermographic Scan should include:
· Inspection for unusual heating of the circuit breaker and truck, cubicle, and bus work, that is not commensurate with local and historical trends.

Principle Failure Locations and Causes:

Thermography will detect increases in temperature that affect the whole cubicle, as well as accessible areas of the buswork. Typically such temperature increases will be associated with main current carrying components and will be caused by loose or contaminated connections, or bus stabs that are misaligned, damaged, or contaminated.

Progression of Failure Mechanisms Over Time:

The accumulation of contamination and corrosion products depends on environmental factors and normally will progress steadily with exposure to the service environment, leading to the expectation of a trouble free period of up to 10 years after cleaning and adjustment, depending on conditions. Sudden, heavy contamination e.g. from nearby construction, can lead to failure within 2 to 3 years.

Loose connections would most likely be the result of inappropriate maintenance since high vibration environments are unusual for switchgear and buswork. Improperly torqued bus connections may still provide a period of satisfactory operation before overheating. In general, preventive maintenance cannot compensate for maintenance error beyond providing opportunities for fault detection.

Task Interval Support:

The normal heating effect of the main current may be allowed for by comparing the breaker or cubicle temperature with that of neighboring breakers carrying similar loads or by trending the temperature readings of a particular unit over time. The recommended period for thermographic inspection is 1 year because of the quick, non-intrusive nature of the task and the ease with which many adjacent cubicles can be surveyed at one time and location. This task interval is significantly shorter than the times to first failure anticipated from the above failure causes, and results in Thermography being an effective condition monitoring task for those failure causes. Consideration should be given to extending thermographic scan intervals taking into account breaker loading conditions and previous thermographic histories.

Breaker – Detailed Inspection

Task Objective:

This task is a more detailed check for damage, degraded connections, and signs of overheating. Check the condition of the lubricant, and cycles the breaker mechanism. The interval is strongly determined by a large number of common wear out failure mechanisms, giving essentially no opportunity to increase the interval.

Task Content:

Breaker Detailed Inspection should include:

· Manual operation – "feel" for binding (experience needed)
· Perform and record as-found electrical open/close and timing test
· Perform pre-disassembly functional tests and visual inspection
· Remove front covers, phase barriers (if present) and arc chutes
· Replace lubricant where accessible
· Lubricate contact stabs and easily accessible pivot points and primary contacts if required
· Generally clean and inspect all accessible parts and surfaces
· Inspect for: pitting or corrosion on primary contacts; damaged, loose, or missing fasteners and setscrews; electrical tracking; cracked welds; rust or corrosion; cracked or burned arc chutes; hard lubricant; secondary control block damage or misalignment; worn or bent mechanical linkage, general cleanliness; wiring harness and protective relay damage.
· Replace known parts subject to wear out or required by OEM
· Verify adjustments
· Inspect puffer and verify operation
· Perform ductor test
· Perform insulation resistance tests
· Calibrate protective devices as required
· Perform over current trip test
· Perform as-left electrical open/close and timing test

Principle Failure Locations and Causes:

The Detailed Inspection includes a comprehensive set of tasks designed to be an effective way to thoroughly check the operating mechanism, main current components, and the racking mechanism for mechanically worn, failed or damaged parts, loose connections and fasteners, to check the condition of the lubricant (and to cycle the operating mechanism so as to mix and distribute the lubricant), to provide an opportunity to add and refresh lubricant, and to check for burn marks or discoloration that might indicate overheating of electrical components such as relays, coils and switches.

Parts that are loose, damaged, or missing may be seen directly, often where they should not be (e.g. on the cubicle floor), even by relatively inexperienced personnel. However, signs of material fatigue, abnormal wear (e.g. worn bushings), or material property changes can best be noted and assessed by having experienced people perform the detailed inspection. A relatively common problem area is the alignment of the prop mechanism, its centering and tightness.

The condition of the lubricant is essential to proper operation. Inadequate lubrication is by far the dominant cause of breaker failures. Assessment of the condition of the lubricating grease should therefore be the prime objective of any inspection. Removal of arc chutes, phase barriers, inspection covers and relay/switch covers will facilitate a fairly thorough check of lubricant condition. However, the detailed inspection does not include extensive disassembly of the breaker; consequently, lubricant internal to bearings and bushings will not, in general, be accessible at the detailed inspection. Hard lubricant in thin films may not be visible at all, or may appear as a varnish-like layer.

Contaminated switches and relay contacts make up a very large proportion of the failure causes and overhaul deficiencies. These contacts should be accessible at a detailed inspection when switch covers are removed. Electrical insulation and wiring is a much smaller contributor to breaker failure.

In addition to visible damage to primary contacts, and deposits and tracking on arc quenching components, the arc contact tips may be damaged or broken off, and the puffer or the blowout coil may have failed. text.

Progression of Failure Mechanisms Over Time:

The likelihood of damaged or failed mechanical parts and loose or missing fasteners is expected to depend on the number of operations of the breaker. This would indicate a continuous progression of these degradation mechanisms, regardless of whether they occur through normal wear, fatigue, or material property changes. Failures should occur only after a trouble free period corresponding to the OEM's maximum recommended number of operations. The failure contribution from loose fasteners is expected after a similar trouble free period. If 2000 cycles is considered to be a generic OEM limit, the boundary between the template high and low duty cycle of 200 operations per year would imply that these failure causes do not require periodic inspection at low duty cycles more often than at a 10 year interval under nominal service conditions.

However, concern over inadequate lubrication may appear more quickly than this, in 3 to 10 years depending on service conditions. If heavy contamination of breakers with dust has occurred during the plant construction phase, or if service conditions involve high temperatures or significant dust or other contamination, e.g. salt and/or high humidity, this is likely to lead to lubrication failure in significantly less than 10 years.

The lubricant can be expected to harden if a breaker is cycled scarcely at all in a period approaching 6 years. This period of inactivity would lead to a high likelihood of binding and a failure to close or open. Cycling the operating mechanism maintains the lubricant in good condition. The combination of normal operations, detailed inspections, and the operability test once per operating cycle should ensure this failure cause is not encountered.

Burn marks and discoloration are symptoms of overheating and may indicate degradation of electrical devices such as coils and relays. Failures of coils, relays and motor windings occur from current-time overload, although age, contamination and environmental factors may also play a part. Current-time overload occurs mainly as a result of energizing the devices for longer than the design intent and is almost always due to lubrication failure which causes the mechanism to move slowly or to seize up.

Consequently the degradation mechanisms in the electrical devices themselves, which can be difficult to test for, are strongly coupled to the time scales and influences affecting lubrication. A trouble free period of operation may be expected, with burn marks and discoloration being visible signs of lubrication failure as well as indicating degraded coils and relays. Regardless of the lubricant condition, a measurement of the electrical resistance of coils and relays using an ohmmeter, if trended over time, will detect progressive failure of winding insulation and give an indication of the condition of these electrical devices.

An insulation resistance test of insulation resistance to ground should be carried out on all subcomponents exposed to line potential. The condition of insulation can also be indicated by a dielectric test, recommended by Westinghouse but not frequently performed by utilities and not recommended here, owing to the possibility that the high potential may precipitate insulation breakdown.

Switch and relay contact failures occur as a result of exposure to the service environment through oxidation and contamination, by wear through the plating, or from lack of contact pressure. High contact resistance may develop over time although a trouble-free period of 10 to 12 years should be obtained under mild service conditions. Switch and relay contact failure may be avoided by measuring the contact resistance at the detailed inspection. A contact resistance of up to 5 ohms (not the 0.1 ohms often quoted) can be tolerated without contact failure, as the passage of current will remove the contaminating film. Lack of use may also lead to contact failure, either because the contacts are not sufficiently wiped or surface contamination is not burned through. The recommended electrical cycling of the breaker in a racked-in position should avoid this failure cause.

Deposition of metals or a variety of glass-like materials, and moisture absorption on arc quenching components may lead ultimately to a failure to quench. These degradation mechanisms are clearly dependent on the number of cycles, age, and service conditions; normal operation should lead to a trouble-free period of approximately 10 to 12 years. Large fault current interruptions should each be accompanied by an inspection of the arcing contacts and arc chutes and thus should not interfere with the expected period of failure free operation. The absorption of moisture by arc chutes can also be indicated by a power factor test.

Failures of the puffer and blowout coil should not occur before 4 to 5 years and tend to be randomly spread over a wide time scale after that period has passed. The condition of the main contacts should be assessed using a ductor test with the passage of a high current to burn off contaminating films, although the ductor test is not a good indicator if the plating is damaged. Damaged plating on main contacts should be visible. The ductor test also demonstrates that neither lubrication failure nor misadjustment or normal wear are affecting the condition of the main contacts.

Task Interval Support:

All of the failure mechanisms discussed above progress continuously for a period of years before the failure point is reached. The minimum duration of this wearout characteristic is usually controlled by the service conditions that affect lubrication failure. Preventive maintenance (PM) within this period can identify and intercept all the failure mechanisms excepting those due to design, manufacturing, and installation defects, and maintenance error. These are excluded from consideration here because their random nature does not lend itself to being addressed by regularly scheduled PM tasks, other than failure finding such as the operability test, trip tests, or calibration. An overhaul is necessary to completely clean out old lubricant and to renew lubricant at every point in the breaker within about 10 years for low duty cycle and mild service conditions. The detailed inspection should be performed in order to replace as much of the lubricant as possible at a shorter interval, about half the overhaul interval.

In a Detailed Inspection, accessible pivot points and bearings can be lubricated, although they probably still can not be properly cleaned. Manual and electrical operation can help to distribute lubricant in all areas and mix it to prevent separation of its constituents. The "feel" of the operating mechanism during manual operation can indicate to an experienced person the general condition of the lubricant. Additionally, the time taken for the breaker to close is a direct indication of a sluggish mechanism. As-found and as-left electrical close-timing tests may be supplemented by a trip load test or by a minimum control voltage test to detect a sluggish mechanism. If the breaker does not pass these tests a detailed inspection or overhaul will be necessary.

A Detailed Inspection will typically be performed to ensure that critical breakers in severe service conditions (e.g. high temperatures, high humidity, and salt laden air) can reach the scheduled overhaul at 8 years. In more normal conditions for critical breakers, detailed inspection can be combined in rotation with visual inspection and overhaul to provide flexibility on when the overhaul is performed (i.e. not strictly at 10 years).

Calibration tasks for the protective devices, instantaneous overcurrent, time-current excess, overvoltage and undervoltage, as appropriate, should follow the requirements of technical specifications. These tasks help to ensure that the protective relays are not already out-of-specification (failed) when needed. Where there are no technical specification requirements the recommended period for calibration can be paired with that of the breaker detailed inspection. At this interval, experience shows that the relays are not usually sufficiently out-of-calibration to be in a failed state.

Breaker – Overhaul

Task Objective:

The breaker overhaul is a complete disassembly to give access to all parts for cleaning, inspection for damage and wear, and complete replacement of lubricant. The interval is strongly determined by a large number of common wear out failure mechanisms affecting both breaker and racking mechanisms, giving essentially no opportunity to increase the interval.

Task Content:

Breaker overhaul should include:

· Replace lubricant where accessible
· Lubricate contact stabs and easily accessible pivot points and primary contacts if required
· Generally clean and inspect all accessible parts and surfaces
· Inspect for: pitting or corrosion on primary contacts; damaged, loose, or missing fasteners and setscrews; electrical tracking; cracked welds; rust or corrosion; cracked or burned arc chutes; hard lubricant; secondary control block damage or misalignment; worn or bent mechanical linkage, general cleanliness; wiring harness and protective relay damage.
· Replace known parts subject to wearout or required by OEM
· Verify adjustments
· Inspect puffer and verify operation
· Perform ductor test
· Perform insulation resistance tests
· Calibrate protective devices as required
· Perform overcurrent trip test
· Perform as-left electrical open/close and timing test
· Manual operation - "feel" for binding (experience needed)
· Perform and record as-found electrical open/close and timing test
· Perform pre-disassembly functional tests and visual inspection
· Perform as-found ductor test
· Perform as-found insulation resistance tests
. Complete disassembly of the breaker
· Inspect for: pitting or corrosion on primary contacts; damaged, loose, or missing fasteners and setscrews; electrical tracking; cracked welds; rust or corrosion; cracked or burned arc chutes; puffer; hard lubricant; secondary control block damage or misalignment; worn or bent mechanical linkage, general cleanliness; wiring harness and protective relay damage.
· Clean parts, visually inspect, measure, and record data on wearable parts

. Replace worn parts
· Replace other parts (normal replacement as indicated by OEM or as indicated by historical records), including control fuses
· Reassemble and lubricate necessary parts
. Verify adjustments
· Perform mechanical functional tests and verify puffer operation
· Perform as-left ductor test
· Perform as-left insulation resistance tests
· Calibrate protective devices
· Perform overcurrent trip test
· Perform and record as-left electrical open/close and timing test Task Content text.

Principle Failure Locations and Causes:

The failure locations and failure causes addressed by the Overhaul are the same as those addressed by the Detailed Inspection. However, in an overhaul the breaker is completely disassembled to give access to all parts for cleaning, inspection for damage and wear, and complete replacement of lubricant. Failure to do this results in wear out of the lubricant in parts inaccessible to the detailed inspection. In addition, an overhaul parts replacement kit should be used for small mechanical items like retainers, washers, nuts and bolts, bushings, gaskets and springs. Individual subcomponent replacement depending on make and model may also be necessary.

Calibration tasks for the protective devices, instantaneous overcurrent, time-current excess, overvoltage and undervoltage, as appropriate, should follow the requirements of technical specifications. These tasks help to ensure that the protective relays are not already out-of-specification (failed) when needed. Where there are no technical specification requirements the recommended period for calibration can be paired with that of the breaker overhaul. At this interval, experience shows that the relays are not usually sufficiently out-of-calibration to be in a failed state.

Progression of Failure Mechanisms Over Time:

Failure of lubrication is the most important reason to perform the overhaul. Exposure to nominal operating conditions may be expected to dry out the lubricant over a period of 8 to 12 years, depending on the temperature and the degree of environmental contamination.

However, concern over inadequate lubrication may appear more quickly than this, in 3 to 10 years depending on service conditions. If heavy contamination of breakers with dust has occurred during the plant construction phase, or if service conditions involve high temperatures or significant dust or other contamination, e.g. salt and/or high humidity, this is likely to lead to lubrication failure in significantly less than 10 years.

The lubricant can be expected to harden if a breaker is cycled scarcely at all in a period approaching 6 years. This period of inactivity would lead to a high likelihood of binding and a failure to close or open. Cycling the operating mechanism maintains the lubricant in good condition. The combination of normal operations, detailed and visual inspections, and the operability test once per operating cycle should ensure this failure cause is not encountered.

Burn marks and discoloration are symptoms of overheating and may indicate degradation of electrical devices such as coils and relays. Failures of coils, relays and motor windings occur from current-time overload, although age, contamination and environmental factors may also play a part. Current-time overload occurs mainly as a result of energizing the devices for longer than the design intent and is almost always due to lubrication failure which causes the mechanism to move slowly or to seize up. Consequently the degradation mechanisms in the electrical devices themselves, which can be difficult to test for, are strongly coupled to the time scales and influences affecting lubrication. A trouble free period of operation may be expected, with burn marks and discoloration being visible signs of lubrication failure as well as indicating degraded coils and relays. Regardless of the lubricant condition, a measurement of the electrical resistance of coils and relays using an ohmmeter, if trended over time, will detect progressive failure of winding insulation and give an indication of the condition of these electrical devices.

Task Interval Support:

The failure mechanisms discussed above progress continuously for a period of years before the failure point is reached. The minimum duration of this wearout characteristic is usually controlled by the service conditions that affect lubrication failure. An overhaul is necessary to completely clean out old lubricant and to renew lubricant at every point in the breaker within about 12 years for low duty cycle and mild service conditions. The detailed inspection should be performed in order to replace as much of the lubricant as possible at a shorter interval, about half the overhaul interval.

Cubicle – Detailed Inspection

Task Objective:

This task inspects the racking mechanism for lubrication failure, damaged and failed parts, and loose or missing fasteners. The interval is constrained by several wearout failure modes, which might limit interval extension, but for the fact that racking mechanism failures are not likely to be as critical as breaker failures.

Task Content:

Cubicle Detailed Inspection should include:
· Racking mechanism - inspection and lubrication (where accessible with no major disassembly)
· Breaker to cubicle interface measurements and adjustment
· Bus-work inspection including joints, covers and insulation
· Inspection of primary disconnects
· Inspection of control wiring for fretting, wear, and damaged insulation, replace fuses
· Inspection of shutters and switch interlocks
· Inspection of fasteners for looseness and welds for cracking
· Inspection and test of the CTs and PTs
· Inspection of secondary contacts and disconnects
· Inspect load side cables
· Fuse drawer inspection (e.g. cleanliness, finger alignment, connections) Task Content text.

Principle Failure Locations and Causes:

The racking mechanism is subject to lubrication failure, damaged and failed parts, and loose or missing fasteners.

Inadequate lubrication is an important cause of failures in the cubicle as it was in the breaker, although the consequences are more likely to be extended maintenance time rather than a critical event such as breaker failure to close or to trip. Assessment of the condition of the lubricating grease should be the prime objective of a cubicle inspection. A visual check of the lubricant at accessible, and hence more frequently lubricated points, should be done but will not provide a reliable assessment of its condition at other points, such as bushings and bearings, which can only be lubricated at overhaul. Hard lubricant in thin films may not be visible at all, or may appear as a varnish-like layer.

Parts that are loose, damaged, or missing may be seen directly, often where they should not be, even by relatively inexperienced personnel. However, signs of material fatigue, abnormal wear, or material property changes can best be noted and assessed by having experienced people perform the inspection. Relatively common problem areas are the alignment of the breaker interface with the cubicle, and alignment problems causing damage to contacts, and to primary and secondary disconnects and switches.

Progression of Failure Mechanisms Over Time:

The aging of the lubricant is continuous in time and dependent on contamination, time, and temperature as it was for the breaker itself. Apart from heavy contamination which might have occurred during initial construction or during subsequent room maintenance, a failure free period of up to 10 years should be expected. Heavy contamination or extreme service conditions might shorten this period to as little as 2 years. Complete inactivity, i.e. where the racking mechanism is not actuated at all may lead to binding of the mechanism in as little as 3 to 5 years or as much as 8 to 10 years depending on the lubricant that has been used. Visual inspection and ease of operation are the methods available to detect aging of the lubricant. Since no disassembly is contemplated for this inspection only accessible points should be lubricated. Lubricant on primary contact stabs should also be replaced.

The degradation mechanisms that lead to damaged and failed parts as well as to loose or missing fasteners will proceed continuously with the number of operations of the mechanism assuming no damage is caused by maintenance personnel in the process of racking the breaker in and out. Such damage has occurred often in the industry but is random in occurrence and should be controlled through training, not preventive maintenance. However, cubicle inspections should inspect for signs of such damage. The expected failure free period for these degradation mechanisms probably exceeds that for lubrication failure as quoted above.

Task Interval Support:

The Cubicle Detailed Inspection may not be carried out at the same time as the Breaker Detailed Inspection, although it may be convenient to synchronize the inspections and overhauls. Inspection of buswork will be visual and by Thermography as described in the Thermography task for breaker and cubicle. Line and load side insulation should be visually inspected and have its insulation resistance tested.

Functional Test

Task Objective:

The functional test is an electrical open and close test which mixes the lubricant and ascertains that the breaker operating mechanism is functional. The interval is not strongly constrained by the failure mode data, but not much latitude exists for interval extension.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

The functional test is not recommended as a scheduled task, but it is nevertheless recommended that the breaker be operated at least once per operating cycle for all critical and non-critical but important breakers. Any breaker, regardless of its functional importance, which remains in a static position for long periods of time, e.g. longer than 2 refueling cycles, should be functionally tested for the above reasons.

This does not test protective trip mechanisms but it ascertains that the breaker operating mechanism is functional and it mixes the lubricant to help prevent seizing of the mechanical parts.

The functional test is an electrical open and close test normally conducted as a post maintenance test on the breaker and also frequently as a post maintenance test on the load.

Progression of Failure Mechanisms Over Time:

Inactivity leads to failure of lubrication at many points in the breaker and cubicle in a time frame from 3 to 6 years.

Task Interval Support:

Although the functional test is not recommended as a scheduled task, it is nevertheless recommended that the breaker be operated at least once per operating cycle for all critical and non-critical but important breakers. Any breaker, regardless of its functional importance, which remains in a static position for long periods of time, e.g. longer than 2 refueling cycles, should be functionally tested for the above reasons.

Otherwise, the functional test should be performed when:
· Returning powered equipment to service
· As per technical specifications
. As a post maintenance test

Relay – Timing

Table A-17 Relay – Timing

Template Data Report: Relay - Timing	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Scheduled Replacement	10Y	AR	10Y	AR	NR	NR	NR	NR
Calibration	AR	AR	AR	AR	AR	AR	AR	AR
Functional Testing	2Y	2Y	2Y	2Y	NR	NR	NR	NR
Thermography	AR	AR	AR	AR	NR	NR	NR	NR

Component PM Assessment

For Relay – Timing the EPRI PMBD recommends four tasks to maintain the inherent reliability of the component, as shown in Table A-17. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-18 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-18 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The execution of one task, Functional Testing, will result in a 90% greater reliability than doing no preventive maintenance at all.

Table A-18 Relay – Timing PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Scheduled Replacement	1.0		
Calibration	1.0		
Functional Testing	0.5	√*	√*
Thermography	0.25		

- *- Performing this one task; Functional Testing will provide a 90% reliability benefit.

Scheduled Replacement

Task Objective:

Scheduled Replacement is a conservative task, performed for Agastat relays only, to prevent these relays reaching a condition where calibration can not compensate for age-related drift. The interval is determined by the failure data, but only under high cycle conditions.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Replacement mainly targets deterioration of the plunger and bellows assembly in pneumatic relays.

Progression of Failure Mechanisms Over Time:

The plunger and bellows assembly experiences a wearout process at around 20 to 40 years.

Task Interval Support

Providing the relay is tested regularly, no failures of the pneumatic type of relays should occur before at least 20 years, making the 10 year replacement interval appropriate only for critical relays in high cycle conditions.

Calibration

Task Objective:

Calibration is mainly focused on correcting drift. The interval is dependent on plant conditions over a wide range.

Task Content:

Calibration should include the following:
· Make adjustments that are necessary.
· Repeat the timing tests three (3) times, until all results are within tolerance, if not, adjust and start over.
· Average the three (3) values and record the result as the as-left value.
· Check contact resistance if necessary.

Principle Failure Locations and Causes:

Calibration is an on-condition task, which is performed whenever Functional Testing discovers improper operation.

The task is mainly focused on correcting drift in the pneumatic type and to a lesser degree in the motor driven type. Sudden failures of electronic components in the solid state type, and problems with contacts or motors in the other types, lead to failures that can be discovered during Functional Testing, but these concerns are less common in the pneumatic types of relays.

Progression of Failure Mechanisms Over Time:

Drift is mainly caused by changes in the plunger and bellows mechanism. This is likely to cause the pneumatic type of relay to be out of tolerance after just a few years, and to be unable to be recalibrated after 20 to 40 years, depending on the ambient temperature.

Task Interval Support:

The Calibration task is recommended to be performed as an on-condition activity after Functional Testing has discovered improper operation. If required, it could be performed as a scheduled task on a timescale between 4 years and 10 years depending on criticality and service conditions.

Functional Testing

Task Objective:

Functional Testing is intended to discover cases where repeatability is unacceptable. The interval is determined by a single wearout failure mode at two years.

Task Content:

Functional Testing should include:
· Perform a test to ensure that the relay operates within the nominal time as required by plant specifications and requirements.

Principle Failure Locations and Causes:

Functional Testing is intended to discover cases where repeatability is unacceptable. Lack of repeatability is likely to be due to a set of bellows that operates erratically by "setting up" and causing an erroneous timing response, especially the first time in a series of tests.

Progression of Failure Mechanisms Over Time:

Lack of repeatability is likely to result from the bellows not being operated for a period of more than two years.

Task Interval Support:

Functional testing will be driven by technical specifications for safety-related relays. Non safety-related critical relays are recommended to receive a functional test at a two year period, if they are not otherwise operated in a two year period.

Thermography

Task Objective

This task is focused on finding hot spots associated with motor winding or contact problems. The task interval is not closely determined by the failure mode data.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

This task is intended to be a scan of all the relays in the panel, and is not specifically focused on one relay at a time. Hot spots can be caused by loose connections, dirty or misaligned contacts, and failed motor winding insulation (for motor driven types).

Progression of Failure Mechanisms Over Time:

High resistance contacts, binding in the mechanism, and thermal aging of the motor winding insulation (for motor driven types) can occur over a wide range of in-service times (from a few years to the life of the plant) depending on service conditions. Contaminated, oxidized, pitted, or otherwise worn contacts (from inappropriate burnishing during maintenance) are the most likely problem areas with contacts, occurring randomly on a scale of several years.

Normal wear on the contacts is not expected to be significant for at least 10 years. However, oxidation and corrosion can degrade the contacts over a wide span of time, from 3 years in severe environments to more than 20 years for mild environments. Contamination of the contacts is reduced by dust covers so that it is not normally a significant problem within at least 3 or 4 years, but isolated occurrences of construction or area cleaning could reduce this time. Manufacturing defects, cracked covers, and personnel errors that result in the covers not being replaced, cause randomly timed problems from high resistance contacts.

The main failure mechanisms are therefore of the wear out kind which do not require Thermography to be performed at an interval shorter than 2 years

Task Interval Support:

The task interval is stated to be As Required. A good starting value for the interval would be 2 years for critical relays, but the periodicity should subsequently be determined by the Thermography results themselves.

Ideally, relays that are not continuously energized would be scanned at the same time as Functional Testing, Calibration, or other surveillance testing. The Thermography task is conducted by opening the panel door, and making the scan of all relays visible at the same time.

Relay – Control (Electromechanical)

Table A-19 Relay – Control (Electromechanical)

Template Data Report: Relay - Control - Electromechanical	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Calibration	AR	AR	AR	AR	NR	NR	NR	NR
Thermography	AR	AR	AR	AR	NR	NR	NR	NR
Scheduled Replacement	10Y	10Y	10Y	AR	NR	NR	NR	NR
Functional Testing	2Y	2Y	2Y	2Y	NR	NR	NR	NR

Component PM Assessment

For Relay – Electromechanical the EPRI PMBD recommends four tasks to maintain the inherent reliability of the component, as shown in Table A-19. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-20 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-20 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The execution of any one of the four tasks shown will result in a 50% greater reliability than doing no preventive maintenance at all. The execution of a Scheduled Replacement Or Thermography And Functional Testing will result in a 90% reliability benefit

Table A-20 Relay – Control (Electromechanical) PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Calibration	1.0	√*	
Thermography	0.25	√*	√**
Scheduled Replacement	1.0	√*	√**
Functional Testing	0.5	√*	√**

- *- Performing any one of these four tasks; Calibration, Thermography, Scheduled Replacement or Functional Testing will provide a 50% reliability benefit.
  **- Performing a Scheduled Replacement Or Thermography And Functional Testing will result in a 90% reliability benefit.

Calibration

Task Objective:

This task is focused on verifying operability of the relay, tightness of connections, and correcting drift. The failure mode data suggest the interval should be shorter than 6 years because the task protects against many common failure mechanisms, mainly random but some wear out, even when Thermography is performed.

Task Content:

Calibration should include the following:
· Verify, record, and trend the reset and pickup times.
· Verify the pick up and dropout voltages are correct, record and trend.
· Verify the voltage settings are correct, if appropriate.
· Verify proper contact operation.

Principle Failure Locations and Causes:

This is a task reserved for a few special types of control relays, and would not normally be performed for the majority. This task is focused on correcting drift, checking tightness of connections, and verifying operability of the relay. Burnishing contacts, cleaning away dust and other foreign material, may be done depending on the as-found condition.

Progression of Failure Mechanisms Over Time:

High resistance contacts, binding in the mechanism and thermal aging of the coil can occur over a wide range of in-service times (from a few years to the life of the plant) depending on service conditions. Contaminated, oxidized, pitted, or otherwise worn contacts (from inappropriate burnishing during maintenance) are the most likely problem areas with contacts, occurring randomly on a scale of several years.

Normal wear on the contacts is not expected to be significant for at least 10 years. However, oxidation and corrosion can degrade the contacts over a wide span of time, from 3 years in severe environments to more than 20 years for mild environments. Contamination of the contacts is reduced by dust covers so that it is not normally a significant problem within at least 3 or 4 years, but isolated occurrences of construction or area cleaning could reduce this time. Manufacturing defects, cracked covers, and personnel errors that result in the covers not being replaced can cause randomly timed problems from high resistance contacts.

Task Interval Support:

This task is not recommended for most control relays. Only in special cases, such as HFA types, would this task provide added value. For the majority of control relays, the combination of Thermography, Functional Testing, and Scheduled Replacement provides a more economic way to address the main failure causes.

The most frequent Calibration is recommended for critical control relays in severe environmental conditions, but wide variations in the relay design and the service conditions do not permit a specific interval to be stated for the highest duty cycles. Other critical control relays might be tested and calibrated at 6 to 8 year intervals. Non-critical relays would not normally be calibrated but might be subjected to As-Found Testing at intervals of 8 years to 12 years. Bearing in mind that doing maintenance on a large number of control relays could produce a risk of plant trip or other upsets, utilities may decide with some justification that control relays in mild conditions may be run to failure for all but the most critical loads. A mitigating factor for the run to failure decision is the likelihood that a failed relay would be discovered during functional testing.

Thermography

Task Objective:

This task is focused on finding hot spots associated with coil or contact problems. The task interval is not closely determined by the failure mode data.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

This task is intended to be a scan of all the relays in the panel, and is not specifically focused on one relay at a time. Hot spots can be caused by loose connections, dirty or misaligned contacts, and failed coil insulation.

Progression of Failure Mechanisms Over Time:

High resistance contacts, binding in the mechanism and thermal aging of the coil can occur over a wide range of in-service times (from a few years to the life of the plant) depending on service conditions. Contaminated, oxidized, pitted, or otherwise worn contacts (from inappropriate burnishing during maintenance) are the most likely problem areas with contacts, occurring randomly on a scale of several years.

Normal wear on the contacts is not expected to be significant for at least 10 years. However, oxidation and corrosion can degrade the contacts over a wide span of time, from 3 years in severe environments to more than 20 years for mild environments. Contamination of the contacts is reduced by dust covers so that it is not normally a significant problem within at least 3 or 4 years, but isolated occurrences of construction or area cleaning could reduce this time. Manufacturing defects, cracked covers, and personnel errors that result in the covers not being replaced, cause randomly timed problems from high resistance contacts.

The main failure mechanisms are therefore of the wear out kind which do not require Thermography to be performed at an interval shorter than 2 years.

Task Interval Support:

The task interval is stated to be **as required**. A good starting value for the interval would be 2 years for critical relays, but the periodicity should subsequently be determined by the thermography results themselves.

Ideally, relays that are not continuously energized would be scanned at the same time as Functional Testing, Calibration, or other surveillance testing. However, the thermography task is conducted by opening the panel door, and making the scan of all relays visible at the same time. Some of these may not be energized at that time, and for these the task has little value in identifying coil problems, although it would be effective for normally closed dirty or misaligned contacts.

Scheduled Replacement

Task Objective:

This task is intended to avoid problems caused by aging. The task interval is not closely determined by the failure mode data.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Scheduled Replacement is intended to avoid aging problems which affect the coil and mechanical assembly.

Progression of Failure Mechanisms Over Time:

The aging mechanisms occur on 5 year to 15 year or longer time scales.

Task Interval Support:

Scheduled replacement is a useful task even at intervals as short as 5 years, although the task is not usually cost-effective at that time. A 10 year replacement interval is probably the shortest feasible, and would be applied to continuously energized relays, or to those which are in other severe service conditions, or which are cycled frequently. For non-continuously energized relays in mild service conditions the replacement interval could be longer, and would be determined by plant experience.

Functional Testing

Task Objective:

This task is focused on verifying operability of the relay. The failure mode data do not restrict the interval, which is normally taken to be the major outage interval.

Task Content:

Functional Testing should include the following:
· Verify proper contact operation.

Principle Failure Locations and Causes:

This task is focused on verifying operability of the relay for critical relays which are not subject to other surveillance tests. The operability check serves as a failure finding task to ensure that the relay function(s) has not failed from high contact resistance, thermal aging of the coil, or from binding in the mechanism.

Progression of Failure Mechanisms Over Time:

High resistance contacts, binding in the mechanism and thermal aging of the coil can occur over a wide range of in-service times (from a few years to the life of the plant) depending on service conditions. Contaminated, oxidized, pitted, or otherwise worn contacts (from inappropriate burnishing during maintenance) are the most likely problem areas with contacts, occurring randomly on a scale of several years.

Normal wear on the contacts is not expected to be significant for at least 10 years. However, oxidation and corrosion can degrade the contacts over a wide span of time, from 3 years in severe environments to more than 20 years for mild environments. Contamination of the contacts is reduced by dust covers so that it is not normally a significant problem within at least 3 or 4 years, but isolated occurrences of construction or area cleaning could reduce this time. Manufacturing defects, cracked covers, and personnel errors that result in the covers not being replaced can cause randomly timed problems from high resistance contacts.

Task Interval Support:

Most of these relays are only accessible for operational testing at an outage. Consequently, an interval of 2 years is recommended. This interval should be interpreted to be 18 months or 2 years depending on the outage cycle.

Pump – Vertical – Deep Draft – Radial Flow – Product Lube

Table A-21 Pump – Vertical – Deep Draft – Radial Flow – Product Lube

Template Data Report: Pump-Vertical-Deep Draft-Radial Flow-Product Lube	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Performance Trending	2Y	2Y	2Y	2Y	NR	NR	NR	NR
Packing or Seal Replacement	AR	AR	AR	AR	AR	AR	AR	AR
System Engineer Walkdown	3M	3M	3M	3M	3M	3M	3M	3M
Refurbishment	AR	AR	AR	AR	AR	AR	AR	AR
Operator Rounds	1S	1S	1S	1S	1D	1D	1D	1D
Borescopic Inspection	AR	AR	AR	AR	AR	AR	AR	AR

Component PM Assessment

For Pump – Vertical – Deep Draft – Radial Flow – Product Lube the EPRI PMBD recommends six tasks to maintain the inherent reliability of the component, as shown in Table A-21. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-22 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-22 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The execution of just one of the five tasks Performance Trending will result in a 90% greater reliability than doing no preventive maintenance at all.

Table A-22 Pump – Vertical – Deep Draft – Radial Flow – Product Lube PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Performance Trending	8.0	√*	√*
Packing or Seal Replacement	16.0		
System Engineer Walkdown	4.0		
Refurbishment	576.0		
Operator Rounds	0.1		
Borescopic Inspection	16.0		

- *- Performing one task; Performance Trending will provide a 90% reliability benefit.

Performance Trending

Task Objective:

This task checks whether the overall pump performance is within specifications. The failure rate is influenced by the underlying failure times, but a modest degree of interval extension may be possible in mild conditions.

Task Content:

Performance Trending should include a record of the following:
- Abnormal conditions
- Suction pressure or sump level
- Process fluid temperature
- Motor current
- RPM
- DP versus flow up to full flow

The intent should be to perform a comprehensive pump test at some point on the pump curve; this is the only way to gain assurance that the pump is performing to its design capability. Pump tests performed using minimum flow recirculation are not effective performance tests.

Principle Failure Locations and Causes:

Performance Trending addresses a wide range of degraded conditions, especially corrosion/erosion damage to the pump bowls and impellers, wear on mechanical or packing type seals, and a worn shaft or sleeve bearings.

Progression of Failure Mechanisms Over Time:

These are all medium to longer term wear out mechanisms.

Task Interval Support:

The recommended task interval of 2 years is suitable for even the most severe service conditions in critical applications. The failure rate is influenced by the underlying failure times, but a modest degree of interval extension may be possible in mild conditions.

Packing or Seal Replacement

Task Objective:

This is an on-condition task focused on replacement of the packing and mechanical seals.

Task Content:

Packing / Seal Replacement is done in place and should include the following:
· Inspect the shaft and shaft sleeve for defects or damage
· Look for loose, missing, or damaged bolts, studs, nuts, and parts
· Verify shaft run out
· Clean and inspect stuffing box for wear, damage, and presence of corrosion

For seals:
· Suggestion: Perform diagnostics on old seal, such as determine amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and the extent of the setscrew indentations into the shaft sleeve
· Check seal injection piping condition and verify flow
· Replace with new correct seal
For packing:
· Inspect and note condition of removed packing and packing sleeve
· Replace sleeve if worn
· Verify configuration of packing and lantern rings
· Replace with new packing using correct configuration, material, and number of rings
· Tighten to plant procedure
· Verify correct seal leak rate

Principle Failure Locations and Causes:

This task is obviously focused on the replacement of mechanical seals and packing and is an on-condition task.

Progression of Failure Mechanisms Over Time:

The seals and packing wear out in 6 to 10 years, at the earliest, under normal circumstances.

Task Interval Support:

This task would only be performed on indication of excessive seal leakage by other PM activities. It would not normally be a regularly scheduled task.

System Engineer Walkdown

Task Objective:

This task addresses a wide range and a large number of failure mechanisms, especially leaks. The failure rate is not strongly affected by the task interval.

Task Content:

System Engineer Walkdown should include the following:
. Review previous motor vibration and motor current for trends
. Verify cathodic protection levels, if present
· Inspect for the general cleanliness and condition of all components
· Inspection for loose, missing, or damaged bolts and parts
· Inspection for abnormal noises and vibration, piping and flange leaks, damaged or missing insulation, abnormal pipe movement and damaged or misadjusted pipe hangers, and the general condition of expansion bellows
· Inspect pump mounting plate for damage, missing or loose bolts / nuts, and damaged grout
· Verify the presence of electrical ground straps
· Verify the presence and condition of the coupling guard
· If present, note Lubrication Flush System flow and pressure, and flush the filter if its DP warrants
· Verify the equipment is tagged and properly identified
For packing:
· Verify proper leak-off rate
· Verify that the gland bolts are not loose or damaged

For seals:
· Note and report any seal leakage
· Verify that the gland bolts are not loose or damaged
· Proper seal injection flow

Principle Failure Locations and Causes:

The System Engineer Walkdown addresses a wide range of degraded conditions but most of these are also addressed by Operator Rounds. This task contributes most to identifying incipient leaks from failing gaskets and o-rings, excessive wear and leakage in pump seals or packing, corrosion of the discharge head and motor mount, and failure of the pump base and mounting.

Progression of Failure Mechanisms Over Time:

These degraded conditions are all medium to long term wearout mechanisms.

Task Interval Support:

The recommended interval is 3 months for all plant conditions, but the interval is not determined by the underlying failure times and has only a weak effect on the failure rate.

Refurbishment

Task Objective:

This is an on-condition task whose objective is to restore the pump to as near to as-new condition as possible.

Task Content:

Refurbishment should include the following:
· Prior to removal and disassembly, check and record uncoupled pump lift and motor thrust, compare to historical
· Document as-found / as-left dimensions on machine fits, clearances, and motor and pumps lifts
· Inspect and document conditions including the presence of corrosion or erosion, of welds, column piping, protective coatings, the suction strainer, and hardware such as bolts, fasteners, and gaskets
· In general replace all components beyond OEM tolerances and specifications; document wear and condition
· Inspect for damage, wear, and deterioration of all gaskets, O-rings, and elastomers
· Replace all gaskets, O-rings, and elastomers
· Replace sleeve bearings; inspect and document wear and condition
· Inspect pump bowl assemblies for thinning, damage, and corrosion / erosion
· Inspect shaft for damage, defects, and run out
· Inspect and clean the pump barrel, if present
· Inspect impellers and wear rings for wear, damage, and galling; balance if required
· Inspect bearing retainers and spiders
· Inspect stuffing box / gland for damage, corrosion, and wear
· Replace / rebuild seals, if present (see below)
· Replace all packing; if present (see below)
· Clean and check for fit and flatness of all mating surfaces and joints
· Verify fit and tolerances of the motor mount
. Inspect discharge head and motor mount for corrosion, cracked welds, and deformation
· Inspect for the general cleanliness and condition of all components
· Inspection for loose, missing, or damaged bolts and parts

· Inspection for abnormal noises and vibration, piping and flange leaks, damaged or missing insulation, abnormal pipe movement and damaged or misadjusted pipe hangers, and the general condition of expansion bellows
· Inspect pump mounting plate for damage, missing or loose bolts / nuts, and damaged grout
· Verify the presence of electrical ground straps
· Verify the presence and condition of the coupling guard
· If present, note Lubrication Flush System flow and pressure, and flush the filter if its DP warrants
· Verify the equipment is tagged and properly identified
· Refer to PM actions for the appropriate Coupling component type.
· After reinstallation and prior to coupling, check and record uncoupled pump lift and motor thrust, compare to historical data
· Verify proper motor rotation before coupling
· Perform PMT of coupled motor and pump

For seals:
. Note and report any seal leakage
· Perform diagnostics on old seal, such as determine amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and the extent of the setscrew indentations into the shaft sleeve
· Check seal injection piping condition and verify flow
. Inspect the shaft and shaft sleeve for defects or damage
· Verify shaft run out
· Look for loose, missing, or damaged bolts, studs, nuts, and parts
· Replace with new correct seal
· Verify that the gland bolts are not loose or damaged
· Proper seal injection flow

For packing:
· Inspect and note condition of removed packing and packing sleeve
· Verify configuration of packing and lantern rings
· Clean and inspect stuffing box for wear, damage, and presence of corrosion
· Replace with new packing using correct configuration, material, and number of rings
· Verify that the gland bolts are not loose or damaged
· Torque to proper value
· Check for leaks
· Verify proper leak-off rate

Principle Failure Locations and Causes:

Refurbishment addresses most parts of the pump and most of the degraded conditions that could be encountered.

Progression of Failure Mechanisms Over Time:

The most influential items are the longer term wearout mechanisms such as the effects of corrosion of bearing retainers and spiders, line shaft coupling, and column piping, erosion/corrosion of the suction strainer and pump bowls, worn sleeve bearings, and a cracked shaft.

Task Interval Support:

This is an on-condition task that is only performed as necessary when indicated by other PM tasks.

Operator Rounds

Task Objective:

Operator Rounds is focused on the condition of mechanical seals, packing, and gaskets. The interval for this task does not have a strong effect on the failure rate providing it is done quite frequently.

Task Content:

Operator Rounds could include a check for
· General cleanliness and condition of all components
· Loose, missing, or damaged bolts and parts
· Abnormal noises and vibration
· Leaks
· If present, note Lubrication Flush System flow and pressure
· Verify proper seal injection flow

Principle Failure Locations and Causes:

Operator Rounds is focused on the condition of mechanical seals, packing, and gaskets, and provides a frequent opportunity to detect other kinds of leaks, e.g. from pipes and fittings..

Progression of Failure Mechanisms Over Time:

Most of these leaks develop from wearout mechanisms over 5 to 10 years but also from a large number of random mechanisms that can cause failure at any time

Task Interval Support:

This task is ideally suited to address leaks caused by a large number of random influences that nevertheless cumulatively do not have a big impact on the failure rate.

Borescopic Inspection

Task Objective:

This is an on-condition task whose objective is to look for corrosion/erosion problems with the discharge bowl, its liner, and the suction bell and impeller without removing the pump from its well.

Task Content:

Borescopic Inspection should include the following:
· Look for erosion of the impellers and pump bowls
. Inspect suction strainer
. Look for the presence of debris, clams, mussels,

Principle Failure Locations and Causes:

Borescopic Inspection can find corrosion/erosion of the discharge bowl, its liner, the suction bell, and the impeller.

Progression of Failure Mechanisms Over Time:

These are 5 to 10 year wear out mechanisms.
Task Interval Support:

The task will not normally have a regular schedule. It will be performed only on-condition that there are other indications that problems might exist.

Pump – Vertical

Table A-23 Pump – Vertical

Template Data Report: Pump - Vertical	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Performance Trending	6M	6M	6M	6M	18M	18M	18M	18M
Packing/ Seal Replacement	AR	AR	AR	AR	AR	AR	AR	AR
System Engineer Walkdown	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Refurbishment	AR	AR	AR	AR	AR	AR	AR	AR
Pump Oil Analysis	AR	AR	AR	AR	AR	AR	AR	AR
Refer to specific motor type	AR	AR	AR	AR	AR	AR	AR	AR
Operator Rounds	1S	1S	1S	1S	1D	1D	1D	1D

Component PM Assessment

For Pump – Vertical the EPRI PMBD recommends seven tasks to maintain the inherent reliability of the component, as shown in Table A-23. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-24 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-24 shows the reliability benefit of the individual tasks assuming the Station is not currently performing any maintenance on the selected component. The execution of just one of the five tasks, Performance Trending, will result in a 50% greater reliability than doing no preventive maintenance at all. Performing two tasks, Performance Trending and Operator Rounds Or Performance Trending And System Engineer Walkdown, will result in a 90% reliability benefit.

Table A-24 Pump – Vertical PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Performance Trending	1.0	√*	√**
Packing or Seal Replacement	8.0		
System Engineer Walkdown	1.0		√**
Refurbishment	114.0		
Pump Oil Analysis	1.0		
Refer to Specific Motor Type	0		
Operator Rounds	0.25		√**

- *- Performing one task; Performance Trending will provide a 50% reliability benefit.
- **- Performing two tasks; Performance Trending And Operator Rounds Or Performance Trending And System Engineer Walkdown will result in a 90% reliability benefit.

Performance Trending

Task Objective:

Performance Trending addresses causes of failure of the impeller, pump bowls, and wear rings, leaks in column piping and some gaskets, and clogging of the suction strainer. The interval is not well determined from the failure mode data, but since a large number of common random modes are addressed, there may not be much opportunity to extend it.

Task Content:

Performance Trending should include the following:
Record
- Abnormal conditions
- Pump bearing temperatures, if available
- Suction pressure or sump level
- Process fluid temperature
- Motor current
- RPM
- Flow

Trend
- DP versus flow up to full

Principle Failure Locations and Causes:

Performance Trending is performed at full flow using installed plant instrumentation where available, and addresses causes of failure of the impeller, pump bowls, and wear rings, leaks in column piping and some gaskets, and clogging of the suction strainer. Where full flow measurements can not be achieved, the value of the task is significantly reduced.

The intent should be to perform a comprehensive pump test at some point on the pump curve; this is the only way to gain assurance that the pump is performing to its design capability. Pump tests performed using minimum flow recirculation are not effective performance tests.

Progression of Failure Mechanisms Over Time:

This task is focused on impellers that have a reduced outside diameter or other cavitation damage, and pump bowls damaged by cavitation or recirculation. These mechanisms can lead to unacceptable conditions randomly within months to a few years. Generally eroded or corroded pump bowls (i.e. not caused by cavitation) have a longer time scale but are unable to be assessed by other means. Leaking gaskets are not particularly common but occur randomly and have little backup from other tasks. The other mechanisms are less important because of their extended time scale of occurrence, or because they can also be detected by other tasks.

Task Interval Support:

The expert panel recommended that the interval for Performance Trending should be 6 months for critical pumps and 18 months for non-critical pumps. More precise hydraulic assessment requires auxiliary instrumentation and would be performed much less frequently. There is an opportunity to explore interval extension, especially on critical pumps, to improve the cost-effectiveness of this task.

On the other hand, the EPRI Maintenance and Diagnostic Center has recommended that V3.0 should include a 6 month interval for non-critical, but severe service condition pumps, rather than 18 months. The choice will depend on the size and value of the pump.

Packing/Seal Replacement

Task Objective:

This task is focused on replacement of the packing and mechanical seal.

Task Content:

Packing / Seal Replacement should include the following:
· Inspect the shaft and shaft sleeve for defects or damage
· Look for loose, missing, or damaged bolts, studs, nuts, and parts
· Verify shaft run out
· Clean and inspect stuffing box for wear, damage, and presence of corrosion
For seals:
· Perform diagnostics on old seal, such as determine amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and the extent of the setscrew indentations into the shaft sleeve
· Check seal injection piping condition and verify flow
· Replace with new correct seal
For packing:
· Inspect and note condition of removed packing and packing sleeve
· Verify configuration of packing and lantern rings
· Replace with new packing using correct configuration, material, and number of rings
· Tighten to plant procedure.

Principle Failure Locations and Causes:

As the name implies this task is focused entirely on replacement of the packing and mechanical seal.

Progression of Failure Mechanisms Over Time:

These items fail by a wide range of mechanisms, some of which are varieties of personnel error, and most of which have essentially random failure times. The result is that the failures are random, and seal failures amount to a dominant failure cause for pumps. The influence of packing wear is a major determinant of shaft wear which is also a dominant pump degradation.

Task Interval Support:

For both seal and packing degradation other tasks also provide protection, and the failure incidence is not sufficiently consistent to require a regularly scheduled task. Failure history therefore is the main determinant of whether this task should be regularly performed. System Engineer Walkdown can detect increasing leakage, and vibration monitoring may give indication of a deteriorating seal. The Template shows the tasks should be done as required. Inspection and diagnostic examination of the old seal may enable interval extension if a regular replacement is desired. Such examination may also indicate the expected life for another pump in a similar situation.

System Engineer Walkdown

Task Objective:

System Engineer Walkdown is primarily a method to discover a leaking seal, packing, or gasket, and insufficient lubrication, as well as a wide range of other conditions. The interval is not well determined by the failure mode data, even though a large number of common random failure modes are potentially addressed.

Task Content:

System Engineer Walkdown should include the following:
· Inspect for the general cleanliness and condition of all components
· Inspection for loose, missing, or damaged bolts and parts
· Inspection for abnormal noises and vibration, oil leaks, piping and flange leaks, damaged or missing insulation, abnormal pipe movement and damaged or misadjusted pipe hangers, and the general condition of expansion bellows
· Inspect pump mounting plate for damage, missing or loose bolts / nuts, and damaged grout
· Verify the presence of electrical ground straps
· Verify the presence and condition of the coupling guard
· If present, note Lubrication Flush System flow and pressure, and flush the filter if its DP warrants
· Verify the proper operation and oil level of the oiler, if present
· Monitor pump bearing temperature, if accessible
· Verify the equipment is tagged and properly identified
For packing:
· Verify proper leak-off rate
· Verify that the gland bolts are not loose or damaged
For seals:
· Note and report any seal leakage
· Verify that the gland bolts are not loose or damaged
· Proper seal injection.

Principle Failure Locations and Causes:

System Engineer Walkdown is primarily an external visual inspection to discover a leaking seal, packing, or gasket; insufficient lubrication (low oil level in oiler); and a range of other conditions such as a clogged or failed flush system filter (inferred from flow, pressure, or pressure drop); a loose or failed pump base, a cracked discharge head, or corroded motor mount, or audible noise from worn bearing retainers or spiders, or a clogged pump suction strainer.

Progression of Failure Mechanisms Over Time:

Seal and packing leaks are essentially random occurrences, as are lubrication problems. These degradation mechanisms taken together tend to occur on a scale of one to a very few years, and the other mechanisms have similar timescales. The detection of seal and packing leaks relies heavily on this task.

Task Interval Support:

The interval should be determined by plant history and experience although 1 year is a typical value for critical pumps. Operator rounds will provide leak detection and recognition of unusual noises on a continuing basis.

Refurbishment

Task Objective:

This is an on-condition task.

Task Content:

Refurbishment should include the following:
- Prior to removal and disassembly, check and record uncoupled pump lift and motor thrust, compare to historical
- Document as-found / as-left dimensions on machine fits, clearances, and motor and pumps lifts
- Inspect and document conditions including the presence of corrosion or erosion, of welds, column piping, protective coatings, the suction strainer, and hardware such as bolts, fasteners, and gaskets
- In general replace all components beyond OEM tolerances and specifications; document wear and condition
- Inspect for damage, wear, and deterioration of all gaskets, O-rings, and elastomers
- Replace all gaskets, O-rings, and elastomers
- Replace anti-friction bearings; inspect and document wear and condition
- Inspect bowl assemblies for thinning, cracking, and corrosion / erosion
- Inspect shaft for damage, defects, and run out
- Inspect and clean the pump barrel
- Inspect impellers and wear rings for wear, and damage; balance if required
- Inspect bearing retainers and spiders
- Inspect stuffing box / gland for damage, corrosion, and wear
- Replace / rebuild seals, if present
- Replace all packing, if present
- Clean and check for fit and flatness of all mating surfaces and joints
- Verify fit and tolerances of the motor mount
- Inspect motor and pump coupling and coupling bolts, replace coupling lock washers, verify proper fit of key and key length
- After reinstallation and prior to coupling, check and record uncoupled pump lift and motor thrust, compare to historical data
- Verify proper motor rotation before coupling
- Perform PMT of coupled motor and pump
- Inspect for the general cleanliness and condition of all components
- Inspection for loose, missing, or damaged bolts and parts
- Inspection for abnormal noises and vibration, oil leaks, piping and flange leaks, damaged or missing insulation, abnormal pipe movement and damaged or misadjusted pipe hangers, and the general condition of expansion bellows
- Inspect pump mounting plate for damage, missing or loose bolts / nuts, and damaged grout

· Verify the presence of electrical ground straps
· Verify the presence and condition of the coupling guard
· If present, note Lubrication Flush System flow and pressure, and flush the filter if its DP warrants
· Verify the proper operation and oil level of the oiler, if present
· Monitor pump bearing temperature, if accessible
· Verify the equipment is tagged and properly identified
For packing:
· Verify proper leak-off rate
· Verify that the gland bolts are not loose or damaged
For seals:
· Note and report any seal leakage
· Verify that the gland bolts are not loose or damaged
· Proper seal injection flow
Inspect the shaft and shaft sleeve for defects or damage
· Look for loose, missing, or damaged bolts, studs, nuts, and parts
· Verify shaft run out
· Clean and inspect stuffing box for wear, damage, and presence of corrosion
For seals:
· Perform diagnostics on old seal, such as determine amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and the extent of the setscrew indentations into the shaft sleeve
· Check seal injection piping condition and verify flow
· Replace with new correct seal
For packing:
· Inspect and note condition of removed packing and packing sleeve
· Verify configuration of packing and lantern rings
· Replace with new packing using correct configuration, material, and number of rings
· Torque to proper value
· Check for leaks
· Verify proper operation
· Check DP across the filter and clean / replace if necessary
· Note condition of all components, especially the filter text.

Principle Failure Locations and Causes:

Refurbishment is basically a corrective action that is not driven on a regular schedule. Because of the degree of disassembly many areas can be inspected as the task content listing shows. However, some of the conditions discoverable during refurbishment have no other means of detection, so the task serves to discover these conditions. These include impeller vane thinning, deformation of the discharge head/motor mount, corroded line shaft couplings, damaged adjustment nut or plate on the pump/motor coupling, loose bolting on column piping, and erosion or corrosion of the pump suction strainer.

Some pumps allow diver access to perform an inspection (sometimes using a borescope) in which it may be possible to identify cavitation and other damaged of the impellers and pump bowls, a clogged, corroded, or damaged suction strainer, and corroded column piping. These items have been included here in Refurbishment

Progression of Failure Mechanisms Over Time:

Deformation of the discharge head, corrosion of line shaft couplings and the pump suction strainer may not occur before 5 to 10 years; however, the other mechanisms have more random occurrences.

Task Interval Support:

The intervals for refurbishment will be driven mainly by the need for corrective actions. There is an implied assumption that condition monitoring and inspection can provide enough advance warning so that failure can be avoided while delaying refurbishment to a convenient outage period.

Performing the refurbishment on a limited sampling basis may provide a reasonable basis for when to perform this task, especially since there can be a wide range of wear rates depending on whether the pump is continuously operating or in standby.

Pump Oil Analysis

Task Objective:

The objective of this task is to indicate the condition of the pump upper bearing, impeller, and shaft. This task is not performed for most pumps, but for those which have a sufficient oil reservoir the interval is not determined closely by the failure mode data, although there are many common random events to protect against.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Pump oil analysis can play an important role in the pump PM program for certain critical pumps where there is a sufficient oil reservoir, by addressing the impeller wear modes and a large number of other failure modes affecting the shaft. Not many pumps fall in this group.

Progression of Failure Mechanisms Over Time:

The impeller failure mechanisms are random and occur commonly. The shaft failure modes contain several wearout cases over about 5 years, as well as a large number of random failure modes.

Task Interval Support:

Most pumps will not have this task performed at all. Critical pumps which have a sufficient oil reservoir and are high duty cycle could have this performed at 3 month intervals, whereas critical low duty cycle pumps would have an interval of 6 months.

Vertical Pump Electric Motor Preventive Maintenance

Task Objective:

The objective of this task is to use motor PM's to address the condition of the pump impeller, bearings, wear rings, and other rotating parts, as well as flow noise such as cavitation. The interval is not definitively established by the failure mode data but there are so many common random failure modes and some short term wearout effects which can be protected, that fairly frequent PM's are required.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Motor PM tasks can provide important information about the condition of the pump. Motor Current Trending and Vibration Analysis are the main motor tasks with direct implications for pump condition. In addition, motor oil analysis may provide some indication about a significant level of degradation of the pump impeller and shaft.

Motor current trending plays an important role in the pump PM program by addressing many degradations of the impeller, bearings, bearing retainers and wear rings, and the lubrication flush system.

Vibration Analysis has a wide scope of application to pumps, addressing sources of vibration in rotating parts as well as flow noise such as cavitation. These sources include: a cracked, misaligned, bent, or worn shaft; worn or failed line shaft couplings; cavitation, or recirculation that can damage the pump bowls or wear the impeller; rubbing or other component damage that can cause impeller wear; improper pump to motor coupling fit and balance; bearing wear; rough bearing journals; defects, corrosion, cracks or improper materials or installation of bearing retainers or spiders; worn or galled wear rings; failed, or clogged column piping; and a clogged pump suction strainer.

Progression of Failure Mechanisms Over Time:

Motor Current Trending:
The failure mechanisms addressed are predominantly random, there is a very large number of them, and many are commonly encountered.

Vibration Analysis:
Shaft problems are unlikely to occur on short time scales but they are a key degradation process for pumps, together with wear or failure of line shaft couplings. These failure processes are mainly addressed by Vibration Analysis, apart from the ability of motor oil analysis to give a general indication of shaft wear. Cavitation or recirculation that causes impeller and bowl degradation are also dominant failure causes and they can arise suddenly. Sources of bearing wear are also relatively common problems with timing aspects that suggest vibration monitoring should be relatively frequent. Several of the other failures mentioned above are not common but also drive the vibration monitoring to be frequent. These are impeller wear and rubbing caused by other component wear, improper fit and balance of the pump to motor coupling, rough sleeve bearing journals, and defects, cracks and corrosion in bearing retainers and spiders. The other processes above have less influence on the timing of this task because they are not commonly encountered and have sufficient backup from other tasks.

Task Interval Support:

The Motor Current Trending interval is determined by the Motor PM tasks.

The Vibration Analysis interval will also be determined by Motor PM Tasks. However, this measurement is only done if the pump is already running because it is not prudent to start an idle pump just to take vibration measurements. Standby pumps are usually monitored only in conjunction with performance testing for surveillance test purposes. It is very important that vibration monitoring on a particular pump should be performed with the pump at the same operating point each time. Vertical pumps with integral motors should have vibration in the horizontal plane monitored at the position of the upper and lower motor flanges. Vibration monitoring of the motor bearings in most cases provides the only meaningful vibration data. The lower bearings may not be accessible for any monitoring.

Operator Rounds

Task Objective:

Operator Rounds is focused on listening for unusual noises, finding leaks, and monitoring bearing temperatures.

Task Content:

Operator Rounds could include a check for
· General cleanliness and condition of all components
· Loose, missing, or damaged bolts and parts
· Abnormal noises and vibration
· Oil and water leaks
· If present, note Lubrication Flush System flow and pressure
· Verify the oil level of the oiler, if present
· Monitor pump bearing temperature, if accessible
· Verify proper seal injection flow.

Principle Failure Locations and Causes:

Operator Rounds is primarily a method to discover leaks, low oil level, and a range of other conditions such as a clogged or failed flush system filter (inferred from flow, pressure, or pressure drop), audible noise from worn bearing retainers or spiders, or cavitation, and to monitor the temperature of bearings.

Progression of Failure Mechanisms Over Time:

This task is useful because of the extremely large number of common and random failure mechanisms which it has a moderate to good chance of detecting.

Task Interval Support:

Operator Rounds should be performed at least daily to ensure good coverage of the random failure modes.

Pump – Positive Displacement

Table A-25 Pump – Positive Displacement

Template Data Report: Pump - Positive Displacement	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Oil Analysis	6M	6M	NA	NA	NA	NA	NA	NA
Performance Monitoring	3M	3M	NA	NA	NA	NA	NA	NA
Coupling Inspection	2Y	2Y	NA	NA	NA	NA	NA	NA
Oil Filter Replacement	6M	6M	NA	NA	NA	NA	NA	NA
Internal Visual Inspection	2Y	2Y	NA	NA	NA	NA	NA	NA
Fluid Cylinder Inspection	AR	AR	NA	NA	NA	NA	NA	NA
Power End (Frame) Inspection	6Y	6Y	NA	NA	NA	NA	NA	NA
Operator Rounds	1S	1S	1S	1S	1D	1D	1D	1D
Thermography	6M	6M	NA	NA	NA	NA	NA	NA
Vibration Analysis	6M	6M	NA	NA	NA	NA	NA	NA

Component PM Assessment

For Pump – Positive Displacement the EPRI PMBD recommends ten tasks to maintain the inherent reliability of the component, as shown in Table A-25. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-26 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-26 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The execution of just one task, Operator Rounds, will result in a 50% greater reliability than doing no preventive maintenance at all. Performing three tasks, Performance Monitoring And Operator Rounds And Oil Analysis; Or Performance Monitoring And Operator Rounds And Power End (Frame) Inspection, will result in a 90% reliability benefit.

Table A-26 Pump – Positive Displacement PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Oil Analysis	1.0		√**
Performance Monitoring	4.0		√**
Coupling Inspection	8.0		
Oil Filter Replacement	2.0		
Internal Visual Inspection	8.0		
Fluid Cylinder Inspection	36.0		
Power End (Frame) Inspection	36.0		√**
Operator Rounds	0.25	√*	√**
Thermography	1.0		
Vibration Analysis	1.0		

- *- Performing one task; Operator Rounds will provide a 50% reliability benefit.
- **- Performing three tasks; Performance Monitoring And Operator Rounds And Oil Analysis; Or Performance Monitoring And Operator Rounds And Power End (Frame) Inspection will result in a 90% reliability benefit.

Oil Analysis

Task Objective:

This task is focused on detecting wear particles or other contaminants in the oil, and on oil quality. The interval is not determined very closely by the failure mode data.

Task Content

Task Content is not included for this release.

Principle Failure Locations and Causes:

Oil analysis is focused on processes that result in wear particles or other contaminants entering the oil and on degradation of the lubricating properties of the oil. This primarily addresses wear and scoring of the cross-head to cross-head surfaces and asymmetric wear of the main gear and pinion teeth, as well as deterioration of bearing oil seals, and wear of the oil pump, drive chain and sprockets in a pressure lubricated system. Wear of the crosshead pin and bearing, main crankshaft bearings, connecting rod bearings, pinion shaft and bearing, and thrust bearing, can also be detected.

Progression of Failure Mechanisms Over Time:

Seal leakage and sources of bearing and gear wear, are relatively common problems. Normal seal wear is expected over a period of 6 months to 1 year in service. Bearing wear and gear wear have timing aspects more coupled to the occurrence of random failures of the oil delivery system or other random events such as misalignment or cavitation, than to intrinsic wear rates through normal aging. This suggests that oil sampling should be more frequent than these random events which appear to occur over a time scale of a few years. There are no failure locations and causes for which oil analysis is the only PM task available but it is the most frequently implemented task for the above failure causes.

Task Interval Support:

The expert group recommended oil analysis every six months for continuously running or alternated critical pumps. This assumes that analysis and evaluation are carried out in timely manner

Performance Trending

Task Objective:

Performance Monitoring mainly addresses cracking and wear of the inlet (suction) and outlet (discharge) valves, valve seats and springs, and cracking of the fluid cylinder. The interval is strongly determined by the presence of commonly occurring wearout and random failure modes.

Task Content:

Performance Monitoring should include:

- Measure and trend pump speed, suction and discharge pressures, and flow. Compare to previous values. Look jagged response of valves during the pressure discharge test.
- Note abnormal noises.
- Inspect for oil and water leaks.
- If visible, verify that the oil level is correct and that the oil is not discolored or "milky".
- Verify that the oil temperatures and pressures are within specifications.
- Verify that the packing coolant temperature is within specification and that the level of the supply tank is correct.

Principle Failure Locations and Causes:

Performance Monitoring mainly addresses cracking and wear of the inlet (suction) and outlet (discharge) valves, valve seats and springs, and cracking of the fluid cylinder. Worn valve guides may also be detected but these are only likely to be common occurrences in specific applications.

Progression of Failure Mechanisms Over Time:

All of the important mechanisms, except for worn valve guides, addressed by performance monitoring are significant because they have predominantly random or short term occurrence times on a scale of a few months to a few years, and they are relatively common events. Although all of them have the possibility of being detected by additional tasks, these characteristics suggest frequent performance trending would be beneficial.

Task Interval Support:

The recommended interval for Performance Monitoring is 3 months. Even more frequent performance monitoring (i.e. weekly) would be needed to have a good chance of completely avoiding valve degradation. Because of the possibility of rapid valve degradation, this task may not avoid the necessity for taking a mid-cycle outage to repair the valves, when dependent upon a single pump, regardless of the interval at which it is performed. After refurbishment a typical value of efficiency is 95%, whereas valve replacement is indicated when the efficiency has fallen to around 87% (at least for Union model QX-300 Quintuplex).

Coupling Inspection

Task Objective:

This task is focused entirely on inspection of the coupling. The task interval is not strongly determined by the failure mode data.

Task Content:

Coupling Inspection should contain the following:
· Inspect for signs of leaking lubricant.
· Inspect mating surfaces for cleanliness, wear, and integrity; record as-found and as-left conditions.
· Verify condition of lubricant looking for dirt, amount of lubricant, and indications of coupling wear; recharge with the proper lubricant and quantity.
· Inspect gear teeth or shim packs for wear and damage.
· Inspect non-metallic parts for condition and wear.
· Inspect bolting for damage.
· Ensure proper orientation during reassembly.
· Perform an as-found / as-left alignment check.

Principle Failure Locations and Causes:

As the name implies this task is focused entirely on inspection for lubrication leaks and wear of the flexible grid type and geared type of pump/motor couplings, and on distortion or cracking of the shims on the shim pack types.

Progression of Failure Mechanisms Over Time:
Insufficient or improper lubrication and installation errors are more important to the timing of this task than normal wear. These sources of degradation can cause rapid deterioration at random times, usually with occurrence times on a scale of a few years.

Task Interval Support:

Continuously operating critical pumps are recommended to have a coupling inspection at 2 years regardless of whether they run continuously or are alternated. Vibration monitoring will not give useful information on alignment or coupling wear because of the high intrinsic vibration levels with these pumps. Thermography would provide indication of a coupling running hot, but was not thought to be sufficiently applicable and cost-effective for inclusion in the PM program as a regularly scheduled task...

Oil Filter Replacement

Task Objective:

This task is focused on clogging of the oil filter and contamination of the lubricant. The interval is not strongly determined by the failure mode data.

Task Content:

Oil Filter Replacement should include the following:
· Check for leaks.
· Verify proper operation.
· Check DP across the filter and trend to provide a basis for interval extension.
· Note condition of all components especially the filter and oil piping.

Principle Failure Locations and Causes:

This task focuses entirely on the condition of the lubrication system. Items to observe are a clogged oil filter and contamination of the lubricant.

Progression of Failure Mechanisms Over Time:

The key task is changing the oil filter. Clogged filters are expected after a period of 2 to 5 years of continuous operation, and trends in oil pressure may give indication of progressive clogging. Although contamination of the oil can occur at any time, oil sampling will give advanced warning at a 6 month interval.

Task Interval Support:

Filter replacement is recommended as a scheduled task at 6 months for continuously operating or alternated pumps..

Internal Visual Inspection

Task Objective:

The main objectives of this task are to assess the condition of the oil pump drive chain and sprockets, the thrust bearing, main gear and pinion, and gaskets that are visible. The interval is not clearly determined by the failure mode data.

Task Content:
Internal Visual Inspection should include:
· Before Shutting down the operating pump, verify that the oil temperatures and pressures are within specifications.
· Inspect for obvious loose, missing, or damaged fasteners.
· Note abnormal noises.
· Inspect for oil and water leaks.
· If visible, verify that the oil level is correct and that the oil is not discolored or "milky".
· Verify that the packing coolant temperature is within specification and that the level of the supply tank is correct.
· Perform a visual axial alignment inspection of the crank shaft.
· Check tension and evidence of wear on oil pump drive chain and sprockets.
· Inspect the integrity of oil lines, fittings, and mounting hardware.

· Inspect the bull gear and pinion teeth for damage and abnormal wear.
· Look for the presence of metallic fines in the oil reservoir.
· Inspect for signs of leaking lubricant.
· Inspect mating surfaces for cleanliness, wear, and integrity; record as-found and as-left conditions.
· Verify condition of lubricant looking for dirt, amount of lubricant, and indications of coupling wear; recharge with the proper lubricant and quantity.
· Inspect gear teeth or shim packs for wear and damage.
· Inspect non-metallic parts for condition and wear.
· Inspect bolting for damage.
· Ensure proper orientation during reassembly.
· Perform an as-found / as-left alignment check.

Principle Failure Locations and Causes:

Internal Visual Inspection is an internal inspection performed when the power end large inspection cover has been removed. The main objectives of this task are to assess the condition of the oil pump drive chain and sprockets, and the tightness of the oil pump mounting bracket in a pressure lubricated system, as well as to assess the condition of the thrust bearing, main gear and pinion, and gaskets that are visible.

Progression of Failure Mechanisms Over Time:

The most time-critical of these degradation mechanisms is the condition of the oil pump drive chain and sprockets in a pressure lubricated system, and the degree of asymmetric wear on the main gear.

Task Interval Support:

This task provides assurance that the Power End Inspection can be reached at 6 years without undue wear on the above components. The Expert Panel thought that a 2 year interval for the Internal Visual Inspection would provide this assurance in a cost-effective manner.

Fluid Cylinder Inspection

Task Objective:

The Fluid Cylinder Inspection provides an opportunity to inspect and repair cylinder head check valves, leaks from oil seals, leaks from packing, and cracked fluid cylinders, and to inspect the integrity of the packing cooling/lubricating system. The failure mode data clearly suggest that this task should be done on a time scale of one year or less.

Task Content:

Fluid Cylinder Inspection should include the following:
· Look for the general condition of all components, signs of leakage, and loose, missing, or damaged fasteners.
· Inspect for evidence of cylinder cracking.
· Inspect the condition of all valve assemblies looking for evidence of wear and damage.
· Inspect all gasket sealing surfaces; replace any damaged or leaking gaskets.
· Drain coolant tank and ensure coolant flows freely, that the tank is free of debris, and does not leak.
· Inspect packing cooling lines for leaks and damage.
· Depressurize the pulsation stabilizing equipment, if applicable, and check that the pre-charge pressure is correct.
· Inspect oil seals for evidence of leakage or damage; replace if necessary.
· Inspect the condition of the crosshead stubs for evidence of wear, misalignment, and scoring.

· Inspect for evidence of excessive packing leakage; if packing is replaced, inspect the stuffing box and plunger for evidence of abnormal wear and scoring.
· If packing is not being replaced, inspect all visible parts of the plunger assembly without removing it.

Principle Failure Locations and Causes:

The Fluid Cylinder Inspection provides an opportunity to inspect and repair cylinder head check valves, leaks from oil seals, leaks from packing, and cracked fluid cylinders, and to inspect the integrity of the packing cooling/lubricating system. This is an on-condition task which may be triggered by observation of leaks during operator rounds, by audible noise and results of performance monitoring with respect to worn or broken valves, and by leakage, performance monitoring, or loss of fluid inventory in the case of a cracked fluid cylinder.

Progression of Failure Mechanisms Over Time:

Oil seals appear to have an expected life of about 6 months to one year, and inlet and outlet valves frequently fail over a period of several months to two years from a number of random causes, even though the disks and seats may have a normal life of about two years. Fluid cylinder cracks have occurred at several plants after in-service times of a few years, occasionally as soon as 1 year. Packing ages on a timescale of one year or longer (or possibly even less than 1 year for original braided packing) and leakage can be expected on a similar timescale. Wear of the inner bore of the stuffing box may be expected after a few years. Many random processes also contribute to packing and plunger wear so that the timing of packing leaks and associated damage to the stuffing box and plunger are essentially random on a scale of a few years. The packing cooling system is similarly affected by random failures.

Task Interval Support:

The above degradation mechanisms and time scales suggest that the Fluid Cylinder Inspection is likely to be required after 1 year of operation. The deterioration rate of inlet and outlet valves is sufficiently rapid after onset, and the predictive capability of Performance Monitoring is sufficiently weak, that positive displacement pump outages in order to perform the Fluid Cylinder Inspection, may not be avoidable between refueling cycles unless a redundant pump is available. When a redundant pump is not available consideration should be given to scheduling the Fluid Cylinder Inspection as a time-directed task with an interval less than 6 years. Carrying out the Performance Monitoring task more frequently (perhaps weekly) does not avoid the problem.

If good performance of packing, valves, and oil seals enables the Fluid Cylinder Inspection to be done only every 3 to 6 years, the valves, oil seals, plunger, and oil pump (if external) should be replaced regardless of condition, especially if a redundant pump is not available..

Power End (Frame) Inspection

Task Objective:

This task focuses principally on the condition of the oil delivery system and the components that depend on it. The interval may offer some opportunity for increase in some circumstances, especially if oil analysis is effective and reliable.

Task Content:

The Power End (Frame) Inspection should include:
· Utilities may wish to consider performing the Fluid Cylinder Inspection at this time.
· Look for the general condition of all components, signs of leakage, loose, missing, or damaged fasteners, oil supply lines, fittings, and hardware.

· Perform all dimensional measurements and compare to OEM specifications.
· Inspect crosshead pin and bearings for proper finish and evidence of wear.
· Inspect the main crank shaft bearings and connecting rod bearings for evidence of wear.
· Measure pinion to main gear backlash and compare to OEM specifications.
· Inspect pinion gear and main gear for evidence of damage, cracking, scoring, pitting, or wear.
· Inspect pinion shaft and bearings for evidence of wear.
· If present, inspect the internal oil pump, drive chain and sprockets for evidence of wear; replace as necessary.
· Inspect the integrity of the oil pump mounting bracket and hardware.
· Measure the crank shaft thrust (end play) and compare to OEM specifications.
· Inspect the thrust bearing for evidence of wear.
· Inspect connecting rods for damage; oil holes should be free, open and of uniform diameter.
· Inspect gasket surfaces for damage; replace all gaskets that were removed, disturbed, leaking, or damaged.
· Perform a crank shaft inspection.
· If there is evidence of packing leaks or scoring of the plunger or stub; verify the concentricity of crosshead and stub.
· Inspect crosshead stub for evidence of damage.
· Inspect crossheads for evidence of wear and scoring.
· Inspect the crankcase breather and clean or replace as necessary.

Principle Failure Locations and Causes:

This task focuses principally on the condition of the oil delivery system: oil pump, drive chain, and sprockets in a pressure lubricated system, or the gear driven external oil pump. Other important components addressed are the crosshead, including the crosshead to stub fit, bearings, crankshaft, gears, gaskets, and the oil heat exchanger, if present..

Progression of Failure Mechanisms Over Time:

Failures or deterioration of the oil delivery system are one of the dominant degradation mechanisms for these pumps, and lead to rapid deterioration in the other components examined in this inspection. Although the oil pumps may be expected to perform well for periods of up to 10 to 12 years from the perspective of normal wear and aging, random failures caused by improper assembly or poor lubricant quality may shorten this time to 5 to 6 years. In a pressure lubricated system the drive chain and sprockets appear to wear significantly faster than the pump so that these two components might be replaced at each Power End Inspection with the pump replaced at every other inspection. The oil heat exchanger, when present, does not appear to be the source of many failures, but oil heat exchangers in general are subject to random causes of leaks and fouling on a time scale of 5 to 10 years. The crosshead, bearings, crankshaft, and gears generally have lifetimes from normal wear in the upper part of the above range (8 to 10 years), but suffer in addition from random effects of poor lubrication, misalignment, incorrect assembly, and system dynamic effects related to hydraulic shock.

Task Interval Support:

A task interval of 6 years adequately addresses the above failure mechanisms. Oil Sampling and the Internal Visual Inspection provide reasonable assurance of avoiding failures from random effects at earlier times.

Operator Rounds

Task Objective:

Operator Rounds is focused on the observation of leaks, unusual noises, and loose, missing, or damaged components. Daily observation is effective for the large number of random degradation mechanisms addressed by the task.

Task Content:

Look for leaks of water or oil, any obviously loose, missing, or damaged fasteners and hardware, and listen for unusual noises. Verify that the oil delivery system and packing cooling system are operating within normal limits.

Principle Failure Locations and Causes:

Operator Rounds provide a frequent opportunity to observe leaks of water or oil, to take account of unusual noises, and to observe any obviously loose, missing, or damaged fasteners and hardware. It also provides an opportunity to verify that the oil delivery system and packing cooling system are operating within normal limits.

Progression of Failure Mechanisms Over Time:

A large number of these degradation mechanisms are random, and occur commonly.

Task Interval Support:

The task is performed at least once per day.

Thermography

Task Objective:

This task is focused on the detection of hot spots. The intervals are not directly determined by the failure mode data but many random mechanisms are addressed

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Thermography will detect hot spots which cause cylinder damage and degradation of packing cooling.

Progression of Failure Mechanisms Over Time:

Most of the protected degradation mechanisms are random.

Task Interval Support:

The task should be moderately effective whenever a direct view can be obtained.

Vibration Analysis

Task Objective:

This task mainly addresses the condition of couplings. The intervals are not directly determined by the failure mode data but many random mechanisms are addressed.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Vibration Analysis can be effective for detecting distorted and cracked shims in couplings, grid type coupling wear, and gear type coupling degradation.

Progression of Failure Mechanisms Over Time:

Most of the protected degradation mechanisms are random.

Task Interval Support:

The task should be moderately effective because the frequencies differ from pump vibrations which would otherwise predominate.

Pump – Horizontal – Multistage – Barrel Type

Table A-27 Pump – Horizontal – Multistage – Barrel Type

Template Data Report: Pump - Horizontal - Multistage - Barrel Type	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Oil Analysis	3M	6M	3M	6M	2Y	2Y	2Y	2Y
Performance Trending	2Y	2Y	2Y	2Y	NR	NR	NR	NR
Oil Filter Change, Clean, and 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 or Seal Replacement	AR	AR	AR	AR	AR	AR	AR	AR
Vibration Analysis	1M	3M	1M	3M	3M	1Y	3M	1Y

Component PM Assessment

For Pump – Horizontal – Multistage – Barrel Type the EPRI PMBD recommends ten tasks to maintain the inherent reliability of the component, as shown in Table A-27. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-28 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-28 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The execution of one of the following two tasks, Oil Analysis Or System Engineer Walkdown, will result in a 50% greater reliability than doing no preventive maintenance at all. Performing three tasks, Vibration Analysis And Oil Analysis And System Engineer Walkdown Or Performance Trending And Oil Analysis And System Engineer Walkdown, will result in a 90% reliability benefit.

Table A-28 Pump – Horizontal – Multistage – Barrel Type PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Oil Analysis	2.0	√*	√**
Performance Trending	8.0		√**
Oil Filter Change, Clean and Inspect	2.0		
System Engineer Walkdown	4.0	√*	√**
Refurbishment	576.0		
Functional Testing	8.0		
Operator Rounds	0.1		
Acoustic Monitoring	2.0		
Packing or Seal Replacement	16.0		
Vibration Analysis	2.0		√**

- *- Performing one of two tasks; Oil Analysis Or System Engineer Walkdown will provide a 50% reliability benefit.

**- Performing three tasks; Vibration Analysis And Oil Analysis And System Engineer Walkdown Or Performance Trending And Oil Analysis And System Engineer Walkdown will result in a 90% reliability benefit.

Oil Analysis

Task Objective:

The task is focused on detecting degraded oil because of its bad effects on other components. Reliability is not very sensitive to the task interval.

Task Content:

Oil Analysis should include:
. Analyze the oil for wear particles, contaminants, water, and lubricity qualities
. Check for signs of oil leakage

Principle Failure Locations and Causes:

Oil Analysis can detect when the oil is getting into a degraded condition from normal use, wear of other components, in-leakage of water from leaks in lube oil cooling heat exchangers or internal bearing coolers, or worn labyrinth seals.

Progression of Failure Mechanisms Over Time:

These are all wearout mechanisms that typically can cause failures after 5 to 10 years of service, but they can also be caused by several random processes at much shorter times.

Task Interval Support:

Because of the impact of random processes it is worth doing this task quite frequently; every 3 months to 6 months for critical applications, although pumps with less functional importance could ignore the effects of random failures and perform the task every 2 years.

Performance Trending

Task Objective:

This task checks whether the overall pump performance is within specifications. The task interval is not directly driven by the underlying failure times and there is therefore considerable opportunity for task interval extension.

Task Content:

Performance Trending should include the following:
Record
· Any abnormal conditions
· Pump bearing temperatures
· Suction pressure
· Discharge pressure
· Process fluid temperature
· Motor current
· RPM
· Flow
· Balancing device leak-off line pressure or flow
· Oil level, pressure, and temperature
Trend
· DP versus flow
· Motor current
· Bearing temperatures
· Balancing device leak-off line pressure or flow
· Oil pressure and temperature

Principle Failure Locations and Causes:

Performance Trending addresses a wide range of degraded conditions, especially wear or erosion damage to diffusers and interstage sealing, wear or damage to mechanical or packing type seals, and fouling of lube oil cooling heat exchangers or internal bearing coolers.

Progression of Failure Mechanisms Over Time:

These are all medium to longer term wearout mechanisms with some contribution to the same conditions from random causes. However, the task is too onerous to perform frequently enough to be effective against random failures.

Task Interval Support:

The recommended task interval of 2 years is suitable for even the most severe service conditions in critical applications. There is not much sensitivity of the failure rate to the task interval until the interval is considerably longer than 2 years..

Oil Filter Change, Clean, and Inspect

Task Objective:

This task basically addresses the condition of the lubrication system. The failure rate depends only weakly on the interval for this task.

Task Content:

Oil Filter Change, Clean and Inspect should include the following:
· Check for leaks
· Verify proper operation
· Check DP across the filter and clean the filter, or replace if necessary
· Note condition of all components especially the filter

Principle Failure Locations and Causes:

This task is focused strongly on preventing blocked oil filters and strainers and on detecting oil leaks in flex hose, piping, housing, fittings, and valves.

Progression of Failure Mechanisms Over Time:

The oil filters and strainers can become blocked in a time scale of 2 to 5 years at the earliest, and oil leaks can be expected to take somewhat longer to appear.

Task Interval Support:

The recommended task intervals can be very dependent on plant conditions and the degree of wear in other components. In the absence of clear determining factors from plant experience it is reasonable to assume that there is only a weak dependence of the failure rate on the interval at which this task is performed.

System Engineer Walkdown

Task Objective:

This task addresses a wide range and a large number of failure mechanisms, especially leaks. The failure rate is not strongly affected by the task interval.

Task Content:

System Engineer Walkdown should include the following:
· Inspect for the general cleanliness and condition of all components
· Inspection for loose, missing, or damaged bolts and parts
· Inspection for abnormal noises and vibration, oil leaks, piping and flange leaks, damaged or missing insulation, abnormal pipe movement and damaged or misadjusted pipe hangers, and the general condition of expansion bellows, if present

· Inspect foundation for damage, missing or loose bolts/nuts, and damaged grout
· Verify the presence and condition of the coupling guard
· Verify the proper operation and oil level of the oiler, if present
· Verify the bearing temperatures are within normal operational limits and slinger rings are moving freely
· Ensure that breather caps and sight glass vents are clear
· Verify the equipment is tagged and properly identified
For packing:
· Verify proper leak-off rate
· Verify that the gland bolts are not loose or damaged
For seals:
· Note and report any seal leakage

Principle Failure Locations and Causes:

The System Engineer Walkdown addresses a wide range of degraded conditions but most of these are also addressed by Operator Rounds. This task consequently contributes most to identifying drift in the auxiliary oil pump pressure switch, excessive wear and leakage in all types of pump seals, a worn bearing oil slinger ring, and other leaks of oil and process medium.

Progression of Failure Mechanisms Over Time:

Most of these degraded conditions are wearout mechanisms with minimum times to failure of a few years. A large number of random failure mechanisms are also addressed and it is felt that the task is a useful adjunct to Operator Rounds in addressing them.

Task Interval Support:

The recommended interval is 3 months for all plant conditions. It has only a weak effect on the failure rate.

Refurbishment

Task Objective:

This is an on-condition task whose objective is to restore the pump to as near to as-new condition as possible.

Task Content:

Refurbishment should include the following:
· All items from the System Engineer Walkdown, and the Oil Filter Change, Clean, and Inspect, plus
· Prior to removal and disassembly, check and record pump thrust, compare to historical
· Perform radial clearance checks of bearings and impeller wear rings
· Document as-found / as-left dimensions on machine fits, clearances, and motor and pump lift
· Inspect and document condition of welds, piping, and hardware such as bolts and fasteners
· In general replace all components beyond OEM tolerances and specifications; document wear and condition
· Inspect for damage, wear, and deterioration of all gaskets, O-rings, and elastomers
· Replace all gaskets, O-rings, and elastomers
· Inspect casing, volute, diffuser, and barrel assemblies for thinning, cracking, and corrosion / erosion
· Inspect shaft for damage, defects, run out, and radial position
· Inspect impellers and wear rings for wear and damage; balance and size if required
· Inspect interior of pump, nozzle, and fits for wear, erosion, damage, and proper clearances

Bearings (general)
· Inspect and note the general condition of the journal and cleanliness of the bearing housing
· Inspect the condition of bearing RTD's and thermocouples
· Inspect the condition of any permanently mounted vibration probes or devices

Anti-Friction Bearings - Replace anti-friction bearings; inspect and document wear and condition
· Before starting disassembly, verify proper oil level
· Verify proper bearing preload where applicable
· Verify bearing part numbers, both as-found and as-left
· Perform as-found inspection of bearing condition, looking for indications of abnormal wear, damage, or fatigue. Also inspect new bearing for damage and freedom of movement prior to installation.
· Ensure proper bearing orientation and installation procedures are followed
· Inspect shaft and bearing housing condition and dimensions at the bearing interface, obtain proper dimensions from OEM technical manual
· Inspect oil passages for clogging, slinger, and flinger rings for damage
· Inspect oil seal and assure proper orientation
· Verify housing to casing dowel pins, and final radial alignment

Sleeve Bearings - Inspect sleeve and thrust bearings; replace as necessary, document as-found and as-left conditions:
· Inspect the condition of and verify against OEM specifications all fits and tolerances
· Inspect integrity of the bearing housing and clean
· Inspect the bearing journal for damage or wear
· Inspect the bearing housing cleanliness and integrity
· Record as-found / as-left dimensions on all machine fits
· Verify the proper orientation of old and new bearings, and the bearing to housing fit
· Inspect the condition and integrity of the bearing babbitt
· Inspect all oil passages, slinger and flinger rings
· Inspect oil seal(s) and verify for proper orientation
· Verify the presence of housing to casing dowel pins, their fit, and final radial alignment

Kingsbury Type Bearings
· Verify as-found and as-left orientation
· Record as-found and as-left end play, and that it is within specifications
· Inspect shoe surface condition and Babbitt integrity
· Inspect shoe button for damage and wear
· Verify anti-rotation pin integrity
· Verify thrust disk to shaft fit
· Verify proper thrust nut integrity, locking method, and torque
· Verify thrust disk flatness, perpendicularity, and run out
· Verify housing condition, cleanliness, and integrity
· Verify housing to casing dowel pins, fits, and final radial alignment

Replace / rebuild seals:
· Inspect the shaft and shaft sleeve for defects or damage
· Look for loose, missing, or damaged bolts, studs, nuts, and parts
· Verify shaft run out
· Clean and inspect stuffing box for wear, damage, and presence of corrosion
· Perform diagnostics on old seal, such as determine amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and the extent of the setscrew indentations into the shaft sleeve
· Check seal injection piping condition and verify flow
· Inspect seal flange to horizontal split case joint for proper engagement
· Replace with new seal
· Inspect stuffing box / gland for damage, corrosion, and wear

Replace packing, if present:
· Inspect and note condition of removed packing and packing sleeve
· Verify configuration of packing and lantern rings
· Replace with new packing using correct configuration, material, and number of rings
. Replace sleeve if damaged
· Torque to proper value
· Clean and check for fit and flatness of mating surfaces and joints

Other:
· Refer to PM actions for the appropriate Coupling component type.
· Check DP across the lube oil filter, clean the filter or replace if necessary. Note condition of the filter and associated components
· Inspect the general cleanliness and condition of all components
· Inspection for loose, missing, or damaged bolts and parts
· Inspection for abnormal noises and vibration, oil leaks, piping and flange leaks, damaged or missing insulation, abnormal pipe movement and damaged or misadjusted pipe hangers, and the general condition of expansion bellows
· Inspect foundation for damage, missing or loose bolts/nuts, and damaged grout
· Verify the presence of electrical ground straps
· Verify the presence and condition of the coupling guard
· Verify the proper operation and oil level of the oiler, if present
· Verify the bearing temperatures are within normal operational limits and slinger rings are moving freely
· Ensure that breather tube and sight glass vents are clear
· Verify the equipment is tagged and properly identified
For packing:
· Verify proper leak-off rate
· Verify that the gland bolts are not loose or damaged
For seals:
· Note and report any seal leakage
· Verify that the gland bolts are not loose or damaged
· Proper seal injection flow

· After reinstallation and prior to coupling, check and record uncoupled pump lift and motor thrust, compare to historical
· Verify proper motor rotation before coupling

Principle Failure Locations and Causes:

Refurbishment addresses most parts of the pump and most of the degraded conditions that could be encountered.

Progression of Failure Mechanisms Over Time:

The most influential items are the longer term wearout mechanisms such as the effects of erosion and damage to the casing penetrations, discharge nozzle, and suction and discharge flanges.

Task Interval Support:

This is an on-condition task that is only performed as necessary when indicated by other PM tasks.

Functional Testing

Task Objective:

The objective of Functional Testing is to verify acceptable operability of the pump and its driver especially in stand-by pumps or in pumps that are not run for any significant periods of time. The failure rate is somewhat sensitive to whether this task is performed or not at 3 months, but there is little sensitivity of the failure rate to increasing the task interval.

Task Content:

The Functional Testing should be performed to verify acceptable operability of the pump and its driver especially in stand-by pumps or in pumps that are not run for any significant periods of time.

Functional Testing may also be performed when returning powered equipment to service.
The test should include verification of:
· Bearing temperatures
· Vibration levels
· Discharge pressure and flow

Principle Failure Locations and Causes:

The Functional Testing task has a significant role to play in preparing an alternated operating pump for being returned to continuous duty, and also for a permanently standby pump by verifying that it has not already failed. In addition it provides the only good opportunity to detect drift in the Auxiliary Oil Pump Pressure Switch.

Progression of Failure Mechanisms Over Time:

The Auxiliary Oil Pump Pressure Switch experiences drift that can lead to failure of the oil pump in a time period of 2 to 4 years at the earliest.

Task Interval Support:

The failure rate is somewhat sensitive to whether this task is performed or not at 3 months, but there is little sensitivity of the failure rate to increasing task interval.

Operator Rounds

Task Objective:

Operator Rounds is focused on the condition of mechanical seals, packing, and gaskets. The interval for this task does not have a strong effect on the failure rate providing it is done quite frequently.

Task Content:

Operator Rounds will detect visible leaks of oil and water, unusual noises, loose or missing hardware, and temperature, pressure, and other parameters which are out of specification.

Principle Failure Locations and Causes:

Operator Rounds is focused on the condition of mechanical seals, packing, and gaskets, and provides a frequent opportunity to detect other kinds of leaks, e.g. from pipes and fittings.

Progression of Failure Mechanisms Over Time:

Most of these leaks develop from wearout mechanisms over 5 to 10 years but also from a large number of random mechanisms that can cause failure at any time.

Task Interval Support:

This task is ideally suited to address leaks caused by a large number of random influences that nevertheless cumulatively do not have a big impact on the failure rate.

Acoustic Monitoring

Task Objective:

This is an on-condition task to discover noise signatures indicating wear or damage to the gears in the auxiliary or main gear lube oil pumps or cavitation that could damage the impeller.

Task Content:

No task content is included for this release.

Principle Failure Locations and Causes:

Acoustic Monitoring can discover evidence of pump or system cavitation which could lead to damage of the pump internals, and excessive or unusual noise levels that indicate wear or damage to the gears in the auxiliary or main gear lube oil pumps.

Progression of Failure Mechanisms Over Time:

Cavitation can arise from very long term wearout effects or from essentially random occurrences of cavitation from low NPSHA or off-BEP operation.

Task Interval Support:

This task is recommended to be performed as an on-condition activity, only when there are other indications of a problem

Packing or Seal Replacement

Task Objective:

This is an on-condition task focused on replacement of the packing and mechanical seals..

Task Content:

Packing / Seal Replacement is done in place and should include the following:
· Inspect the shaft and shaft sleeve for defects or damage
· Look for loose, missing, or damaged bolts, studs, nuts, and parts
· Verify shaft run out
· Clean and inspect stuffing box for wear, damage, and presence of corrosion

For seals:
· Suggestion: Perform diagnostics on old seal, such as determine amount of seal face wear for wear rate evaluation, condition of elastomers, presence of any debris, condition of the spring, and the extent of the setscrew indentations into the shaft sleeve
· Check seal injection piping condition and verify flow
· Replace with new correct seal
For packing:
· Inspect and note condition of removed packing and packing sleeve
· Replace sleeve if worn
· Verify configuration of packing and lantern rings
· Replace with new packing using correct configuration, material, and number of rings
· Tighten to plant procedure
· Verify correct seal leak rate

Principle Failure Locations and Causes:

This task is obviously focused on the replacement of mechanical seals and packing and is an on-condition task

Progression of Failure Mechanisms Over Time:

The seals and packing wear out in 6 to 10 years, at the earliest, under normal circumstances.

Task Interval Support:

This task would only be performed on indication of excessive seal leakage by other PM activities. It would not normally be a regularly scheduled task.

Vibration Analysis

Task Objective:

The task addresses sources of vibration in rotating parts as well as flow noise such as cavitation. Reliability is not very sensitive to the task interval.

Task Content:

Vibration Analysis should include:
(Note: Vibration is performed on the driver and driven components.)
· Analysis of the readings looking for evidence of misalignment and unusual spectrums that may indicate the existence of problems
Additionally:
· Visually inspect for signs of leaking lubricant, if present
· Listen for unusual noises that may indicate coupling problems
· Visually inspect for loose fasteners and damage
· Visually inspect the coupling guard, if present, for signs of loose fasteners and damage

Principle Failure Locations and Causes:

Vibration Analysis mainly addresses wear and damage to rotating components such as bearings and the pump shaft, the balancing device, and gear drive and auxiliary oil pumps, as well as wear or damage caused by erosion on impellers and internal parts such as diffusers and interstage sealing.

Progression of Failure Mechanisms Over Time:

These can nearly all develop as long term wearout mechanisms with at least 20 years or much longer before expected failure occur. However, a wide variety of random causes of damage to the same components can also occur unless this task is performed very frequently, in sharp contrast to the much more relaxed time frame that would be suggested by the longer term wearout mechanisms.

Task Interval Support:

The task should be performed at least every 3 months, and more frequently for the most critical, high duty applications. Pumps with lower functional importance and low duty cycles could ignore the effects of random failures and perform the task every year because the random failures only contribute to the failure rate at a 10% level.

I&C Pressure Switch

Table A-29 I&C Pressure Switch

Template Data Report: I&C - Pressure Switch	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Operator Rounds	1S	NA	1S	NA	1D	NA	1D	NA
Calibration	18M	NA	3Y	NA	4Y	NA	6Y	NA
Scheduled Replacement	10Y	NA	12Y	NA	AR	NA	AR	NA

Component PM Assessment

For I&C Pressure Switch the EPRI PMBD recommends three tasks to maintain the inherent reliability of the component, as shown in Table A-29. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-30 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-30 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The execution of any one of the two tasks, Calibration Or Scheduled Replacement, will result in a 50% greater reliability than doing no preventive maintenance at all. Additionally, Calibration alone will result in a 90% reliability benefit.

Table A-30 I&C Pressure Switch PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Operator Rounds	0.1		
Calibration	4.0	√*	√**
Scheduled Replacement	4.0	√*	

- *- Performing any one of these two tasks; Calibration Or Scheduled Replacement will provide a 50% reliability benefit.
  **- Performing a Calibration will result in a 90% reliability benefit.

Operator Rounds

Task Objective:

Operator Rounds focuses on detection of leaks and visible damage.

Task Content:

Operator Rounds generally detects large leaks of air, as well as loose, damaged or missing fasteners, abnormal pressures, and alarms.

Principle Failure Locations and Causes:

Operator Rounds will only be able to detect leaks from broken, cracked, loose, and leaking sensing lines and fittings.

Progression of Failure Mechanisms Over Time:

These degradation mechanisms have both random components and short term wearout components.

Task Interval Support:

Operator Rounds are performed sufficiently frequently to be effective against all these degradation mechanisms.

Calibration

Task Objective:

Calibration assures that the device is performing within specification, and confirms traceability to NIST standards in demonstrating the absolute accuracy of the output. The intervals are fairly clearly determined by the underlying failure time data.

Task Content:

Calibration should include the following:
· A visual inspection or walkdown, as far as practical, of the instrument's sensing line looking for evidence of air leaks, damaged, crushed or broken tubing, loose tubing connections, loose or missing tubing clamps, or corroded tubing and connectors.
· Verify and adjust, as needed, the device's zero span.
· Verify and adjust, as needed, the device's linearity and hysteresis.
· It is strongly suggested that a minimum 5 point calibration response check be performed, a 9 point check should be considered for more critical devices.

Principle Failure Locations and Causes:

Calibration addresses age related drift, cracked or corroded switches, sticking of the switch button in high cycle situations, degrading elastomers, and leaking lines and valves

Progression of Failure Mechanisms Over Time:

These failure mechanisms are all wearout situations with an expected failure free period of at least 3 years (drift and leaks) or much longer.

Task Interval Support:

Calibration at 18M to 3Y will provide good protection from the age related failure mechanisms, but is not very effective against other, random, mechanisms. Note that here, and in the listing of degradation mechanisms, remaining failure free means remaining within specifications.

Scheduled Replacement

Task Objective:

Scheduled Replacement is done to prevent failure from the end of life of various subcomponents. The interval is strictly determined by the failure timing data

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Replacement at a predetermined interval will prevent failures from the switch button sticking, age related drift, and degrading elastomers

Progression of Failure Mechanisms Over Time:

These are all wearout modes with expected failure free intervals in excess of 5 years (elastomers).

Task Interval Support:

Scheduled Replacement at 10 to 12 years will be effective against age related drift, and sticking switch buttons, provided the device is not exposed to significant levels of vibration. Vibration drives a number of shorter term wearout modes and some random failure modes. If in a vibration environment there needs to be a design change. Replacement at these long intervals is not an effective defense against aging of the elastomers which proceeds on a much shorter time scale.

I&C Temperature Switch

Table A-31 I&C Temperature Switch

Template Data Report: I&C - Temperature Switch	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Operator Rounds	1S	NA	1S	NA	1D	NA	1D	NA
Calibration	18M	NA	3Y	NA	4Y	NA	6Y	NA
Scheduled Replacement	12Y	NA	15Y	NA	AR	NA	AR	NA

Component PM Assessment

For I&C Temperature Switch the EPRI PMBD recommends three tasks to maintain the inherent reliability of the component, as shown in Table A-31. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-32 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-32 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. The execution of any one of the two tasks, Calibration Or Scheduled Replacement, will result in a 50% greater reliability than doing no preventive maintenance at all. Performing two of the following tasks: Calibration And Operator Rounds, Or Calibration and Scheduled Replacement will result in a 90% reliability benefit.

Table A-32 I&C Temperature Switch PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Operator Rounds	0.1		√**
Calibration	6.0	√*	√**
Scheduled Replacement	6.0	√*	√**

- *- Performing any one of these two tasks; Calibration Or Scheduled Replacement will provide a 50% reliability benefit.
  **- Performing two of the following tasks; Calibration And Operator Rounds; Or Calibration And Scheduled Replacement will result in a 90% reliability benefit.

Operator Rounds

Task Objective:

Operator Rounds focuses on visible detection of loss of fill from the bulb and capillary.

Task Content:

Operator Rounds generally detects large leaks of air, as well as loose, damaged or missing fasteners, abnormal pressures, and alarms.

Principle Failure Locations and Causes:

Operator Rounds will only be able to detect loss of fill of the temperature bulb and capillary.

Progression of Failure Mechanisms Over Time:

This degradation mechanism has a random component from personnel error, and a wearout component driven by vibration.

Task Interval Support:

Operator Rounds are performed sufficiently frequently to be effective against these degradation mechanisms.

Calibration

Task Objective:

Calibration assures that the device is performing within specification, and confirms traceability to NIST standards in demonstrating the absolute accuracy of the output. The intervals are fairly clearly determined by the underlying failure time data.

Task Content:

Calibration should include the following:
· A visual inspection should be performed to check for tightness of the connections, general cleanliness, over heated components, and cracked terminations and cases.
· Verify and adjust, as needed, the device's zero/span.
· Verify and adjust, as needed, the device's linearity and hysteresis.
· It is strongly suggested that a minimum 5 point calibration response check be performed, a 9 point check should be considered for more critical devices.

Principle Failure Locations and Causes:

Calibration addresses age related drift, cracked or corroded switches, and sticking of the switch button in high cycle situations.

Progression of Failure Mechanisms Over Time:

These failure mechanisms are all wearout situations with an expected failure free period of at least 5 years (drift) or much longer.

Task Interval Support:

Calibration at 18M to 3Y will provide good protection from the age related failure mechanisms, but is not very effective against other, random, mechanisms. Note that here, and in the listing of degradation mechanisms, remaining failure free means remaining within specifications.

Scheduled Replacement

Task Objective:

Scheduled Replacement is done to prevent failure from the end of life of various subcomponents. The interval is strictly determined by the failure timing data

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Replacement at a predetermined interval will prevent failures from the switch button sticking, and age related drift.

Progression of Failure Mechanisms Over Time:

These are both wearout modes with expected failure free intervals in excess of 10 years.

Task Interval Support:

Scheduled Replacement at 12 to 15 years will be effective against aging in general, provided the device is not exposed to significant levels of vibration. Vibration drives a number of shorter term wearout modes and some random failure modes. If in a vibration environment there needs to be a design change.

I&C Positioner

Table A-33 I&C Positioner

Template Data Report: I&C - Positioner	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Calibration	18M	18M	18M	3Y	3Y	5Y	AR	AR
Diagnostic Testing	18M	18M	18M	3Y	3Y	5Y	AR	AR
Rebuild or Replace	5Y	5Y	5Y	8Y	8Y	10Y	AR	AR
Functional Testing	AR	AR	AR	AR	AR	AR	AR	AR

Component PM Assessment

For I&C Positioner the EPRI PMBD recommends four tasks to maintain the inherent reliability of the component, as shown in Table A-33. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-34 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-34 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. Performing any one of these three tasks: Calibration Or Diagnostic Testing Or Rebuild/Replace will provide a 50% reliability benefit over doing no Preventive Maintenance at all. Performing both of the following tasks: Rebuild or Replace And Functional testing will result in a 90% reliability benefit.

Table A-34 I&C Positioner PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Calibration	6.0	√*	
Diagnostic Testing	8.0	√*	
Rebuild or Replace	10.0	√*	√**
Functional Testing	2.0		√**

- *- Performing any one of these three tasks; Calibration Or Diagnostic Testing Or Rebuild/Replace will provide a 50% reliability benefit.
  **- Performing both of the following tasks; Rebuild or Replace And Functional Testing will result in a 90% reliability benefit.

Calibration

Task Objective:

Calibration assures that the positioner is performing within specification. The intervals are fairly clearly determined by the underlying failure time data.

Task Content:

Calibration should include the following:
· A visual inspection should be performed to check for tightness of the connections, general cleanliness, proper mechanical alignments, free movement of the mechanical assembly, evidence of air leaks, and damaged tubing.
· Verify and adjust, as needed, the device's zero/span.
· Verify and adjust, as needed, the device's linearity and hysteresis.
· It is strongly suggested that a minimum 5 point calibration response check be performed, a 9 point check should be considered for more critical devices.

Principle Failure Locations and Causes:

Calibration addresses several sources of drift, as well as wear of cams and bushings, worn poppet valve seats, and loose wiring and connections.

Progression of Failure Mechanisms Over Time:

Most of these degradation mechanisms have wearout time of 3 years or considerably longer.

Task Interval Support:

Calibration at 18M to 3Y will provide good protection from the age related failure mechanisms, but is not very effective against other, random, mechanisms. Calibration and Diagnostic Testing should be performed at the same time. Note that here, and in the listing of degradation mechanisms, remaining failure free means remaining within specifications.

Diagnostic Testing

Task Objective:

Diagnostic Testing provides assurance that the total performance of the valve as a whole (i.e. including positioner, booster, actuator etc.) is within specifications. The intervals are clearly determined by the failure time data.

Task Content:

Diagnostic Testing (such as Flow Scan) is usually performed as a part of valve testing, which measures characteristics such as:
· Total Friction, packing drag etc.
· Seat Load, lift-off and seating points
· Travel
· Available actuator thrust / torque
· Accessory signatures
· Air pressures
· Spring rate
· Spring preload
This task is performed with the valve off-line, but is done in-place, and is relatively non-intrusive.

Principle Failure Locations and Causes:

Diagnostic Testing addresses the same degradation mechanisms as Calibration, including several sources of drift, as well as wear of cams and bushings, worn poppet valve seats, and loose wiring and connections.

Progression of Failure Mechanisms Over Time:

Most of these degradation mechanisms have wearout time of 3 years or considerably longer.

Task Interval Support:

Diagnostic Testing at 18M to 3Y will provide good protection from the age related failure mechanisms, but is not as effective against other, random, mechanisms. Calibration and Diagnostic Testing should be performed at the same time.

Rebuild or Replace

Task Objective:

Rebuild or Replace prevents wearout failures of subcomponents, including, but not limited to, elastomers. The intervals are clearly determined by the failure mode data.

Task Content:

Rebuild or Replace should consist of the following:
- Inspection for damage, over heating of components, corrosion, evidence of air leakage, tightness and conditional of all electrical and mechanical connections, loose, or missing parts.
- The entire device may be replaced with a refurbished or new device at this time.

Principle Failure Locations and Causes:

Rebuild or Replace is directed mainly at the aging of elastomers, as well as wear of cams and bushings, and worn poppet valve seats.

Progression of Failure Mechanisms Over Time:

Most of these degradation mechanisms have wearout time of 5 years or considerably longer.

Task Interval Support:

Rebuild or Replace at 5 years will address these wearout mechanisms very effectively. Many other failure mechanisms which are more random in occurrence are not addressed effectively because the task is not performed more frequently.

Functional Testing

Task Objective:

Functional Testing is primarily a failure finding task. The interval should be short to enable the testing to address random sources of failure effectively.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Functional Testing is primarily a failure finding activity which addresses failure of the positioner from a wide range of degradation mechanisms.

Progression of Failure Mechanisms Over Time:

The task is not very effective at defending against the failures - only finding them after they have occurred. A possible exception is the clogging of pneumatic devices such as orifices.

Task Interval Support:

Functional Testing is effective at finding a wide range of failures if performed very frequently.

I&C Pneumatic Controller

Table A-35 I&C Pneumatic Controller

Template Data Report: I&C - Pneumatic Controller	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Operator Rounds	1S	1S	1S	1S	1D	1D	1D	1D
Calibration	18M	18M	18M	3Y	6Y	6Y	10Y	10Y
Channel Check	AR	AR	AR	AR	AR	AR	AR	AR
Scheduled Replacement	10Y	10Y	12Y	15Y	AR	AR	AR	AR
Internal Inspection	AR	AR	AR	AR	AR	AR	AR	AR

Component PM Assessment

For I&C Pneumatic Controller the EPRI PMBD recommends five tasks to maintain the inherent reliability of the component, as shown in Table A-35. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-36 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-36 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. Performing any one of these four tasks: Calibration Or Channel Check Or Scheduled Replacement Or Internal Inspection will provide a 50% reliability benefit over doing no Preventive Maintenance at all. Performing a Calibration will result in a 90% reliability benefit.

Table A-36 I&C Pneumatic Controller PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Operator Rounds	0.1		
Calibration	4.0	√*	√**
Channel Check	2.0	√*	
Scheduled Replacement	4.0	√*	
Internal Inspection	8.0	√*	

- *- Performing any one of these four tasks; Calibration Or Channel Check Or Scheduled Replacement Or Internal Inspection will provide a 50% reliability benefit.
  **- Performing a Calibration will result in a 90% reliability benefit.

Operator Rounds

Task Objective:

Operator Rounds are done to detect gross failure of the device.

Task Content:

Operator Rounds generally looks and listens for large leaks of air, as well as loose, damaged or missing fasteners, abnormal pressures, alarms, and mis-positioned devices.

For Pneumatic Controllers it includes essentially a channel check looking for indication that the set point, the process input, and controller output are reasonable compared to a redundant indication.

Additionally, controller knob functions will be exercised during normal use and their correct functioning verified.

Principle Failure Locations and Causes:

Operator Rounds is only capable of detecting a gross failure such as elastomers failure.

Progression of Failure Mechanisms Over Time:

Elastomer failure can have long term wearout causes as well as random causes.

Task Interval Support:

Operator Rounds will be done very frequently, so it is very effective at detecting this kind of failure, but probably offers no protection against it.

Calibration

Task Objective:

Calibration assures that the device is performing within specification, and confirms traceability to NIST standards in demonstrating the absolute accuracy of the output. The interval is determined by the failure timing data.

Task Content:

Calibration should include the following:
- A visual inspection or walkdown, as far as practical, of the instrument's sensing line looking for damaged, crushed or broken tubing, loose tubing connections, loose or missing tubing clamps, or corroded tubing and connectors.
- Verify and adjust, as needed, the device's zero/span.
- Verify and adjust, as needed, the device's linearity and hysteresis.
- It is strongly suggested that a minimum 5 point calibration response check be performed, a 9 point check should be considered for more critical devices.

Principle Failure Locations and Causes:

Calibration is focused on detecting drift that can no longer be compensated by the controller especially if due to air leaks, worn, loose, or binding mechanical parts, and elastomer failure.

Progression of Failure Mechanisms Over Time:

These degradation mechanisms all have wearout failure patterns with an expected failure free period of at least three years.

Task Interval Support:

The 18 month interval will provide good protection against the wearout failure modes. However, because the controller will compensate for drift to some maximum extent, Calibration is less critical for controllers than for other I&C components.

Channel Check

Task Objective:

The purpose of Channel Checks is to identify any channel which is behaving abnormally. The interval is usually sufficiently frequent to provide protection against random failure mechanisms.

Task Content:

Channel Check provides an opportunity make a gross comparison between like instruments monitoring the same process condition, and assures that the output of the device is correct and typically within a few percent of the medium channel or has not drifted significantly from previously noted values.

Principle Failure Locations and Causes:

Channel Checks look for fairly gross differences between similar redundant channels, caused mainly by wear and binding of mechanical components, and elastomer failures.

Progression of Failure Mechanisms Over Time:

These degradation mechanisms have wearout failure patterns with an expected failure free period of at least 5 years.

Task Interval Support:

Channel Checks will be done very frequently, so they are very effective at detecting these failure mechanisms.

Scheduled Replacement

Task Objective:

Scheduled Replacement prevents long term wearout failures. The interval is clearly determined by the failure mode data.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Scheduled Replacement prevents failures caused by drift which can no longer be compensated by the controller, wear and binding of mechanical components, and age related failures of elastomers.

Progression of Failure Mechanisms Over Time:

These degradation mechanisms have wearout failure patterns with an expected failure free period of at least 5 years (wear and binding), and considerably longer for the other failure mechanisms.

Task Interval Support:

The 10 year interval provides good protection against all the longer term wearout modes

Internal Inspection

Task Objective:

Internal Inspection is performed to prevent failures due to mechanical wear and binding and elastomer aging. The task would be effective at a 3 year interval.

Task Content:

Internal Inspection consists of vendor-specified maintenance to clean, lubricate and inspect all sub-components, and involves a high level of disassembly. It should include:
- Inspect for loose, damaged, or missing parts
- Inspect the condition of all elastomers for evidence of age related wear, hardening, and loss of elastic properties; some or all elastomeric components may be replaced at this time.
- Inspect the general condition of all internal parts looking for excessive wear, damage, distortion
- Check for evidence of corrosion and air leakage
- Clean and lubricate all parts as required

Although the instrument is dismantled to the piece-part level, this task is often less than a rebuild, although similar to it, because many of these parts will not automatically be renewed, especially if the task is performed at the same time as Calibration.

Principle Failure Locations and Causes:

Internal Inspection provides an opportunity to detect and repair degradation caused mainly by wear and binding of mechanical components, and elastomer failures.

Progression of Failure Mechanisms Over Time:

These degradation mechanisms have wearout failure patterns with an expected failure free period of at least 5 years.

Task Interval Support:

This task may be performed as an option, especially in severe environments. In some plants it is done at the same time as Calibration, but if so, most of the subcomponents will not need to be replaced this frequently. The task could be performed quite effectively at every other Calibration.

I&C – I/P-E/P Transducer

Table A-37 I&C – I/P-E/P Transducer

Template Data Report: I&C - I/P and E/P Transducer	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Calibration	18M	NA	3Y	NA	5Y	NA	10Y	NA
Scheduled Replacement	6Y	NA	10Y	NA	AR	NA	AR	NA
Functional Testing	AR	NA	AR	NA	AR	NA	AR	NA

Component PM Assessment

For I&C – I/P-E/P Transducer the EPRI PMBD recommends three tasks to maintain the inherent reliability of the component, as shown in Table A-37. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-38 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-38 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. Performing any one of two tasks, Calibration Or Scheduled Replacement, will provide a 50% reliability benefit over doing no preventive maintenance at all. Performing both a Calibration and Scheduled Replacement will result in a 90% reliability benefit.

Table A-38 I&C – I/P-E/P Transducer PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Calibration	8.0	√*	√**
Scheduled Replacement	6.0	√*	√**
Functional Testing	4.0		

- *- Performing any one of these two tasks; Calibration Or Scheduled Replacement will provide a 50% reliability benefit.
  **- Performing both a Calibration and Scheduled Replacement will result in a 90% reliability benefit.

Calibration

Task Objective:

Calibration assures that the device is performing within specification, and confirms traceability to NIST standards in demonstrating the absolute accuracy of the output. The interval is clearly determined by the failure timing data.

Task Content:

Calibration should include the following:

- A visual inspection should be performed to check for tightness of the connections, general cleanliness, proper mechanical alignments, free movement of the mechanical assembly, evidence of air leaks, damaged tubing, corroded edge connectors, over heated components on printed circuit boards, leaking capacitors, and cracked terminations and cases.
- Verify and adjust, as needed, the device's zero/span.
- Verify and adjust, as needed, the device's linearity and hysteresis.
- It is strongly suggested that a minimum 5 point calibration response check be performed, a 9 point check should be considered for more critical devices.

Principle Failure Locations and Causes:

Calibration of I/P and E/P transducers mainly addresses drift of the instruments due to age and elevated temperature

Progression of Failure Mechanisms Over Time:

The age and temperature-related components of drift occur with a wearout pattern and an expected failure free period of at least 3 years. Additional contributions to drift as well as several random failure mechanisms occur randomly, but can not be effectively addressed by Calibration unless it is performed more frequently

Task Interval Support:

The suggested interval of 18 months to 3 years for critical transducers will provide good protection against age and temperature related drift. Note that here, and in the listing of degradation mechanisms, remaining failure free means remaining within specifications.

Scheduled Replacement

Task Objective:

Scheduled Replacement is done to prevent failure from the aging of elastomers, and to a some degree from failures of other subcomponents. The interval is strictly determined by failure timing data.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Scheduled Replacement primarily addresses the aging of elastomers.

Progression of Failure Mechanisms Over Time:

The elastomers should have a failure free life, through normal use and aging, of at least 5 years, and probably 10 years under good conditions.

Task Interval Support:

Although the recommended interval of 6 years for critical instruments in severe service provides protection against age related failures, the effect of significantly elevated temperature could still cause failure at earlier times.

Functional Testing

Task Objective:

Functional Testing is performed as a go/no go test to identify the need for Calibration or other action. The interval is not well determined by the failure timing data, but the task needs to be done frequently to be effective.

Task Content:

Task Content is not included for this release.

Principle Failure Locations and Causes:

Functional Testing is effective as a failure finding task to indicate the need for recalibration due to drift, intervention to clean orifices, nozzles and other pneumatic components, clean and tighten corroded or loose wiring, terminations and connections, or to replace the instrument due to the failure of other subcomponents.

Progression of Failure Mechanisms Over Time:

Most of the sources of failure which are addressed by this task occur randomly.

Task Interval Support:

Functional Testing should be performed frequently enough to address the random failure mechanisms. The task is essentially performed as a Go / No Go test to identify the need for calibration.

Pressure Sensors and Transmitters

Pressure sensors and transmitters have very little time directed tasks associated with them. Most I&C components really benefit from calibration and functional checks.

Table A-39 Pressure Sensors and Transmitters

Template Data Report: I&C - Pressure Sensor And Transmitter	Critical				Minor			
	HI	LO	HI	LO	HI	LO	HI	LO
	SEVERE		MILD		SEVERE		MILD	
	CHS	CLS	CHM	CLM	MHS	MLS	MHM	MLM
Operator Rounds	1S	NA	1S	NA	1D	NA	1D	NA
Calibration	18M	NA	3Y	NA	3Y	NA	6Y	NA
Channel Check	AR	NA	AR	NA	AR	NA	AR	NA
Scheduled Replacement	15Y	NA	20Y	NA	AR	NA	AR	NA

Component PM Assessment

For I&C – Pressure Sensors and Transmitters the EPRI PMBD recommends three tasks to maintain the inherent reliability of the component, as shown in Table A-39. The PMBD 2.0 software tool was used as a guide for determining the resources required to execute this all-inclusive type of PM strategy. The following PM program strategy shown in Table A-40 could be implemented with the reduced amount of execution resources and still maintain reasonably effective failure mode mitigation for the component.

Table A-40 shows the reliability benefit of the individual tasks assuming the station is not currently performing any maintenance on the selected component. Performing any one of two tasks, Calibration Or Channel Check, will provide a 50% reliability benefit over doing no Preventive Maintenance at all. Performing a Channel Check alone will result in a 90% reliability benefit.

Table A-40 I&C – Pressure Sensors and Transmitters PM Optimization

PM Task	PM Resources Required (mhrs)	Task(s) to Perform to Obtain ≥ 50% Reliability Benefit	Task(s) to Perform to Obtain ≥ 90% Reliability Benefit
Operator Rounds	0.1		
Calibration	4.0	√*	
Channel Check	2.0	√*	√**
Scheduled Replacement	8.0		

- *- Performing any one of these two tasks; Calibration Or Channel Check will provide a 50% reliability benefit.
  **- Performing a Channel Check will result in a 90% reliability benefit.

Operator Rounds

Task Objective:

Operator Rounds are mainly focused on detecting air leaks from components associated with the sensing lines.

Task Content:

Operator Rounds generally detects large leaks of air, as well as loose, damaged or missing fasteners, abnormal pressures, and alarms.

Principle Failure Locations and Causes:

Operator Rounds is effective for detecting broken, cracked, loose, and leaking components associated with sensing lines.

Progression of Failure Mechanisms Over Time:

These components suffer a few randomly occurring failure mechanisms as well as a few much longer term wearout mechanisms.

Task Interval Support:

Operator Rounds is performed frequently enough to be highly effective against the random sources of failure.

Calibration

Task Objective:

Calibration assures that the device is performing within specification, and confirms traceability to NIST standards in demonstrating the absolute accuracy of the output. The intervals are fairly clearly determined by the underlying failure time data.

Task Content:

Calibration should include the following:
- A visual inspection or walkdown, as far as practical, of the instrument's sensing line looking for evidence of air leaks, damaged, crushed or broken tubing, loose tubing connections, loose or missing tubing clamps, or corroded tubing and connectors.
- Verify and adjust, as needed, the device's zero/span.
- Verify and adjust, as needed, the device's linearity and hysteresis.
- It is strongly suggested that a minimum 5 point calibration response check be performed, a 9 point check should be considered for more critical devices.

Principle Failure Locations and Causes:

Calibration detects and corrects age related drift of the electronics and Bourdon tube (if present), age related sources of broken, cracked, loose and leaking sensing line components, and leaking bellows.

Progression of Failure Mechanisms Over Time:

The age related effects have wearout times from 3 to 5 years and longer. Many other random degradation mechanisms, potentially detected by this task, are not addressed very effectively because Calibration is not performed frequently enough.

Task Interval Support:

The suggested intervals provide good protection against the age related effects. Calibration does play a role with regard to the many random sources of failure when it is combined with frequent channel checks. Since the channel checks are a fairly gross cross channel comparison, they may usually serve only as a failure finding task. Note that here, and in the listing of degradation mechanisms, remaining failure free means remaining within specifications.

Channel Check

Task Objective:

The purpose of Channel Checks is to identify any channel which is behaving abnormally. The interval is usually sufficiently frequent to provide protection against random failure mechanisms.

Task Content:

Channel Check provides an opportunity to make a gross comparison between like instruments monitoring the same process condition, and assures that the output of the device is correct and typically within a few percent of the medium channel or has not drifted significantly from previously noted values.

Principle Failure Locations and Causes:

Channel checks offer a gross level of defense against essentially all the failure mechanisms affecting pressure sensors and transmitters.

Progression of Failure Mechanisms Over Time:

The majority of these degradation processes occur randomly, requiring a frequent task to address them.

Task Interval Support:

Channel Checks provide a fairly gross indication of the need to recalibrate against drift, and are also effective as failure finding checks to discover channel failures or out-of-specification conditions. Because Channel Checks are performed very frequently, they are effective against the many random sources of these problems.

Scheduled Replacement

Task Objective:

Scheduled Replacement is done to prevent failure from the end of life of subcomponents. The interval is fairly closely determined by failure timing data.

Task Content:

Scheduled Replacement should replace the entire sensor and transmitter as a complete package.

Principle Failure Locations and Causes:

Scheduled Replacement primarily addresses the age related failure of transmitter electronics and sensors.

Progression of Failure Mechanisms Over Time:

Bourdon tubes and strain gauges should have a failure free life, through normal use and aging, of 10 to 20 years, and capacitance cells and piezo sensors of 10 to 15 years. There may also be a significant random contribution to these failures.

Task Interval Support:

The recommended interval of 15 years for critical instruments in severe service provides protection against age related failure of transmitter electronics and sensors, and is also driven by consideration of the approaching end of life of the device as a whole

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