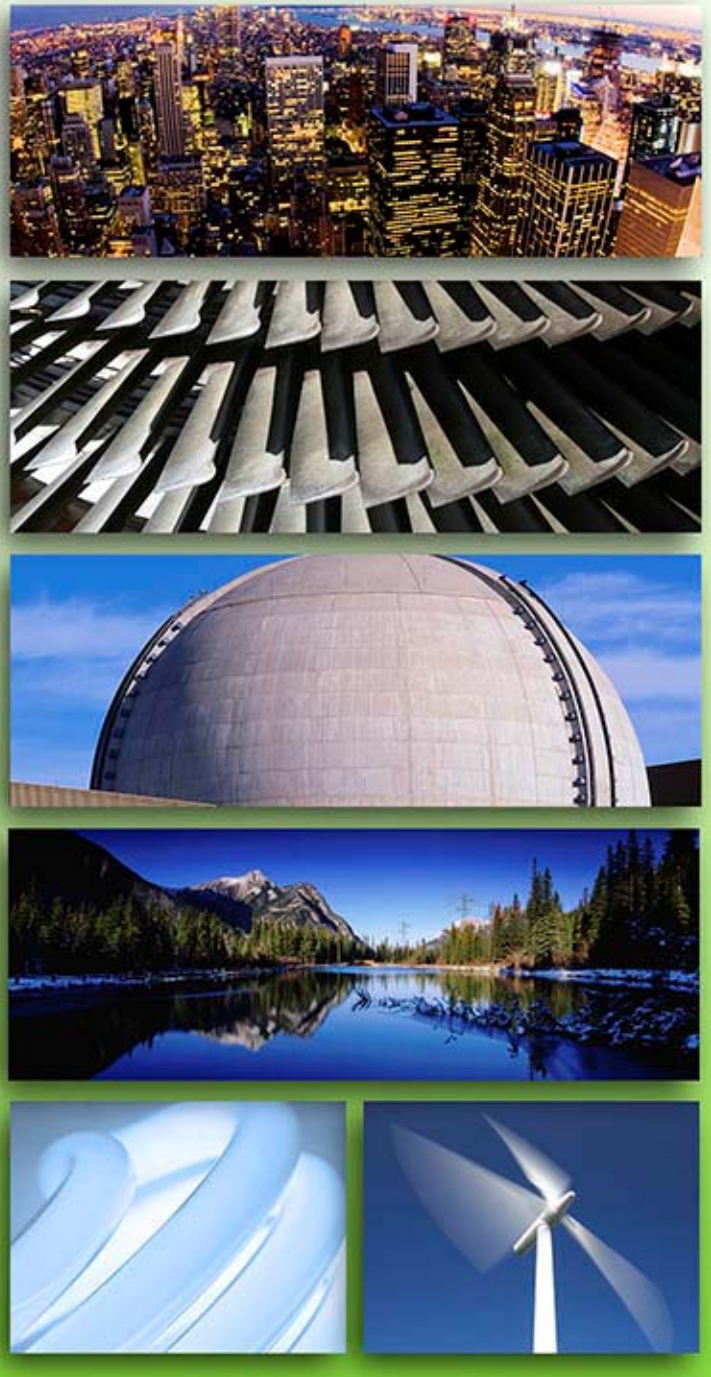

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Equipment Condition Monitoring
A Nuclear Prospective

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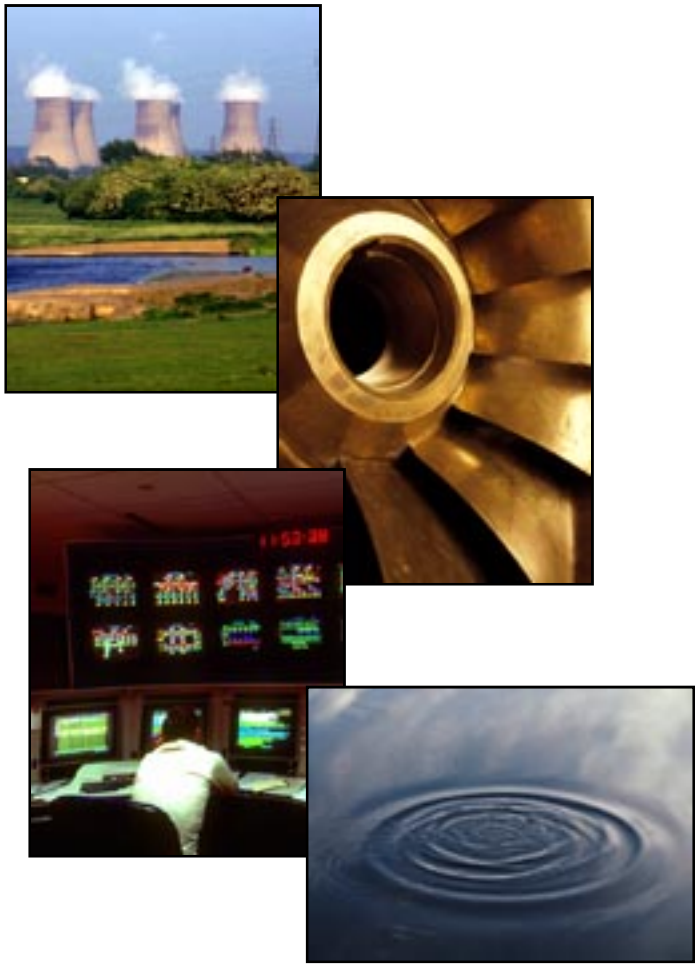
Together…shaping the future of electricity

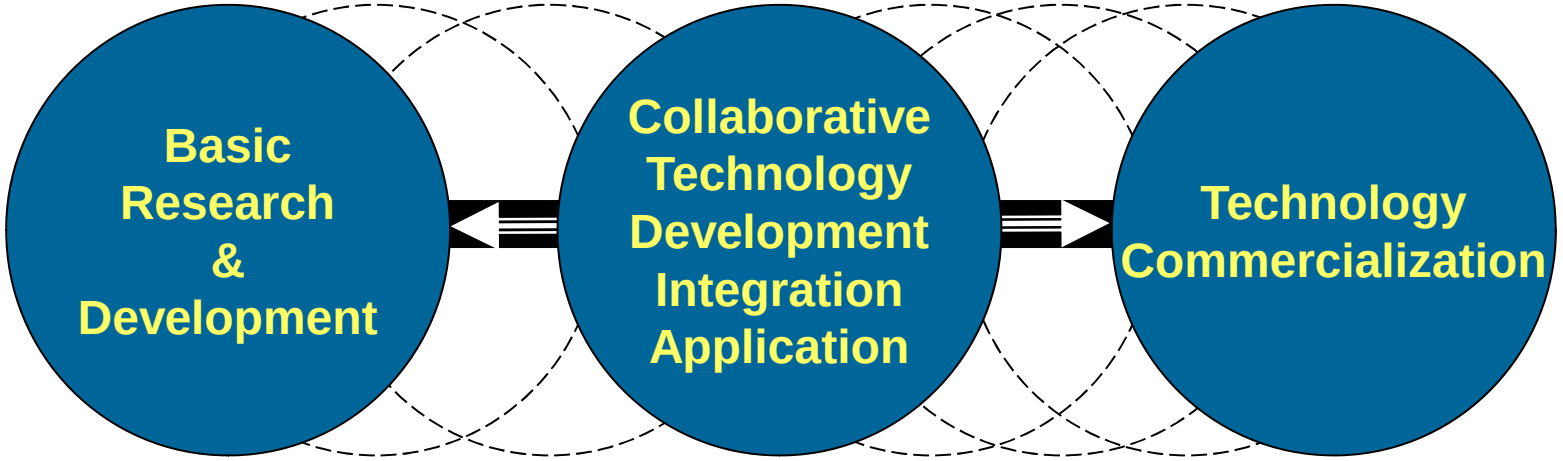
- EPRI Founded in 1973
- Objective: non-profit electricity collaborative research organization
- Technology development, integration, demonstration and application
- Broad technology portfolio ranging from near-term solutions to long-term strategic research (Innovation Program)
- Major office locations in Charlotte, NC and Palo Alto. CA

One of the World's Largest & Most Successful R&D Collaborations



- Over 700 North American members alone
  - Over 90% of North American electricity generated
- Over 130 international participants
- Independent electricity research
  - Major issue focus
  - Major opportunity focus

EPRI's Role in the Technology Development to Commercialization Cycle



Research Institutes,
e.g. INL, PNNL, Paul Scherer Institute, CRIEPI, KEPRI, etc.

Universities

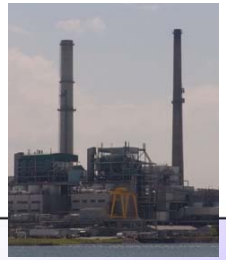
EPRI

Suppliers

Vendors

Depends On The Specific Technology

An Extensive Energy Research Program



Generation

Distributed Resources
Environmental Control
Fossil Steam Plants
Combustion Turbines
Market Analysis
Hydroelectric

Nuclear Power

Equipment Reliability
Nuclear Operations & Asset Management
High Performance Fuel
Nondestructive Evaluation
Human Performance
Risk/Safety Management

Power Delivery & Markets

Transmission
Substations
Grid Reliability
Power Markets
Distribution
Power Quality
Energy Utilization

Environment

Air Quality
Global Climate Change
Renewables
Occupational Health & Safety
Land & Groundwater
Water & Ecosystems

Equipment Condition Monitoring - Nuclear

Nuclear Reliability Incentives

- Nuclear Safety, an absolute must for survival
- Low cost of centralized base load generation
- Large and very reliable capacity
- Organizations Involved
  - Nuclear Regulatory Commission is responsible for regulation, not tied financially to the government
  - Institute of Nuclear Power Operation, INPO, self-imposed industry oversight
  - North American Electric Reliability Corporation, NERC, develops and enforces reliability standards
  - EPRI voluntary nonprofit support for research on equipment reliability among other activities

Equipment Condition Monitoring - Nuclear

Required Examination Of Nuclear Safety Related Components

- Code of Federal Regulations 10CFR50.55 requires operating plants to implement:
  - American Society of Mechanical Engineers (ASME) Section XI – Inservice Inspection of Nuclear Power Plant Components
  - Includes periodic examination of the reactor pressure vessel and associated connected piping
  - Established in 10 year inspection intervals
  - Examination methods include: visual, surface and volumetric examinations
  - Also requires performance testing of key pumps and valves in safety systems

Equipment Condition Monitoring - Nuclear

Non-Destructive Testing - Nuclear

- Three Uses for System and Component Health Monitoring for Nuclear Systems, Structures, and Components, SSCs
  - Plant license commitments require periodic examination of safety related and non-safety pressure boundary components
  - Supplemental examinations performed in conjunction with condition monitoring to detect flaws or monitor flaw growth
  - Root cause examinations to determine why a component failed

Equipment Condition Monitoring - Nuclear

Nondestructive Examination (NDE) – Safety Related

- Visual
  - Detect flaws, leakage, or conditions open to surface;
  - Direct or Remote (underwater cameras, pipe crawlers, etc.)
- Surface
  - Detect and size flaws, cracks, and conditions open to surface;
  - Penetrant and magnetic particle testing,
- Volumetric
  - Detect and characterize flaws within the volume of the component or weld (ASME Class 1 components – reactor and piping) using
    - ✓ Ultrasonic examination of welds, components,
    - ✓ Radiography of welds, piping, components
    - ✓ eddy current testing for tubing

Equipment Condition Monitoring - Nuclear

Nondestructive Examination (NDE) –Non-Safety Related

- Evaluation for flow assisted corrosion, FAC, in steam piping
  - Mixed steam/water flow causes erosion/corrosion
  - Ultrasonic examination or radiography (conventional and digital) to determine remaining pipe wall and condition
- Condition monitoring of secondary piping and buried piping
- Evaluation of environmentally assisted (biological and chemical) degradation of secondary piping systems

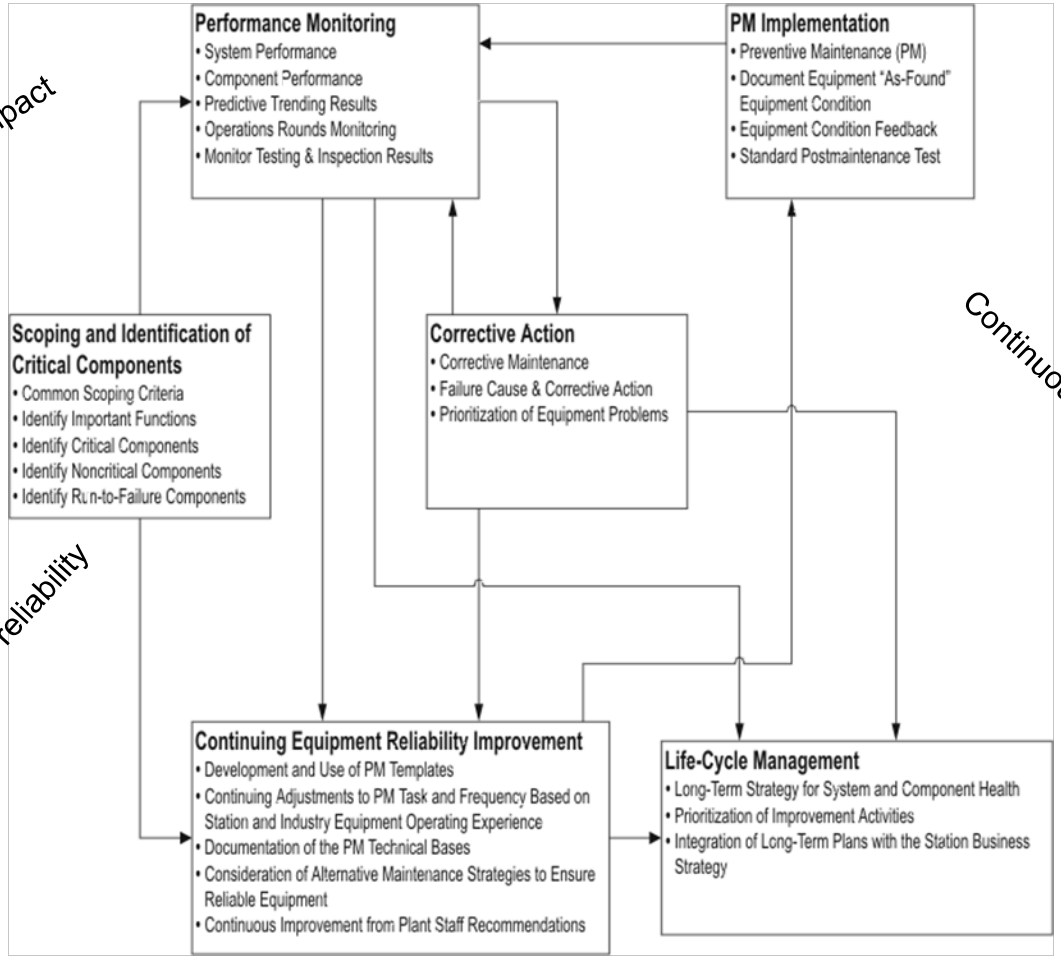
Equipment Condition Monitoring - Nuclear

Evolution of Reliability Philosophies in Nuclear

- Pre-1979: Similar to the commercial industry
- 1980 to 1995: Structured commercial approach
  - Reliability Centered Maintenance (United Airlines)
    - ✓ RCM overloaded the industry
  - Streamline RCM, the fast track RCM
- 1996 to 1998: An intolerance to any failure
  - Failure avoidance overloads the industry again
- 1999 to present use trends of deteriorating equipment conditions to direct maintenance actions
  - Non-impacting failure risk acceptance

Equipment Condition Monitoring - Nuclear

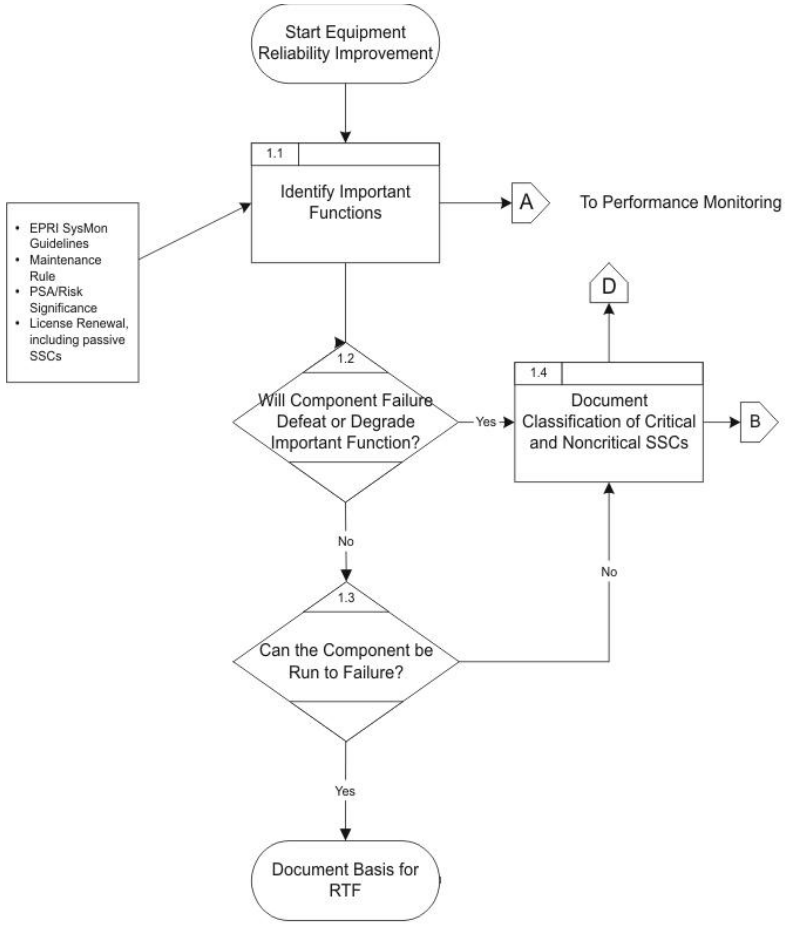
Nuclear Equipment Reliability Process, AP-913



Equipment Condition Monitoring - Nuclear

Equipment Criticality Determination Process of AP-913

- Critical Equipment,
- Important Equipment
- Run To Failure Equipment



Equipment Condition Monitoring - Nuclear

System and Component Health Monitoring of AP-913

- Engineering and technical staff collect input data
  - Constantly monitor many parameters
  - Quantitative data from measurements
  - Qualitative information
    - ✓ inspections,
    - ✓ maintenance reports, and
    - ✓ failure reports
- Management oversight via summary reporting and Dashboards

Equipment Condition Monitoring - Nuclear

Continuous Improvements And Adjustments of AP-913

- Aging effects
- Human performance
- Inputs to long term strategies
  - Changing operational conditions
  - New technology developments
  - Parts obsolescence
- Continuous realignment of the maintenance basis
  - Update the PM templates for components based on knowledge
  - Implemented in a structured repetitive maintenance process with key performance indicators, KPIs
  - Remaining life projections from predictive maintenance tests

EPRI Support of Fleet Monitoring

Fleet Wide Monitoring Initiatives in Nuclear

- Fleet-wide monitoring of key equipment and systems seen as more effective
  - Fewer onsite engineers and technical staff to monitor
  - 24/7 coverage by experienced personnel centrally located
  - Sites structured for Operations and Maintenance
- Combined fleets of nuclear, fossil, combined cycle CTs, etc.
- Expectations driven by the success of the nuclear reliability process
- Attrition of the knowledge base from the companies
- Consistency in approach

EPRI Support of Fleet Monitoring

Monitoring Trends Fleet Wide

- More centralized decision-making in managing plant assets
  - *Leverage fewer technical experts*
  - *Can apply uniform strategy across fleet*
- Greater structure, documentation to corporate processes
  - *Good application for enterprise-wide software*
  - *Efficient and consistent, even if staff changes*
  - *Effective form of tacit knowledge capture*
  - *Software tool must be intuitive and customizable*
- Use of technology and existing equipment knowledge to improved condition-based maintenance (CBM)
  - *Allows best use of limited maintenance resources*

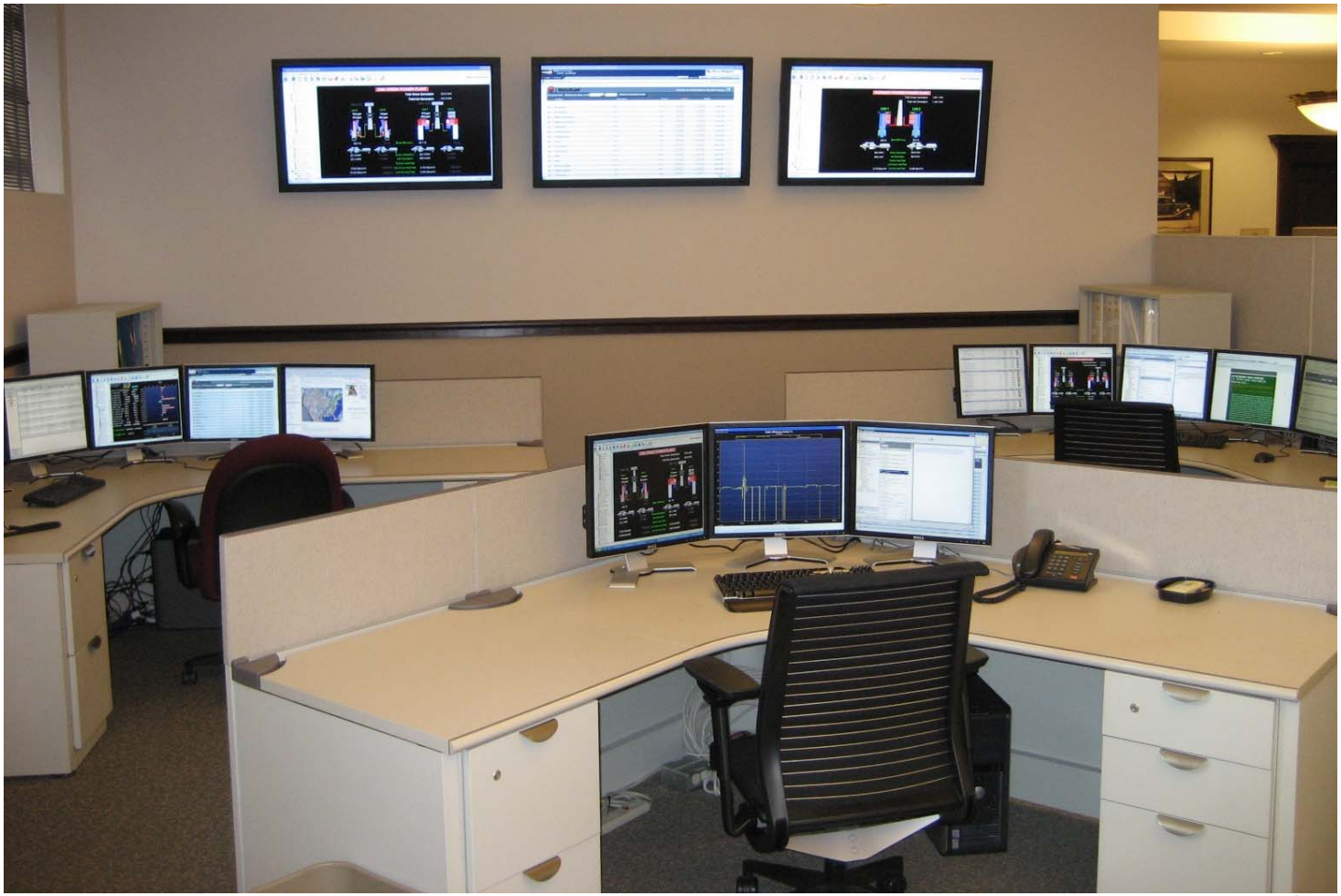
EPRI Support of Fleet Monitoring

Typical Monitoring Activities

- **Operations** staff monitor process variables
  - Pressure
  - Temperature
  - Flow
- **Maintenance** staff collect and analyze predictive maintenance data
  - Vibrations
  - Oil samples
  - Thermographs
- **Engineering** staff are challenged with assessing equipment health
  - Operations and maintenance information
  - Thermodynamic performance

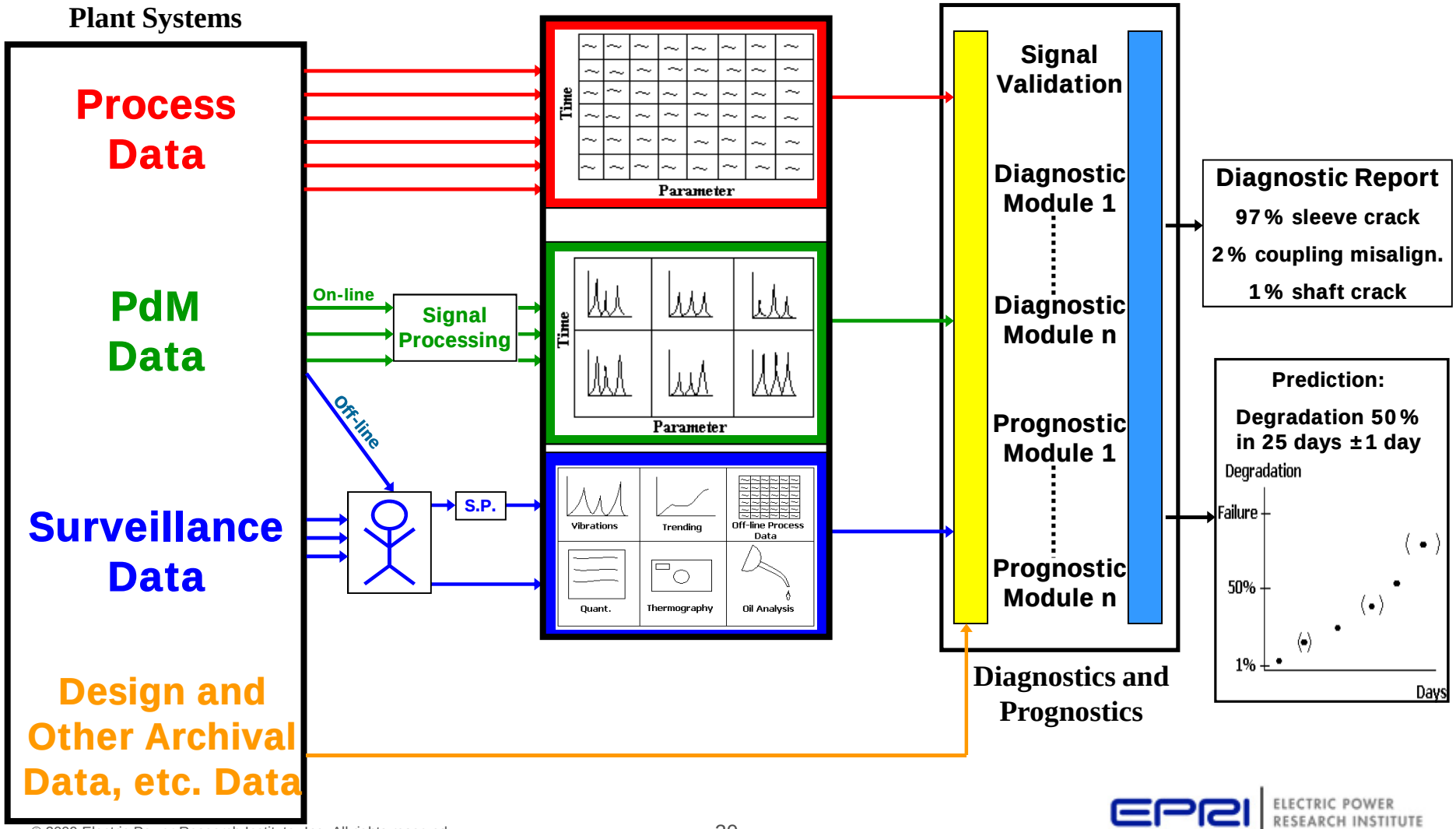
EPRI Support of Fleet Monitoring

Centralized Monitoring



EPRI Support of Fleet Monitoring

EPRI's Member Collaborative Group on Fleet Wide Monitoring



EPRI Support of Condition Monitoring

Predictive Maintenance Primer

- Guidance on establishing a PdM program.
- Training on the technologies
- How to establish limits
- Typical program outline of how communication of results should be accomplished

EPRI Support of Condition Monitoring

EPRI's Maintenance Guidelines

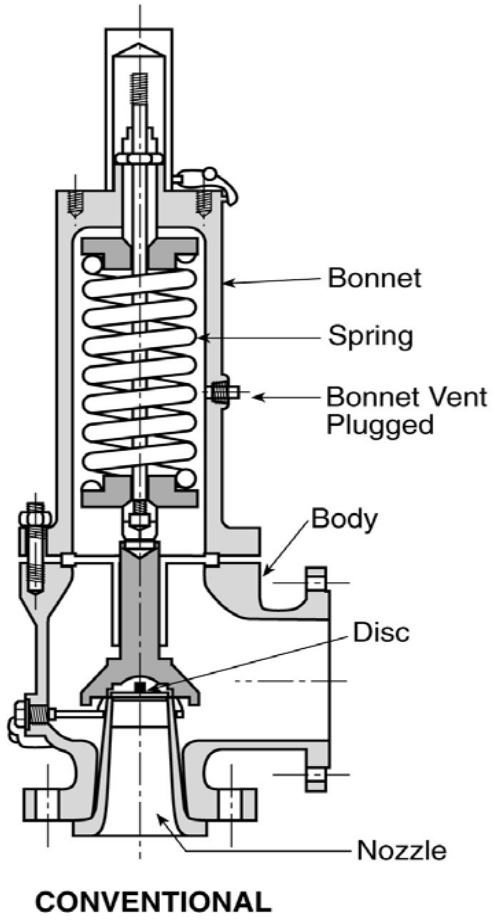
- Maintenance Application Centers' focus is to provide component-based information
- Introduce functional details that exceed most original equipment manufacturers', OEM, information
- Provide recommendations on cyclic maintenance and condition based maintenance routines that are based on acquired experience of many companies
- Preserve equipment knowledge for next generation workers

EPRI Support for O&M Reliability Activities

Maintenance Center Objectives

Support the plants to:

- **Reduce maintenance related O&M costs and improve equipment reliability**
- **Enhance equipment knowledge and provide a resource for training**
- **Supplement information needed for quality job planning and PM optimization**
- **Develop technical basis for outsourced maintenance specifications**



EPRI Support for O&M Reliability Activities

Typical Maintenance Guide Outline

Description

Applications

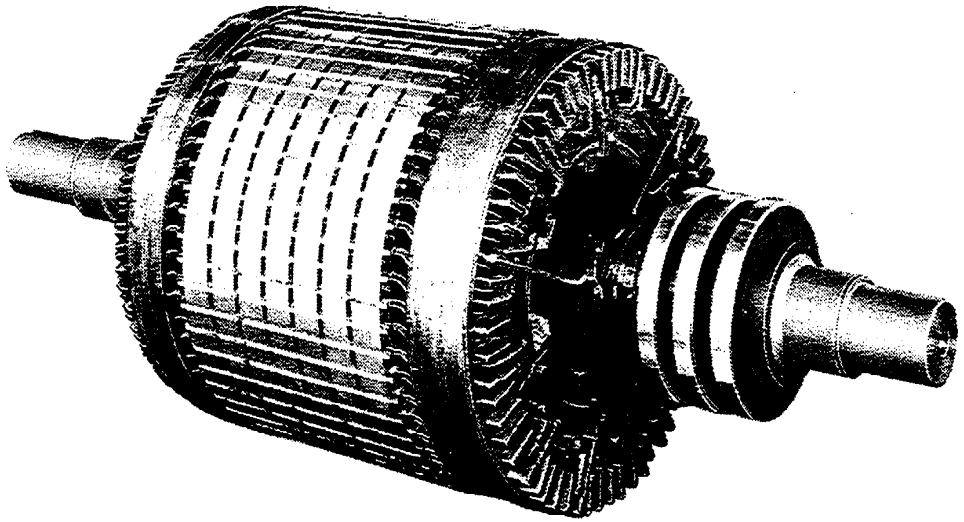
Failure Modes

Troubleshooting

PdM Cond, Tech

PM Freq, Basis

Special Tasks



EPRI Support for O&M Reliability Activities

Examples of PdM and PM Material

4
CONDITION MONITORING AND INSPECTION

4.1 Condition Monitoring of Gearbox Assemblies

Gearbox instrumentation can be furnished by the manufacturer to accommodate condition monitoring of certain performance parameters in the field. The following performance parameters can be monitored by plant personnel in accordance with the guidance discussed in this section:

- Temperature
- Oil pressure
- Noise and/or vibration
- Oil flow

Additionally, the condition monitoring of the lubricant furnished with the gearbox is critical to ensuring design performance.

4.1.1 Temperature Measurement

Temperature is an important indicator of the operation of any gear system. The actual point of measurement is determined by what performance characteristic the user is interested in monitoring.

On a splash-lubricated unit, housing temperature is a common concern for trouble-free operation. In a pressure-lubricated system, inlet and outlet oil temperatures will give a good indication of both the lubrication system and gearbox health. In critical and high-speed applications, the ability to determine the actual operating temperatures of the individual bearings, in addition to the previously discussed monitoring, is beneficial in determining changes in component health and potential future failures.

4.1.1.1 Thermometers

These are the simplest of all gearbox temperature-monitoring devices. They are usually used to report oil temperature in the gearbox supply or drain lines. Thermometers are slow to respond to changes and require visual examination and human input to evaluate the operational health of the gearbox.

5
PREVENTIVE MAINTENANCE

A complete preventive maintenance program for a gearbox should include the elements shown in Figure 5-1. The figure illustrates how a combination of visual inspections, condition monitoring, regular lubricant analysis, and lubricant change, all contribute to ensuring optimum performance of the equipment.

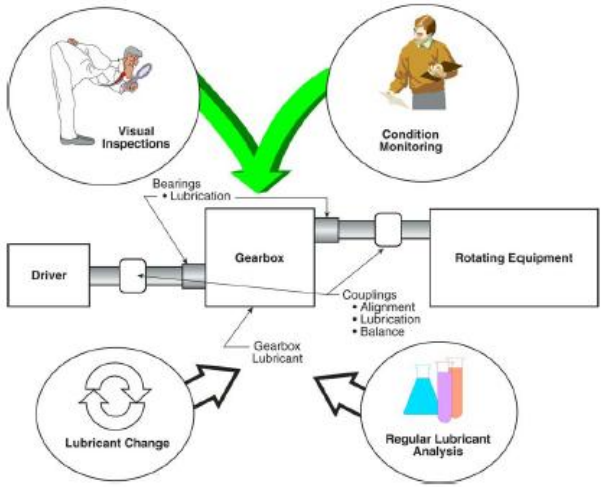


Figure 5-1
Elements of a Preventive Maintenance Program for Gearboxes
(Courtesy of Sequoia Consulting Group, Inc.)

Section 6 of this guide discusses several maintenance activities that require gearbox disassembly and would be performed in most cases to address a known failure or degraded gearbox performance.

EPRI Support for O&M Reliability Activities

Generic EPRI Gearbox PM Task List and Frequency

Frequency	PM Activities
Daily	Check oil temperature. Check oil pressure. Check for vibration. Check for excessive noise. Check for oil leaks.
Monthly	Check operation of auxiliary equipment. Check operation of alarms. Check for oil contamination.
Quarterly	Analyze oil sample.
Annually	Check bearing clearance and end-play. Check tooth contact pattern. Visually inspect couplings and check alignment. Inspect tags and labels showing replacement part numbers. Inspect safety warning signs and caution labels.

EPRI Support for O&M Reliability Activities

Generic EPRI Gearbox Inspection Criteria and Examples from the Guidelines

3.1.1 Wear

Wear is a term describing change to a gear tooth surface involving the removal or displacement of material due to mechanical, chemical, or electrical action. Figures 3-1 and 3-2 show mild and moderate mechanical wear. They are not intended to indicate the mode of wear.

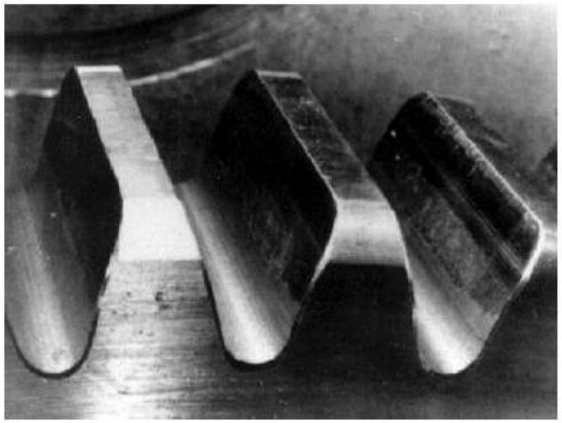


Figure 3-1
Mild Wear
(Courtesy of ANSI/AGMA 1010-E95)

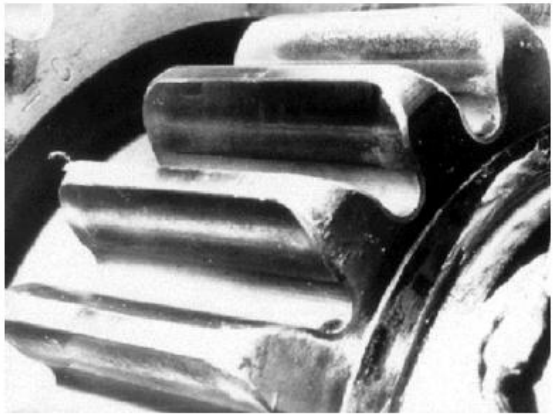


Figure 3-2
Moderate Wear
(Courtesy of ANSI/AGMA 1010-E95)

Explains and shows the inspectors what should be observed

EPRI Support for O&M Reliability Activities

Example of the Guideline Condition Monitoring Tasks

These examples are for the noise monitoring section of tasks that could be performed on gearboxes

The need to determine if all or any should be applied drove the development of the *Plant Maintenance Basis Database*

Sound	Features	Causes
Chatter	Noticeable at low speeds. Continuous at high speeds.	Bumping in cage pockets (insufficient lubricant). Eliminated by clearance reduction or pre-loading. Rollers bumping into each other on full-roller bearing.
Clang/Clatter	Metallic, loud bumping sound. Thin-section, large bearing at low speeds.	Bearing ring deformed. Grating of key.
Screech/Howl	Occurs mainly on cylindrical roller bearings. Sound changes with speed. Loud metallic sound that disappears temporarily when grease is added.	Large radial clearance. Poor lubrication or grease consistency.
Squeak	Metal-to-metal spalling sound. High pitch.	Spalling of roller and rib of roller bearing. Small clearance. Poor lubrication.
Squeal	Generated irregularly due to grating.	Slip on fitting surfaces. Grating on mounting seat, of key, and so on.
Faint tinkle	Irregular (not changing with speed). Primarily on small bearings.	Dust in bearing.
Rustle	Sound quality remains the same even if speed changes (dirt). Sound quality changes with speed (scoring).	Dirt. Raceway, ball, or roller surfaces are rough.
Rustle	Generated intermittently at regular intervals.	Chafing at the labyrinth. Contact of cage and seal.
Rustle patter	Regular and continuous at high speed.	Generated by retainer. Normal if sound is clear. Grease is inadequate if sound is generated at low temperatures (use soft grease). Wear of cage pockets. Insufficient lubricant. Low bearing load.
Growl	Continuous at high speeds.	Scoring on raceway, balls, or rollers.
Quiet Fizzing/Popping	Generated irregularly on small bearings.	Bursting sound of bubbles in grease.
Large sound pressure	Large sound pressure.	Rough raceway, roller, or ball surfaces. Raceway, rollers, or balls are deformed by wear. Large clearance due to wear.

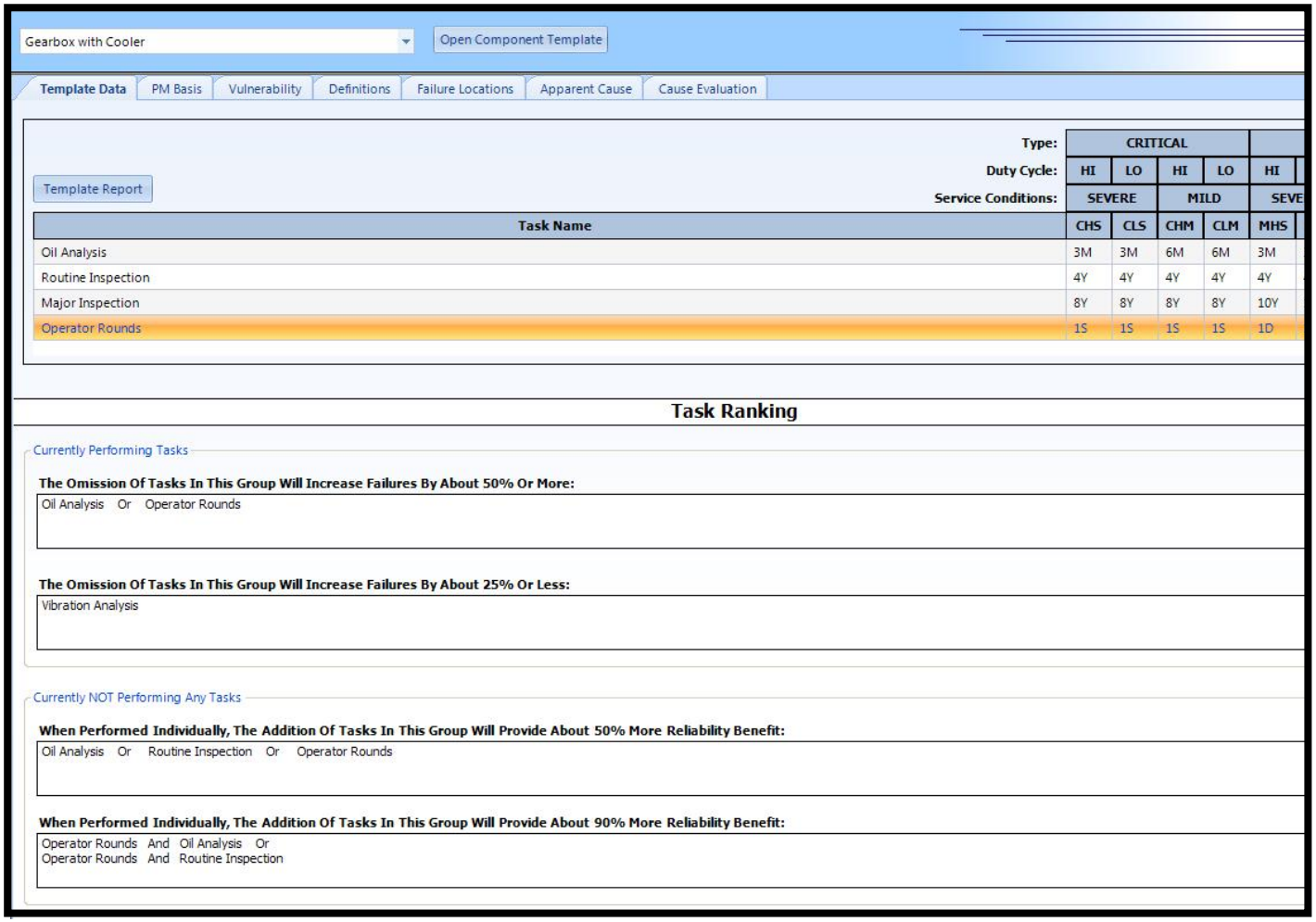
EPRI Support for O&M Reliability Activities

EPRI Plant Maintenance Database on Components

- Software to help the EPRI member to develop or update their PM Basis
- Uses OEM and Experience information
- Has a vulnerability analysis to determine impact of changes to PMBD
- Most of the base tasks and failure information comes from background information used to develop guidelines
- Used by Nuclear, Fossil, and Power Delivery groups within EPRI

EPRI Support for O&M Reliability Activities

EPRI Plant Maintenance Database



Gearbox with Cooler

Open Component Template

Template Data | PM Basis | Vulnerability | Definitions | Failure Locations | Apparent Cause | Cause Evaluation

Template Report

Task Name	Type:	CRITICAL				
	Duty Cycle:	HI	LO	HI	LO	HI
	Service Conditions:	SEVERE		MILD		SEVE
		CHS	CLS	CHM	CLM	MHS
Oil Analysis		3M	3M	6M	6M	3M
Routine Inspection		4Y	4Y	4Y	4Y	4Y
Major Inspection		8Y	8Y	8Y	8Y	10Y
Operator Rounds		1S	1S	1S	1S	1D

Task Ranking

Currently Performing Tasks

The Omission Of Tasks In This Group Will Increase Failures By About 50% Or More:

Oil Analysis Or Operator Rounds

The Omission Of Tasks In This Group Will Increase Failures By About 25% Or Less:

Vibration Analysis

Currently NOT Performing Any Tasks

When Performed Individually, The Addition Of Tasks In This Group Will Provide About 50% More Reliability Benefit:

Oil Analysis Or Routine Inspection Or Operator Rounds

When Performed Individually, The Addition Of Tasks In This Group Will Provide About 90% More Reliability Benefit:

Operator Rounds And Oil Analysis Or
Operator Rounds And Routine Inspection

Templates

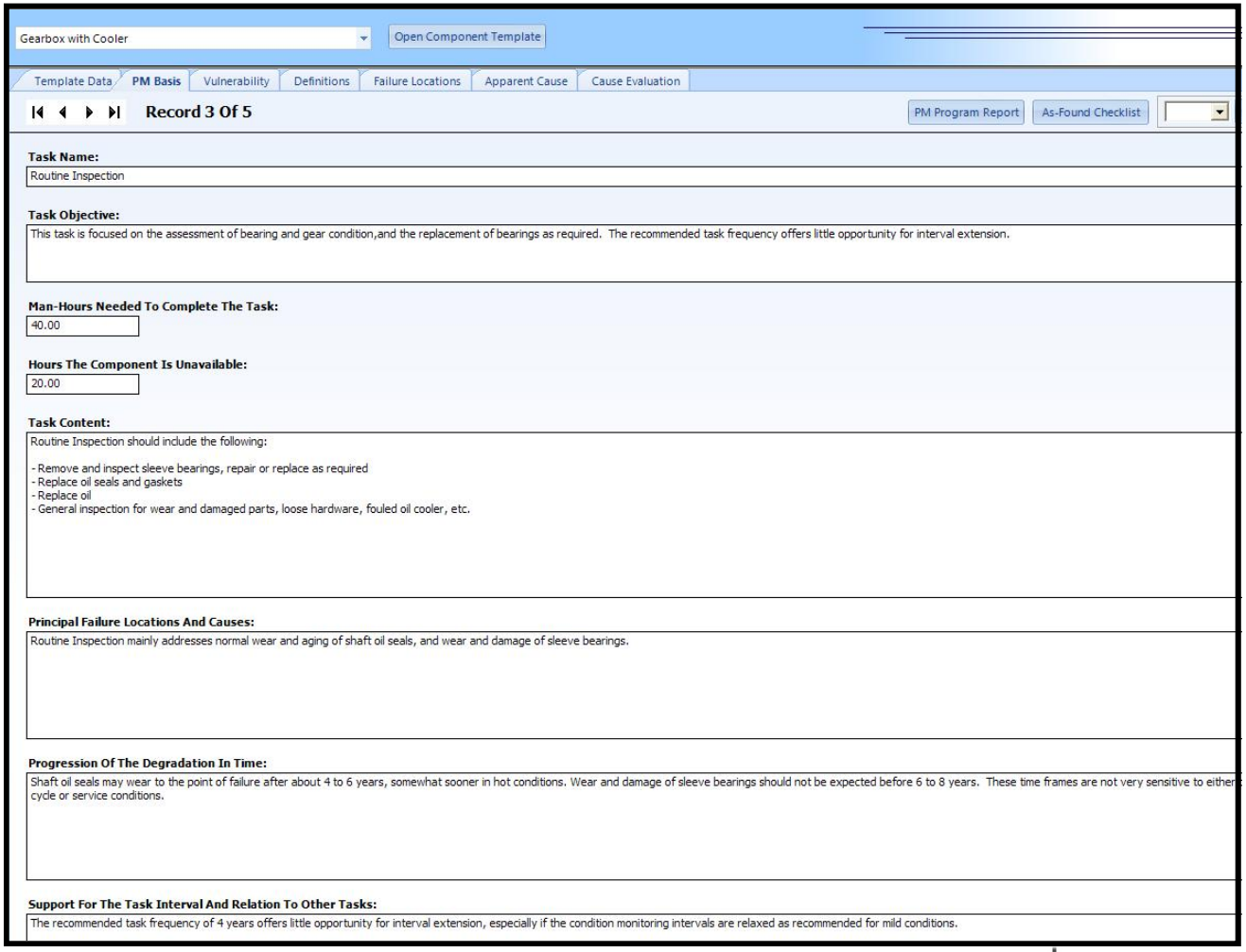
- Component based
- List all tasks
- Establishes the importance
- Intervals are related to:
  - Criticality
  - Duty Cycle
  - Conditions
- Example is for a gearbox with cooler system

EPRI Support for O&M Reliability Activities

EPRI Plant Maintenance Database

Task Basis

- Background info on the task
- Ensures understanding of task
- Allows intelligent changes to be made
- Reflects links to other tasks

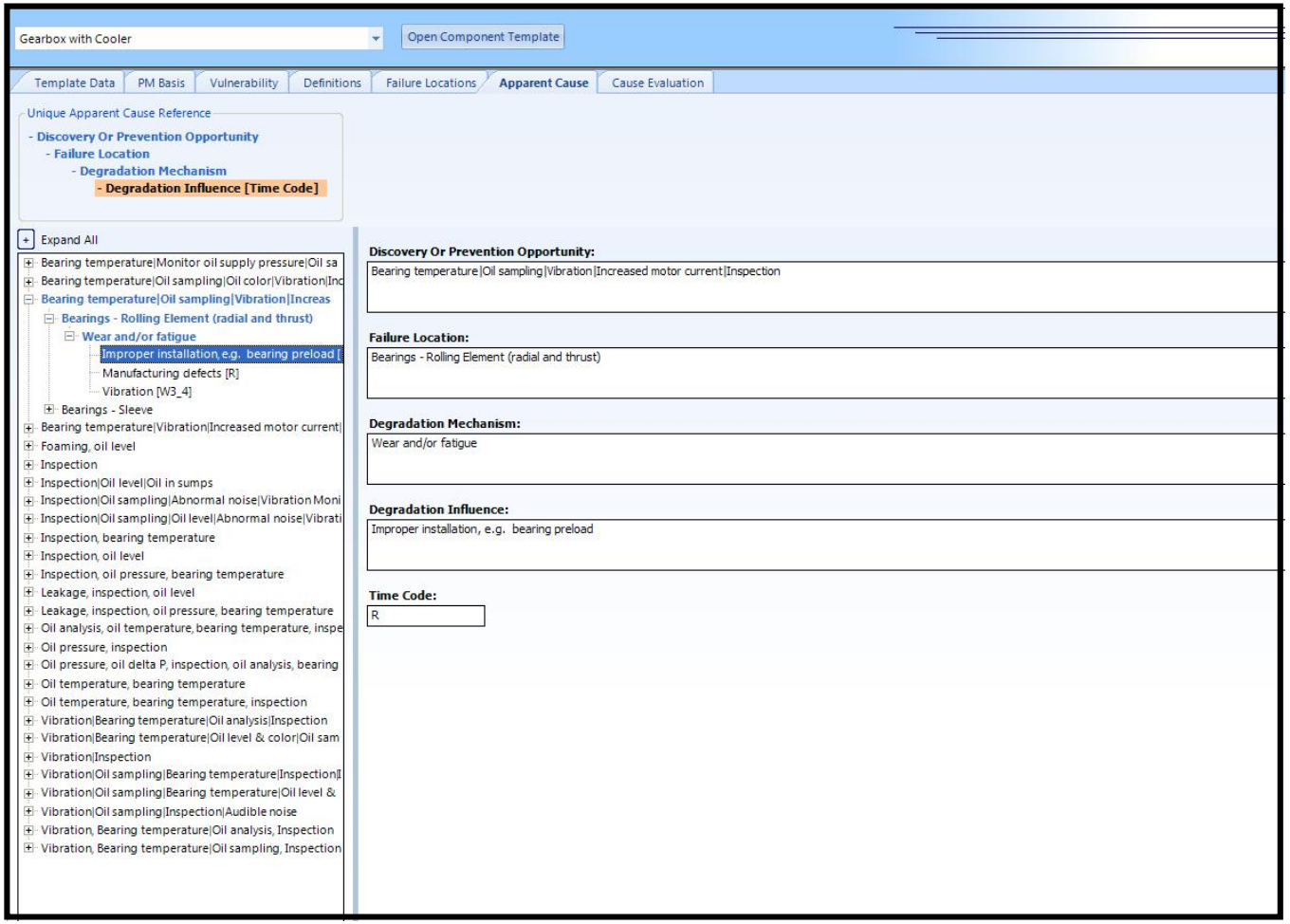


EPRI Support for O&M Reliability Activities

EPRI Plant Maintenance Database

Apparent Cause

- List all potential causes
- Causes are linked to barriers
- Barriers develop into tasks



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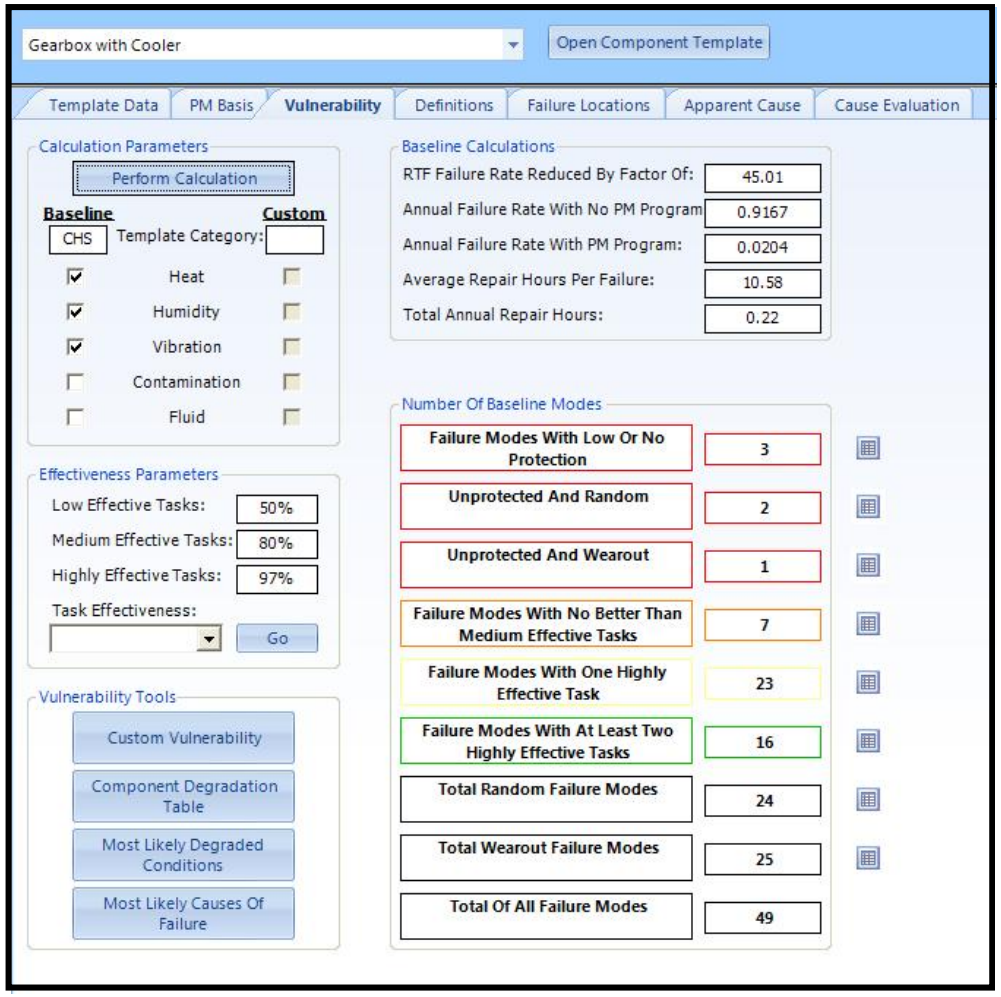
EPRI Support for O&M Reliability Activities

EPRI Plant Maintenance Database

Vulnerability Analysis

- Allows users to do what if's in selection of tasks
- Can also change categories from severe to mild or critical or noncritical
- Change stressors
- Review failure modes
- Allows intelligent decisions



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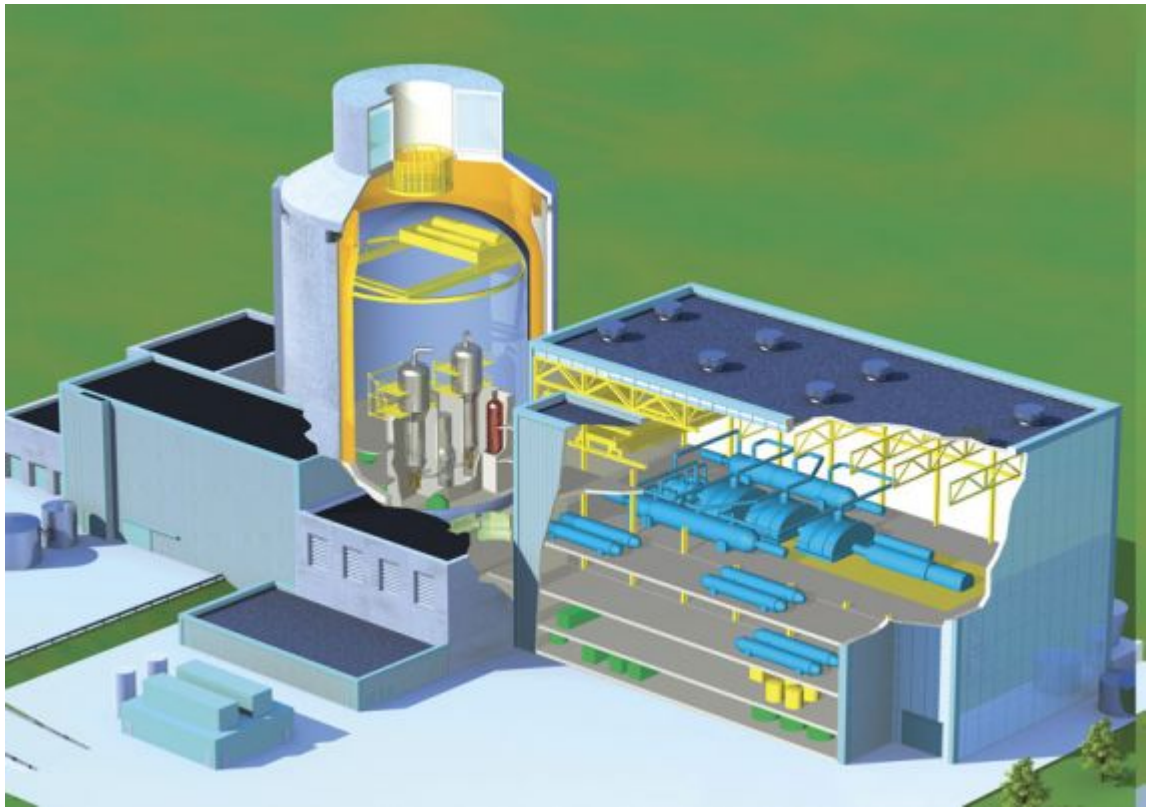
EPRI Support for O&M Reliability Activities



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