

Resource Guide for Technology Transfer to the Pulp and Paper Industry

Part 4: Power Plant Maintenance and Repair



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REPORT SUMMARY

In response to requests from EPRI's member utilities, EPRI's Pulp, Paper and Forest Products Office has developed a Resource Guide for technology products related to that industry. The Resource Guide contains an initial listing of technical reports, software, and products associated with power plant maintenance and repair as found in the EPRIWeb electronic database. These products are arranged to provide the reader with a quick evaluation of each item for applicability to the reader's specific needs.

Background

EPRI established the Pulp, Paper and Forest Products Office (PPFPO), a national research and development (R&D) applications office, to service the needs of EPRI-member utilities and their customers. The office is hosted by the Institute of Paper Science and Technology (IPST) and supported by an R&D contract managed by EPRI's Industrial and Agricultural Business area in EPRI's Retail Market Segment.

The PPFPO office has critically reviewed the EPRI research database for products relative to the pulp, paper and forest products industry. This is the fourth Resource Guide in a series that was developed using information derived from this review process.

Previous reports include:

- Part 1: Environmental Resources
- Part 2: Corrosion/Erosion/Scaling and Control
- Part 3: Power Plant Efficiency and Optimization

Objectives

To provide a way for EPRI's member utilities and their customers to quickly and easily locate information about electrotechnology products related to specific areas of interest within the pulp and paper industry.

To provide an evaluation of each product in order to help EPRI's member utilities and their customers decide which technologies are most appropriate to address specific needs.

Approach

Products are grouped into major categories within the Resource Guide. The Table of Contents is organized to allow the reader to quickly scan it and choose topic headings. Individual product titles guide the reader to specific products of interest. Each product description contains a standardized summary of the product's features, applications, and benefits, together with computer requirements (if any) and the listed EPRI business group responsible for its development.

Results

Readers can request copies of the products listed in the resource guide from the EPRI Pulp, Paper and Forest Products Office. Non-utility readers should contact their electric utility company representative to order products. The EPRI Pulp, Paper and Forest Product Office will make the necessary contact and arrangements to access the requested information.

EPRI Perspective

EPRI's Pulp, Paper and Forest Products Office (PPFPO) is devoted to facilitating the development and proliferation of electrotechnologies for the pulp, paper and allied industries in the United States. This report reflects EPRI's continuous dedication to their member utilities and is a response to the expressed needs of these members. EPRI believes that this report will help its member utilities to determine which technologies are most appropriate for them to market to their customers in the pulp and paper industries.

Key Words

Maintenance

Predictive Maintenance

Preventive Maintenance

Repair

Diagnostics

Welding Techniques

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BACKGROUND AND INTRODUCTION

The Electric Power Research Institute (EPRI) is a research and development institute financially supported by member United States electric utility companies numbering some 700. As a result, EPRI manages and conducts a research, development and demonstration program on a scale far greater than any single utility can afford. The scope of EPRI's research projects range widely across technologies related to the generation, delivery, uses, and environmental consequences of electricity. At any given time, more than 1600 projects under EPRI management are being pursued at hundreds of individual organizations—mainly industrial and commercial firms, universities, utilities, and government laboratories.

The Process Industry Office for Pulp, Paper and Forest Products Industries (PPFP) is a national research and development (R&D) applications office established by EPRI to serve the needs of EPRI-member utilities and their customers. Supported by an R&D contract managed by EPRI's Industrial Program in the Customer Systems Group, the office is hosted by the Institute of Paper Science and Technology (IPST). Located in Atlanta, Georgia, IPST is the preeminent research and teaching institution for the United States pulp, paper and allied industries.

The EPRI research, development and demonstration program is structured into five (5) product sectors as follows:

- Environmental
- Generation
- Retail
- Power Delivery
- Nuclear

Documentation of EPRI Research

To facilitate effective technology transfer, research results are presented via a number of different publications, software and hardware packages. The following materials provide an archive of EPRI results.

- Technical reports on individual research projects. Over the years, EPRI has published over 10,000 such reports and some 900 new reports each year.
- Report Summaries are issued as new research results are published.
- Software products provide a computer-based problem solving tool for utility companies and their customers to derive more benefit from EPRI research.

- Hardware products, such as bundled workstations, provide EPRI software preloaded into a PC so that a utility company member can access faster EPRI's technology transfer program.

EPRIWeb provides electronic access to abstracts of projects, publications and products.

EPRI Products

EPRI product books are one of a number of facilitating systems for effective technology transfer, and provide a direct path to information by pulling together the various individual research of deliverables into a single entity, or product. Some products may involve as many as 10-12 reports published over several years, while others may consist of a single publication, such as a handbook. The format identifies the problem addressed by the product and explains how application of the product leads to a solution and resulting benefits. The user can judge quickly whether a product might be applicable to a particular situation and where to find additional information.

These products include hardware, process technology, computer software, test methodologies, how-to manuals, design guidelines, diagnostic techniques, databases, state-of-the-art assessments, scientific findings and meet three important criteria: (1) they are ready and available for immediate application; (2) they meet a need of utility operations, and (3) literature on their development and use is available. Whether applied directly by a utility or its customer or indirectly on a utility's behalf, these products yield explicit benefits that are usually quantifiable in financial terms.

Technology Transfer to the Pulp and Paper Industry

In response to the desire of member utility companies, the EPRI Pulp, Paper and Forest Products Office has undertaken a critical review of the EPRI research database for products deemed likely applicable to the pulp, paper and forest products industry.

This resource guide book contains an initial listing of technical reports, software and products associated with power plant maintenance and repair as found in the EPRIWeb electronic database. These are arranged to provide the pulp and paper industry user with a quick evaluation of each item for applicability to the user's specific needs with the needed references for accessing.

Part 1 Environmental Resources was published in December 1996.

Part 2 Corrosion/Erosion/Scaling and Control was published in September 1997.

Part 3 Power Plant Efficiency and Optimization was published in March 1999.

Part 4 Power Plant Maintenance and Repair was published in March 2000.

Future resource guide inclusion are planned for the following topics:

- Power System Protection
- Transmission and Distribution

- Power Electronics and Control
- Plant/Component Design and Specifications
- Combustion Turbine/Combined-Cycle Plants
- Hydroelectric Systems
- Water Management
- Advanced Fossil Fuel Power Plants
- Pulp and Paper Industry Projects

How to Use This Resource Guide

Resource documents are grouped into major categories. The user can quickly scan and choose topic headings from the Table of Contents. Titles of the individual documents will guide the user to specific products of interest.

Each document description is a standardized summary of the document's features, applications, and benefits, together with computer requirements (if any) and the listed EPRI business group responsible for its development.

The Table of Contents lists documents under each major category with the page numbers.

Pulp and paper industry users desiring access to a particular document(s) need only contact the electric utility company representative serving the user's mill giving the document number, name, and EPRI business group listed. The utility company representative will then arrange for transfer of the desired document and related information.

Utility Company representatives, upon receipt of a product request from a pulp and paper industry customer, should contact:

EPRI Pulp, Paper and Forest Products Office
Institute of Paper Science and Technology
500 Tenth Street N. W.
Atlanta, Georgia 30318-5751
Phone: (404) 894-5751

Following a request from a utility company representative, the EPRI Pulp, Paper and Forest Products Office will make the necessary contacts and arrangements for accessing the requested information.

It should be noted that some of the EPRI documents listed may involve patented or commercialized products and there may be some associated costs and/or licensing requirements. Any related cost and/or licensing information will be made available at the time of a request.

2

DIAGNOSTICS

Diagnostic Monitoring Products Guide: Volume 1 AP-101840-V1

DETAILS: Products Guide (Vol. 1-177 pages)

DATE: Dec. 1992

KEYWORDS: Diagnostic Techniques
Monitoring
Technology Utilization
Fossil-Fuel Power Plants
Nuclear Power Plants
Predictive Maintenance

ABSTRACT:

This products guide focuses on effective, field-proven diagnostic monitoring technologies, which are suitable for use in predictive maintenance programs at fossil-fired plants and several can be used at nuclear plants. A “Product Profile” and “Technology Review” are provided for each of the monitoring systems and techniques covered in this first release of the Guide. A Product Profile provides high-level descriptions of diagnostic monitoring products, and includes concise information of product features, benefits derived from using the product, utility users, vendors, the price of the products, and, when available, installation and operating costs. Technology Reviews include all the information offered in the Product Profiles, but give more detailed accounts, make extensive use of illustrations, and list other publications that may interest readers. Technology Reviews also discuss principles of science and engineering underlying specific products.

EPRI BUSINESS GROUP: Energy Conversion Division

**Acoustic Gas Temperature Monitors: 1992 Product Profile Set From the Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P1**

DETAILS: Product Profile (Vol. 1-2 pages)

DATE: Dec. 1992

KEYWORDS: Acoustic Monitoring
Temperature Monitoring
Tools
On-line Measurement Systems
Gas Analysis
Furnaces

ABSTRACT:

This product profile features acoustic gas temperature monitors, which are acoustic practical tools for on-line continuous measurement of gas temperatures in hostile environments. They can give measurements of furnace gas temperatures not available before, and prepare two- and three-dimensional temperature profiles that make it easy to locate “hot spots” and “cold spots” in a furnace.

Useful both in diagnosis and operation, data provided by these systems can help boiler operators avoid temperature excesses, which shorten component life, and improve adjustment of controls that influence combustion efficiency and the need for sootblowing.

EPRI BUSINESS GROUP: Energy Conversion Division

**Boiler Tube Leak Detection System: 1992 Product Profile Set From the
Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P2**

DETAILS: Product Profile (Vol. 2-2 pages)

DATE: Dec. 1992

KEYWORDS: Boiler Tubes
Leak Detectors
Shutdown
Outages
Monitoring
Maintenance Costs

ABSTRACT:

This Product Profile features boiler tube leak detection systems. Until recently, utilities had no reliable means of detecting boiler tube leaks early enough to respond effectively. More than 80% of boiler tube failures forced unit shutdowns, and these failures were the leading cause of forced outages in fossil-fired units.

Boiler tube leak detection (BTLT) systems can detect boiler tube leaks early. With these systems, utilities can locate leak sources, assess leak severity, and monitor leak growth. As a result, utilities can avert forced outages and schedule repair work to minimize power replacement costs.

EPRI BUSINESS GROUP: Energy Conversion Division

**Ferrography-Based Wear Monitors: 1992 Product Profile Set From the
Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P4**

DETAILS: Product Profile

DATE: Dec. 1992

KEYWORDS: Wear
Analysis
Rotating Machinery
Maintenance Costs
Failures
Lubricants

ABSTRACT:

Ferrography-Based Wear Monitors are the subject of this Product Profile. A method of analyzing wear particles suspended in lubricants, ferrography can detect particles that remain undetected by other wear-analysis methods.

When used to examine the size-distribution, concentration, composition, and shape of metal particles present in lube oil, as well as the rate of particle-generation, ferrographic techniques can indicate the onset of abnormal wear and help determine the cause and severity of machine wear. By using ferrography to monitor the condition of rotating equipment, users can reduce maintenance costs, improve maintenance scheduling, and avoid machinery failures.

EPRI BUSINESS GROUP: Energy Conversion Division

**Generator Expert Monitoring System: 1992 Product Profile Set From the Diagnostic Monitoring Products Guide – Volume 1
AP-101840-VIP5**

DETAILS: Product Profile (Vol. 1-12 pages)

DATE: Dec. 1992

KEYWORDS: Monitoring
Software Tools
Data Analysis
Sensors
Diagnostic Techniques
Computers

ABSTRACT:

The focus of this Product Profile is Generator Expert Monitoring System (GEMS) software, which interprets sensor data and provides both detailed diagnoses of developing generator problems and recommendations for corrective action. A stand-alone system designed to run on dedicated computers installed in control rooms, GEMS can use input from any number of sensors, has no minimum requirement list of sensors, correlates sensor data in real time, and cycles fast enough for the operator and shift supervisor to take recommended action. Users can configure GEMS to work with generators and auxiliaries from all generator manufacturers.

EPRI BUSINESS GROUP: Energy Conversion Division

**Metal-Loss Monitoring System: 1992 Product Profile Set From the
Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P6**

DETAILS: Product Profile (Vol. 1-2 pages)

DATE: Dec. 1992

KEYWORDS: Metals
Erosion
Corrosion
Wear
Life Extension
Monitoring

ABSTRACT:

This Product Profile features metal-loss monitoring systems. Metal loss or wastage in power plants—caused by solid particle erosion, corrosion, and wear—limits the life of many components, including turbine blades and nozzles, bearings, valves, and boiler tubes. Until recently, few methods were available for detecting material loss from critical surfaces—and none could accurately determine the condition of steam turbine components on-line.

On-line wastage monitoring techniques based on the principle of surface layer activation (SLA) provide accurate data on the metal-loss rate and the pattern of metal loss in key steam turbine and boiler components. Using these techniques, users can replace worn parts or take corrective actions before in-service failures occur.

EPRI BUSINESS GROUP: Energy Conversion Division

**MUSYC Corrosion Monitoring System: 1992 Product Profile Set From the Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P7**

DETAILS: Product Profile (Vol. 1-2 pages)

DATE: Dec. 1992

KEYWORDS: Corrosion Monitoring
Corrosion
Fossil-Fuel Power Plants
Data Acquisition
Data Analysis
Probes

ABSTRACT:

This Product Profile features the MUSYC Corrosion Monitoring System, which is an advanced electrochemical corrosion-monitoring system (Multitechnique System for continuous Corrosion surveillance). The system provides important new corrosion-monitoring capabilities, valuable to fossil-fired power plants where corrosion is a prominent problem. The system is particularly useful in the thin condensate films, where conventional monitors cannot function.

EPRI BUSINESS GROUP: Energy Conversion Division

**Periodic Vibration-Monitoring Systems: 1992 Product Profile Set From the Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P8**

DETAILS: Product Profile (Vol. 1-2 pages)

DATE: Dec. 1992

KEYWORDS: Vibration
Rotating Machinery
Outages
Predictive Maintenance
Availability
Monitoring

ABSTRACT:

Vibration problems in rotating machinery are a primary cause of load reductions and forced outages at power plants. Now, using new periodic vibration-monitoring equipment, users can implement predictive maintenance programs with significantly reduced manpower and capital investments while increasing unit availability, avoiding forced outages, and minimizing equipment damage. The new periodic vibration-monitoring systems consist of integrated hardware and software packages that use host computers for data storage and diagnostic analysis, and portable, “intelligent”, microprocessor-based devices for collecting survey data. The host computer executes software capable of performing a variety of database-management functions, data retrieval and display, and engineering analysis. This report profiles this product, its features and benefits.

EPRI BUSINESS GROUP: Energy Conversion Division

**Plant Monitoring Workstation: 1992 Product Profile Set From the
Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P9**

DETAILS: Product Profile (Vol. 1-2 pages)

DATE: Dec. 1992

KEYWORDS: Monitoring
Workstations
Software Tools
Performance Evaluation
Fossil-Fuel Power Plants
Instrumentation

ABSTRACT:

This Product Profile examines EPRI's Plant Monitoring Workstation (PMW), which is an easy-to-use software package designed to monitor, track, trend, troubleshoot, and report on performance of fossil-fired power plants. Using performance monitoring data obtained through plant instrumentation, PMW can help lower heat rates, achieve economic unit dispatch, increase unit availability, and to improve maintenance programs.

EPRI BUSINESS GROUP: Energy Conversion Division

**Rotor Balancing Software System: 1992 Product Profile Set From the
Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P10**

DETAILS: Product Profile (Vol. 1-2 pages)

DATE: Dec. 1992

KEYWORDS: Rotors
Rotating Machinery
Software Tools
Efficiency
Inspection
Computer Codes

ABSTRACT:

This product Profile examines rotor balancing software systems. Most-higher performance rotating machines as well as those that operate in hostile environments require periodic balancing. The sophistication of the balancing approach required for these machines varies greatly and encompasses the range from simple single-plane, single-speed balancing to complex multiplane, multispeed balance “shots”. EPRI has developed and field-tested a powerful multiplane, multispeed balancing code for power plant applications. The code is a key part of EPRI’s ROBAL (Rotor Balancing) software system, a state-of-the-art package that provides an efficient and easy-to-use solution to utility balancing problems.

EPRI BUSINESS GROUP: Energy Conversion Division

**Ultrasonic Bearing-Wear Monitor: 1992 Product Profile Set From the
Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P11**

DETAILS: Product Profile (Vol. 1-2 pages)

DATE: Dec. 1992

KEYWORDS: Bearings
Failures
Steam turbines
Outages
Monitoring
Wear

ABSTRACT:

For years, bearing failures have been a leading cause of forced outages on large steam turbine generating units. To avoid these costly outages, utilities often incur significant costs associated with unnecessary inspections and premature bearing replacements. Now, a bearing-wear monitoring system based on ultrasonic technology provides highly accurate information on the location and extent of the wear problem, enabling users to reduce inspection costs, and to avoid equipment damage and forced outages. This Product Profile features ultrasonic bearing-wear monitors.

EPRI BUSINESS GROUP: Energy Conversion Division

**Acoustic Gas Temperature Monitors: From the Diagnostic Monitoring
Products Guide – Volume 1
AP-101840-V1P12**

DETAILS: Product Profile (Vol. 1-12 pages)

DATE: Dec. 1992

KEYWORDS: Acoustics
Temperature
Monitoring
Instrumentation
Measurement
Temperature Measurement

ABSTRACT:

The following topics are highlighted in this Technology Review of acoustic gas temperature monitors: Acoustic pyrometry systems are practical tools for on-line continuous measurement of gas temperatures in hostile environments; Acoustic pyrometry systems can represent temperature distributions over an entire plane or volume of interest and give measurements of gas temperatures not available before; Useful in diagnosis and operation, acoustic pyrometry systems enable users to improve control of boiler startups, increase the effectiveness of sootblower operation and of temperature-dependent emissions control processes, correct burner problems, and extend component life. In use at several utilities, acoustic pyrometry systems are available from at least four vendors.

EPRI BUSINESS GROUP: Energy Conversion Division

**Acoustic Leak Detection for Boiler Tubes: From the Diagnostic Monitoring
Products Guide – Volume 1
AP-101840-V1P13**

DETAILS: Product Profile (Vol. 1-12 pages)

DATE: Dec. 1992

KEYWORDS: Boiler Tubes
Leak Detectors
Steam
Maintenance Costs
Preventive Maintenance
Acoustic Monitoring

ABSTRACT:

Acoustic leak detector systems can spot small leaks in boiler tubes not detectable by normal means. They are designed to detect the sound of expanding steam as it escapes through even the smallest hole. These systems identify the general location of leaks within the boiler. Advanced warning of noncatastrophic leaks hours or days before they become larger may allow operators to shut the plant down at a convenient time. As a result, users can minimize damage to adjacent tubes and reduce maintenance and replacement power costs. This report reviews the technology of acoustic leak detection for boiler tubes.

EPRI BUSINESS GROUP: Energy Conversion Division

**Continuous Vibration-Monitoring Systems: From the Diagnostic Monitoring Products Guide – Vol. 1
AP-101840-V1P14**

DETAILS: Technology Review (Vol. 1-8 pages)

DATE: Dec. 1992

KEYWORDS: Vibration
Monitoring
Rotating Machinery
Turbines
Data Analysis
Data Acquisition

ABSTRACT:

Thirty to fifty percent of all fossil plant downtime is caused by the failure of such rotating equipment as turbine generators, pumps, and fans. This downtime is very expensive, often costing more than \$250,000 pr day for a 500-MW plant. Condition monitoring can improve anticipation of rotating-equipment failures and help reduce outage costs significantly.

This Technology Review offers highlights of continuous vibration-monitoring systems, such as: provide automated acquisition, storage, and interpretation of dynamic data; provide significant fault-warning and diagnostic capabilities; increase the reliability and availability of turbine generators and other critical equipment, improve maintenance planning and machinery protection, and avoid costly forced outages and; enable vibration analysts at central facilities to remotely monitor critical machinery and to bring expert advice to bear on vibration problems.

EPRI BUSINESS GROUP: Energy Conversion Division

**Lube Oil Ferrography for Wear-Particle Analysis: From the Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P15**

DETAILS: Technology Review (Vol. 1-12 pages)

DATE: Dec. 1992

KEYWORDS: Lubricants
Wear
Analysis
Rotating Machinery
Predictive Maintenance
Vibration
Wear-Particle Analysis
Ferrography

ABSTRACT:

This Technology Review examines lube oil ferrography for wear-particle analysis. The following are highlights of this technique: ferrographic techniques can detect particles undetected by other wear-analysis methods, and can help determine the cause and extent of equipment deterioration; by using ferrography to monitor the condition of rotating equipment, users can reduce maintenance costs, improve maintenance scheduling, and avoid machinery failures; over two dozen U.S. utility companies own ferrographic equipment and use it to perform wear-particle analyses at their facilities and; a wear-particle “atlas” has been incorporated in software that facilitates analytical ferrography diagnoses.

This Technology Review also discusses the different kinds of ferrography, procedural controls, user applications of this technique, and gives commercial information.

EPRI BUSINESS GROUP: Energy Conversion Division

**Generator Expert Monitoring System: From the Diagnostic Monitoring
Products Guide – Volume 1
AP-101840-V1P16**

DETAILS: Technology Review (Vol. 1-12 pages)

DATE: Dec. 1992

KEYWORDS: Monitoring
Expert Systems
Data Analysis
Failures
Outages
Maintenance

ABSTRACT:

This Technology Review focuses on Generator Expert Monitoring Systems (GEMS). The system is described in detail, including it's components and capabilities, the software system, and user applications. The highlights of the system include: designed specifically to address the needs of utility industry generator operators. GEMS interprets sensor data and provides station operators with both detailed diagnoses of developing generator problems and recommendations for corrective action; GEMS software is a stand-alone system designed to run on dedicated computers installed in control rooms; GEMS works with the generator sensors that are in common use today and can easily be installed on generators from all major generator manufacturers and; two utility companies are using prototype GEMS software on large turbine generators.

EPRI BUSINESS GROUP: Energy Conservation Division

**Periodic Vibration-Monitoring Systems: From the Diagnostic Monitoring
Products Guide – Volume 1
AP-101840-V1P19**

DETAILS: Technology Review (Vol. 1-12 pages)

DATE: Dec. 1992

KEYWORDS: Vibration
Monitoring
Software Tools
Computers
Predictive Maintenance
Outages

ABSTRACT:

Because of the relationships between vibration patterns and certain machinery defects, it is possible to correlate spectral analyses (and other vibration data and analyses) directly with the causes of malfunctions. As a result, the use of vibration measurements and dynamic analyses for diagnosing problems with rotating equipment has become standard practice in many power plants.

This Technology Review focuses on periodic vibration-monitoring systems, highlighting the following features:

- Using an integrated system that includes a portable, microprocessor-based data collector, a desktop computer, and data-management and analysis software, a user can cost-effectively monitor vibration periodically in a large array of plant equipment.
- Use of integrated hardware/software packages for periodic vibration monitoring forms a solid starting point for predictive maintenance programs, in which maintenance decisions are based on actual equipment condition.
- Predictive maintenance efforts, which often integrate several monitoring techniques, can help increase unit availability, avoid forced outages, minimize equipment damage, and reduce maintenance costs.
- Expert-system-based software, designed for use with portable vibration-monitoring equipment, can now automate advanced diagnosis of vibration problems.

EPRI BUSINESS GROUP: Energy Conversion Division

**On-Line Ultrasonic Monitoring of Bearing Wear: From the Diagnostic Monitoring Products Guide – Volume 1
AP-101840-V1P22**

DETAILS: Technology Review (Vol. 1-12 pages)

DATE: Dec. 1992

KEYWORDS: Outages
Failures
Bearings
Wear
Ultrasonic Testing
Technology Utilization

ABSTRACT:

This Technology Review focuses on an on-line ultrasonic monitoring of bearing wear which has been developed that has an operational accuracy of ± 0.0002 inch. This level of accuracy indicates a diagnostic ability far more sensitive to wear than indirect techniques such as vibration monitoring. In addition, such a system gives information on the location as well as the extent of the wear problem. Further, the ultrasonic technique reduces inspection costs, and eliminates the risk of improper reassembly that may accompany inspections. This review also includes information about current applications and experience with bearing monitoring.

EPRI BUSINESS GROUP: Energy Conversion Division

**1992 Products Profile Set: From the Diagnostic Monitoring Products
Guide – Volume 1
AP-101840-V1P23**

DETAILS: Product Profile (Vol. 1-28 pages)

DATE: Dec. 1992

KEYWORDS: Temperature Monitoring
Detection
Vibration
Monitoring
Corrosion Monitoring
Software Tools

ABSTRACT:

This product set profiles the following items: Acoustic Gas Temperature Monitors; Boiler Tube Leak Detection System; Continuous Vibration Monitors; Ferrography-Based Monitors; Generator Expert Monitoring System; Metal-Loss Monitoring System; MUSYC Corrosion Monitoring System; Periodic Vibration-Monitoring Systems; Plant Monitoring Workstation; Rotor Balancing Software System; and Ultrasonic Bearing-Wear Monitor. Product profiles are addressed to user personnel wanting quick overviews of the products. The profile contains concise information on product features, benefits derived from using the product, utility industry users, vendors, the price of the product, and, when available, installation and operating costs.

EPRI BUSINESS GROUP: Energy Conversion Division

Diagnostic Monitoring Products Guide – Volume 2; Volume 3
AP-101840-V2
AP-101840-V3

DETAILS: Products Guide (Vol. 2-130 pages; Vol. 3-108 pages)

DATE: Dec. 1993

KEYWORDS: Diagnostic Techniques
Monitoring
Technology Assessment
Operating Costs
Maintenance Costs
Installation

ABSTRACT:

EPRI's Diagnostic Monitoring Products Guide focuses on effective, field-proven diagnostic monitoring technologies, suitable for use in predictive maintenance programs at fossil-fired plants and many can also be used at nuclear plants.

Volume two contains product profile sets for the following products: bearing troubleshooting advisor, broken rotor bar detection systems; carbon-in-ash monitors; fossil plant cycle chemistry tools; feedwater heater (FWH) leak detection systems; infrared thermography instruments; O&M workstation; and on-line creep and fatigue monitor. This volume also contains technology reviews in the following categories: bearing troubleshooting advisor; system for on-line detection of broken rotor bars in induction motors; carbon-in-ash monitors; methods and tools for improving fossil plant cycle chemistry; acoustic feedwater heater leak detection systems; infrared thermography instruments; MICA – software for winding condition assessment; operations & maintenance workstation; and Creep-FatiguePro – an on-line creep and fatigue monitoring system.

Volume three contains technology reviews for the following categories: acoustic coal flow monitor; condenser on-line leak-detection system; electric motor predictive maintenance tools and practices; heat exchanger workstation; operation & maintenance workstation applications; rotating machinery workstation – RMW™; tools for on-line coal quality evaluation; tools for state-of-the-art thermography programs; and UCA/DAIS specifications; tools for network and data access integration.

EPRI BUSINESS GROUP: Energy Conversion Division

**Bearing Troubleshooting Advisor: 1993 Product Profile From the
Diagnostics Monitoring Products Guide – Volume 2
AP-101840-V2P1**

DETAILS: Product Profile (Vol. 2-2 pages)

DATE: Dec. 1993

KEYWORDS: Bearings
Maintenance Costs
Failures
Maintenance
Component Reliability
Outages

ABSTRACT:

Bearing system failures cost the electric power industry an estimated \$150 million annually. Identifying the code and possible cause of bearing failure is an essential element in preventing future bearing failures. By using EPRI's Bearing Troubleshooting Advisor (BTA™) to manage bearing maintenance records and determine the causes of bearing failures, users can base bearing maintenance decisions on component history and condition data and thereby reduce the number of bearing failures and forced outages.

EPRI BUSINESS GROUP: Energy Conversion Division

**Broken Rotor Bar Detection System: 1993 Product Profile From the
Diagnostics Monitoring Products Guide – Volume 2
AP-101840-V2P2**

DETAILS: Product Profile (Vol. 2)

DATE: Dec. 1993

KEYWORDS: Rotors
Motors
Failures
Monitoring
Maintenance
Efficiency

ABSTRACT:

This Product Profile describes Rotor Bar Detection Systems. Broken rotor bars and cracked end rings can cause an induction motor to spark, vibrate, and emit excessive noise, thus impairing motor efficiency and contributing to the premature failure of other motor components. By using motor current monitoring techniques to detect rotor bar faults early, users can avoid motor failures and forced reductions of unit load, and improved maintenance planning.

EPRI BUSINESS GROUP: Energy Conversion Division

**Infrared Thermography Instruments: 1993 Product Profile From the
Diagnostics Monitoring Products Guide – Volume 2
AP-101840-V2P6**

DETAILS: Product Profile (Vol. 2-2 pages)

DATE: Dec. 1993

KEYWORDS: Infrared Thermography
Instruments
Monitoring
Diagnostic Techniques
Energy Management
Heat

ABSTRACT:

This Product Profile features infrared thermography instruments. Used in a variety of commercial applications since the early 1970s, infrared thermography (IRT) has become a well-recognized, cost-effective technique for use in energy management and equipment monitoring and diagnostics. This nonintrusive method readily represents thermal patterns and can be used to identify locations where heating is excessive and to evaluate the severity of heating problems. By using thermographic equipment to inspect electrical and mechanical components at power plants, users can extend component life, reduce downtime and maintenance costs, and improve unit heat rate.

EPRI BUSINESS GROUP: Energy Conversion Division

**MICAA: 1993 Product Profile From the Diagnostic Monitoring Products
Guide – Volume 2
AP-101840-V2P7**

DETAILS: Product Profile (Vol. 2-2 pages)

DATE: Dec. 1993

KEYWORDS: Software Tools
Predictive Maintenance
Rotors
Stators
Windings
Life Assessment

ABSTRACT:

MICAA software is the subject of this Product Profile. To implement effective condition-based predictive maintenance programs for rotor and stator windings, users must first be able to determine the actual condition of windings. EPRI's MICAA™ software enables maintenance personnel to readily assess the condition of electrical windings in large motors and generators. Using MICAA, users can avoid forced outages of motors and generators caused by winding failures, reduce maintenance costs and improve maintenance planning.

EPRI BUSINESS GROUP: Energy Conversion Division

**O&M Workstation: 1993 Product Profile From the Diagnostic Monitoring
Products Guide – Volume 2
AP-101840-V2P8**

DETAILS: Product Profile (Vol. 2-2 pages)

DATE: Dec. 1993

KEYWORDS: Maintenance
Workstations
Predictive Maintenance
Outages
Software Tools
Computers

ABSTRACT:

This Product Profile deals with EPRI's Operations and Maintenance (O&M) Workstation software, which is designed to serve as the foundation for effective, condition-based predictive maintenance programs. The workstation, to be demonstrated in the spring of 1994, will facilitate condition assessment by enabling users to integrate on-line data from monitoring and control systems with design and performance data, maintenance records, and other plant information. To help users evaluate this data and bring it to bear on O&M decision making and scheduling, the workstation will also include sophisticated, versatile and easy-to-use engineering, cost-benefit analysis, and report-generation tools.

Using the workstation, user personnel will be able to make timely analyses of equipment condition, perform root cause analyses, and make highly-informed decisions concerning maintenance, shortening outages, and improving unit operation.

EPRI BUSINESS GROUP: Energy Conversion Division

Bearing Troubleshooting Advisor: Technology Review AP-101840-V2P10

DETAILS: Technology Review (Vol. 2)

DATE: Dec. 1993

KEYWORDS: Bearings
Turbines
Turbine Life Management
Steam Turbines
Software Tools
Maintenance

ABSTRACT:

Turbine generator bearings operate at relatively high temperatures and speeds and under variable loads, and must maintain extremely tight tolerances. They are vulnerable to a variety of failure mechanisms that often lead to plant outages and costly repairs. Identifying the mode and possible cause of bearing failure is an essential element in preventing future bearing failures. EPRI's Bearing Troubleshooting Advisor (BTA™) is a software product that provides assistance in troubleshooting hydrodynamic and rolling element bearing failures and documenting bearing maintenance events. It includes a database management system that helps store and track information on each configured bearing; expert-system modules for use in determining possible failure causes; and hypertext reference manuals that aid in diagnosing and repairing bearing problems. Using BTA, users can base maintenance decisions on component history and condition data and thereby reduce the number of bearing failures and forced outages.

EPRI BUSINESS GROUP: Energy Conversion Division

**On-Line Creep and Fatigue Monitor: 1993 Product Profile From the
Diagnostics Monitoring Products Guide – Volume 2
AP-101840-V2P9**

DETAILS: Product Profile (Vol. 2-2 pages)

DATE: Dec. 1993

KEYWORDS: Creep
Fatigue Testing
Monitors
On-line Measurement Systems
High Temperature
Simulation

ABSTRACT:

EPRI'S on-line Creep FatiguePro monitor is the subject of this Product Profile. High temperatures, cyclic operation, and load transients can combine to inflict serious creep and fatigue damage on boiler headers, main steam piping and other fossil-fired power plant components. Users can reduce such damage by using EPRI's Creep-FatiguePro monitoring system to perform on-line, automated monitoring of creep and fatigue effects in high-temperature power plant components.

EPRI BUSINESS GROUP: Energy Conversion Division

**System for On-Line Detection of Broken Rotor Bars in Induction Motors:
Technology Review
AP-101840-V2P11**

DETAILS: Technology Review (Vol. 2)

DATE: Dec. 1993

KEYWORDS: Rotors
Induction Motors
Maintenance
Monitors
Transformers
On-line Systems

ABSTRACT:

Broken rotor bars and cracked end rings can cause an induction motor to spark, vibrate, and emit excessive noise, impairing efficiency and contributing to premature failure of other motor components. A broken bar may be undetectable by nonanalytic means, and analytic detection methods often give false readings. Also, vibration and noise may result from other problems in the motor. Motor current monitoring is a noninvasive method for detecting broken rotor bars, which can be performed on motors while they operate normally under load. Effective monitoring and early problem detection can help to avoid motor failures and forced reductions of unit load, and improve maintenance planning. To perform motor current monitoring failures and forced reductions of unit load, and spectrum analysis equipment available at many power plants. Computer-based broken rotor bar detection systems, which process motor current data automatically, are also available commercially.

EPRI BUSINESS GROUP: Energy Conversion Division

Acoustic Feedwater Heater Leak Detection Systems: Technology Review AP-101840-V2P14

DETAILS: Technology Review (Vol. 2)

DATE: Dec. 1993

KEYWORDS: Feedwater
Feedwater Heaters
Detection
Leak Detectors
Leakage
Acoustic Testing

ABSTRACT:

Leaks in feedwater heaters (FWHs) can increase unit heat rate and lead to significant availability losses at fossil-fired and nuclear power plants. Remedial leak plugging increases the flow rate in remaining tubes, degrading FWH performance and accelerating erosion. An undetected leak may cause escaping feedwater to damage adjacent tubes, leading to greater efficiency losses and repair costs. On-line acoustic FWH leak detection systems can help users detect FWH leaks early and thereby extend FWH life, increase unit efficiency, avoid forced outages, and improve maintenance planning. High- and low-frequency acoustic sensors and signal-conditioning equipment, developed with EPRI support, are available. The use of portable FWH leak detection systems during off-line, hydrostatic testing can yield significant savings at nuclear units where permanent wiring of FWHs for on-line monitoring may not be accomplished easily.

EPRI BUSINESS GROUP: Energy Conversion Division

Infrared Thermography Instruments: Technology Review AP-101840-V2P15

DETAILS: Technology Review (Vol. 2)

DATE: Dec. 1993

KEYWORDS: Infrared Thermography
Waste Heat
Heat Losses
Thermal Analysis
Predictive Maintenance
Software Tools

ABSTRACT:

With infrared thermography (IRT) instruments, users can detect overheating early and can quickly evaluate the severity of thermal anomalies. Using thermographic equipment to inspect electrical and mechanical components at power plants, users can extend component life, reduce downtime and maintenance costs, and improve the thermal efficiency of power plants. Sophisticated thermal imaging software tools support a wide range of diagnostic activities, and a knowledge-based system, developed by EPRI, can assist users in diagnosing possible faults detected with IRT instruments.

EPRI BUSINESS GROUP: Energy Conversion Division

MICAA—Software for Winding Condition Assessment: Technology Review AP-101840-V2P16

DETAILS: Technology Review (Vol. 2)

DATE: Dec. 1993

KEYWORDS: Windings
Stators
Rotors
Software Tools
Maintenance
Preventive Maintenance

ABSTRACT:

Windings are complete groups of insulated conductors in motors, generators, and other electrical machines and are designed to produce or be acted upon by a magnetic field. A significant portion of failures are due to stator winding problems and rotor winding problems, and windings also affect generator reliability. EPRI's knowledge-based system software, MICAA™, enables maintenance personnel to readily assess the conditions of electrical windings in large motors and generators. Using MICAA, users can avoid forced outages or motors and generators caused by rotor or stator winding failures, reduce maintenance costs and improve maintenance planning. The MICAA knowledge base contains key information on the major brands of motors and generators rated 2300 V and above, and covers 39 possible failure mechanisms and 49 diagnostic tests and inspections. Suitable for use with gas and steam turbine generators, hydrogenerators, and squirrel cage induction motors, MICAA runs on IBM-type personal computers.

EPRI BUSINESS GROUP: Energy Conversion Division

Operations & Maintenance Workstation AP-101840-V2P17

DETAILS: Technology Review (Vol. 2-12 pages)

DATE: Dec. 1993

KEYWORDS: Maintenance Costs
Operating Costs
Life Assessment
Availability
Predictive Maintenance
Outages

ABSTRACT:

This Technology Review contains information about EPRI's Operations & Maintenance (O&M) Workstation. The workstation will include a variety of analytic tools that can speed up comprehensive condition assessment, support O&M planning and decision making, and thereby help users increase unit availability and reduce O&M costs while extending component life. It will also give users quick access to data from diagnostic monitoring systems and to other critical plant process, maintenance, operating and engineering data.

EPRI BUSINESS GROUP: Energy Conversion Division

**Creep-FatiguePro—An On-Line Creep and Fatigue Monitoring System:
Technology Review
AP-101840-V2P18**

DETAILS: Technology Review (Vol. 2-12 pages)

DATE: Dec. 1993

KEYWORDS: Creep
Fatigue (Materials)
FATIGUEPRO Code
On-line Measurement Systems
Piping Systems
Crack Detection

ABSTRACT:

This Technology Review presents EPRI's on-line creep and fatigue automated monitoring system, Creep-FatiguePro. This microcomputer-based software package allows user personnel to accurately assess the condition of monitored components based on actual plant operations, and make realistic decisions concerning operating procedures, inspection intervals, and repair and replacement schedules.

EPRI BUSINESS GROUP: Energy Conversion Division

Condenser On-Line Leak-Detection System: Technology Review AP-101840-V3P2

DETAILS: Technology Review (Vol. 3)

DATE: Dec. 1995

KEYWORDS: Condensers
Steam Condensers
Leak Detectors
Cooling Water
Corrosion Potential
Sulfur Hexafluoride

ABSTRACT:

Tube leaks in power plant condensers allow sodium, chlorides, silica and other contaminants in the circulating cooling water to enter the highly purified water of the steam cycle. These impurities lead to corrosion or fouling of major plant equipment, including feedwater systems, boilers, and turbines, and to failures of steam generators, reactors, and heaters. Proper monitoring of cycle chemistry can give early indication that condensate conductivity is rising and condenser tube leakage is occurring. EPRI has developed a condenser on-line lead detection system (COLDS) that uses targeted injection of sulfur hexafluoride to detect and locate condenser tube leaks while the condenser is in full operation. The COLDS can locate leaks with flow rates as low as one gallon of water per day, and small leaks that cannot be located with off-line techniques. With COLDS, users can avoid prolonged shutdowns to locate leaks and realize quick payback on investment in the system.

EPRI BUSINESS GROUP: Energy Conversion Division

Operation & Maintenance Workstation Applications Technology Review AP-101840-V3P5

DETAILS: Technology Review (Vol. 3)

DATE: Dec. 1995

KEYWORD: Maintenance
Predictive Maintenance
Operation
Monitoring
Diagnostic Techniques
Workstation

ABSTRACT:

New, high-tech diagnostic monitoring systems have increased the ability of utility companies to monitor the condition of power plant equipment in real time, to reduce or eliminate unexpected equipment failures by detecting incipient problems early, to avoid unnecessary time-based maintenance, and to focus maintenance efforts where needed. EPRI's Operating and Maintenance (O&M) Workstation integrates plant operating and maintenance information into a component-based decision-support tool, that gives users quick access to data from on-line and periodic diagnostic monitoring systems and other critical plant process, maintenance, operating, and engineering sources. The O&M Workstation can speed up comprehensive analyses of equipment condition, support O&M planning and decision making, and help users increase unit availability and reduce O&M costs while extending component life. Using EPRIWorks™, the O&M Workstation provides an open system environment that complies with EPRI's Utility Communications Architecture (UCA); the O&M Workstation library, which contains UCA-compliant interfaces to leading diagnostic monitoring and control systems, facilitates development of applications by users.

EPRI BUSINESS GROUP: Energy Conversion Division

Rotating Machinery Workstation—RMW™: Technology Review AP-101840-V3P6

DETAILS: Technology Review (Vol. 3)

DATE: Dec. 1995

KEYWORDS: Rotating Machinery
Workstations
Maintenance
Predictive Maintenance
Software Tools
Computer Programs

ABSTRACT:

EPRI's Rotating Machinery Workstations (RMW) is a software tool designed to support condition-based maintenance efforts, improving the quality or and increasing accessibility to recorded data on rotating machinery maintenance, testing, and inspections. RMW also functions as an application environment, providing easy linkage to several EPRI condition monitoring, assessment, and troubleshooting software products, as well as third party software. It provides users with maximum flexibility in deciding what products and databases to include in the workstation. By supporting the work of engineering, planning, maintenance, and repair personnel, RMW can help users improve maintenance planning, extend intervals between outages, prolong component life, and reduce operations and maintenance costs. It can be applied at the plant level and at the system-wide level, where it can play a critical role in fleet management programs.

EPRI BUSINESS GROUP: Energy Conversion Division

Tools for State-of-the-Art Thermography Programs: Technology Review AP-101840-V3P8

DETAILS: Technology Review (Vol. 3-12 pages)

DATE: Dec. 1995

KEYWORDS: Infrared Thermography
Inspection
Predictive Maintenance
Diagnostic Techniques
Software Tools
Databases

ABSTRACT:

By using infrared thermography (IRT) equipment to routinely inspect electrical and mechanical components at power plants, many users have reduced downtime and maintenance costs, improved unit heat rates, increased personnel safety and extended component life. To help identify predictive maintenance programs meet their IRT training and diagnostic needs, EPRI's M&D Center is developing the Infrared Inspection Technical Evaluator (IRITE), a knowledge-based system software tool that now includes a module covering molded-case breakers. The M&D center has developed guidelines for performing IRT inspections of condensers and boiler casings, and has developed high-temperature lens systems for on-line inspection of boiler interiors. To reduce the time needed to complete IRT surveys, the M&D Center has developed software and a supporting speech-activated system that facilitates the recording of IRT inspection results and the maintenance of IRT databases.

EPRI BUSINESS GROUP: Energy Conversion Division

Infrared Thermography Anomaly Assessment TR-111916

DETAILS: Final Report (54 pages)

DATE: Dec. 1998

KEYWORDS: Infrared Thermography
Nondestructive Evaluation
Predictive Maintenance
Cost Benefit Analysis

ABSTRACT:

Infrared Thermography (IRT) is a non-intrusive diagnostic technique that has become an important tool in the establishment of predictive maintenance programs. By presenting specific case histories, this report shows how IRT can be applied in the field to detect anomalies in a wide-range of power plant systems and result in corrective actions with real dollar cost benefits.

DISCUSSION:

Most of the equipment found in a typical electric generating station exhibits some type of abnormal thermal pattern prior to failure. IRT is a non-invasive diagnostic technique that can detect these abnormal thermal patterns by making simultaneous temperature measurements of multiple points on the surface of a piece of equipment. These data are displayed as pictures, commonly referred to as thermograms, that can be analyzed in real-time or stored electronically and analyzed later. Information from thermograms can be used by electric utilities to plan maintenance and avoid catastrophic equipment failures and unscheduled downtime. This report extends the case histories previously reported in the “Infrared Thermography Anomalies Manual” (EPRI report TR-108925) and also relates to “Infrared Thermography Development for Boiler, Condenser, and Steam Cycle” (EPRI report TR-109529).

After a brief introduction to the technical background of IRT, the report describes several infrared thermography case histories where thermal anomalies were detected in various types of power plant equipment. The thermal anomalies illustrated in this document include station electrical appliances, rotating equipment applications, transmission and distribution applications, and performance applications. Some of the cases are analyzed quantitatively while others are analyzed qualitatively. Most of the cases feature a thermal image that is accompanied by a corresponding visual image. An arrow superimposed on the visual image allows the reader to match locations on the visual image with the corresponding locations on the thermal image.

The information contained in this document was acquired while using IRT to identify potential problems in the field. In each case feedback was received from maintenance personnel involved with repair work regarding the “as found” condition of the equipment. This feedback helps refine diagnostic techniques and should be an integral part of preventive maintenance. All detected anomalies should also be re-inspected with IRT after repairs are completed to verify

that the problem has been corrected. In addition, cost benefit analyses should be made to demonstrate to management the projected dollars saved by applying IRT and setting up a comprehensive IRT program.

EPRI BUSINESS GROUP: Energy Conversion Division

Diagnostic Monitoring Products Guide AP-101840-V4

DETAILS: Products Guide (89 pages)

DATE: Dec. 1996

KEYWORDS: Fossil-Fired Power Plants
Sensors
Substations
Acoustic Testing
Technology Assessment
Technology Utilization

ABSTRACT:

EPRI's Diagnostic Monitoring Products Guide focuses on effective, field-proven diagnostic monitoring technologies. This fourth release of the Guide contains seven Technology Reviews on a variety of hardware and software products that give users new opportunities to lower plant O&M costs substantially. The products are applicable at fossil-fired plants.

Technology Reviews are addressed to engineers and O&M supervisors interested in determining how the products might be used at their plants. The Technology Reviews include detailed information on product features, benefits derived from using them, utility industry users, vendors, and when available, the price of the product and installation and operating costs. These reviews treat principles of science and engineering underlying specific products. The seven Technology Reviews included in this Guide are:

- **Acoustic Emission Monitoring of High-Energy Steam Piping:** (AP-101840-V4P1). This cost-effective method uses acoustic emission (AE) testing to screen entire seam-welded hot reheat piping and other high-energy piping systems used during normal unit operation and cooldown. Follow-up inspection using other nondestructive examination methods can focus economically on suspect locations and quantify material defects generated by high-temperature creep and fatigue. Used successfully at subcritical and supercritical units, AE testing allows users to: inspect high-energy steam piping without removing thermal insulation; conduct re-inspection at short intervals; and reduce the cost and improve the quality of piping inspections.
- **Advanced Sensors for Fossil-Fired Power Plant Applications:** (AP-101840-V4P2). Advanced sensors can provide accurate on-line power plant data that are otherwise difficult or impossible to obtain, and that can help reduce maintenance costs, improve plant performance, and extend component life. EPRI has developed a versatile fiber-optic sensor for measuring strain and other parameters in high-temperature structures, and a distributed fiber-optic sensor system for measuring temperature in generators, circuit breakers, and other electrical equipment. Further, EPRI is developing several other advanced sensors, including: a self-calibrating, high-temperature resistance temperature detector; fiber-optic sensors designed to measure levels of nitric oxide and ammonia in flue gas, and pH levels of hot water, and instruments that can measure pulverized coal flow in situ.

- **Carbon-in-Ash Monitors:** (AP-101840-V4P3). At least six vendors offer on-line-carbon-in-ash monitors (CIAMs) designed to quickly and accurately determine levels of unburned carbon (UBC) in power plant fly ash. Using CIAMs, users can improve burner performance, lower heat rate, increase ash utilization, and diagnose developing problems with pulverizers, dampers and burners. Semi-continuous or continuous UBC data from CIAMs can be sent to the control room for use by the operator, and to the plant or unit computer, where performance monitoring software and software designed to optimize nitrogen oxide emissions and boiler performance may use the data. Southern Company, EPRI, and the U.S. Department of Energy recently completed performance evaluation testing of four CIAMs at two utility plants.
- **Control Maintenance Workstation for Power Plants:** (AP-101840-V4P4). An integrated software package, the Control Maintenance Workstation (CMW™) assesses distributed control system (DCS) performance on-line, and assists in control system, troubleshooting and tuning. CMW is also designed to function as a comprehensive control system, maintenance database, giving users an easy way to review recorded maintenance activities and to document new activity. By using CMW to keep power generation control systems operating optimally, users can improve plant efficiency, increase unit maneuverability, and reduce equipment wear-and-tear costs, while safely operating units closer to emission limits.
- **On-Line Condenser Fouling Monitor:** (AP-101840-V4P5). Using probes installed at one or more locations within a condenser, the condenser fouling monitor (CFM) provides more accurate heat transfer data than are provided by other approaches. CFM-supplied data can help maintenance engineers detect condenser fouling, minimize performance and availability losses caused by biological and/or chemical fouling, optimize condenser cleaning schedules, and evaluate the effectiveness of mechanical or chemical cleaning treatments. Successfully demonstrated at three utility sites, the CFM does not interfere with routine plant operations and can readily be installed during a scheduled outage, with only minor modification to the condenser waterbox.
- **SLEAK™ and Other Tools for Stator Winding Leak Problems:** (AP-101840-V4P6). Water leakage into stator windings has occurred in several General Electric Co. (GE) generators and may affect over 300 GE generators. EPRI has developed and demonstrated a stator bar wetness detector; one of many tools that gives users an array of options for monitoring and repairing water leaks in stator water-cooling systems. EPRI has developed SLEAK, a turbine generator stator winding leak decision software program that enables users to readily identify the optimum monitoring or repair options for specific generators, and possibly to avoid costly winding replacement. SLEAK has been successfully beta tested by six utility companies.
- **Substation/Switchyard Predictive Maintenance Tools and Practices:** (AP-101840-V5P7). By implementing substation and switchyard predictive maintenance (SPDM), users can detect developing substation equipment problems early, improve maintenance planning, increase substation reliability and availability, and reduce O&M costs. The M&D Center has developed guidelines covering the key forms of SPDM testing and a database and associated tools for use in recording, reviewing, and trending substation survey data. Now, it is building up a multi-utility database that will facilitate diagnosis of substation equipment problems. Several utility companies have initiated SPDM programs, and three estimate that their SPDM efforts will provide them with \$23 million in avoided costs over a six-year period.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

Individual parts of this Products Guide are available separately as listed.

**Diagnostic Monitoring Product Guide: Volume 5 – Product Book for
Generation
AP-101840-V5**

DETAILS: Computer Code Manual

DATE: Mar. 1998

KEYWORDS: Monitoring
Technology Utilization
Operating Costs
Maintenance Costs
Diagnostic Techniques
Software Tools

ABSTRACT:

EPRI's Diagnostic Monitoring Products Guide focuses on effective, field-proven diagnostic monitoring technologies. This FIFTH release of the Guide contains four Technology Reviews on a variety of hardware and software products that give users new opportunities to lower plant O&M costs substantially. The products are applicable at fossil-fired plants.

Technology Reviews are addressed to engineers and O&M supervisors interested in determining how the products might be used at their plants. The Technology Reviews include detailed information on product features, benefits derived from using them, utility industry users, and when available, the price of the product and installation and operating costs. These reviews treat principles of science and engineering underlying specific products.

EPRI BUSINESS GROUP: Energy Conversion Division

Diagnostic Monitoring Product Guide: Volume 6 – Computerized Operators Log AP-101840-V6

DETAILS: Computer Code Manual

DATE: July 1998

KEYWORDS: Monitoring
Technology Utilization
Operating Costs
Maintenance Costs
Diagnostic Techniques
Software Tools
Diagnostic Monitoring

ABSTRACT:

EPRI's Diagnostic Monitoring Products Guide focuses on effective, field-proven diagnostic monitoring technologies. This SIXTH release of the Guide contains four Technology Reviews and a variety of hardware and software products that give new opportunities to lower plant O&M costs substantially. The products are applicable at fossil-fired plants.

Technology Reviews are addressed to engineers and O&M supervisors interested in determining how the products might be used at their plants. The Technology Reviews include detailed information on product features, benefits derived from using them, utility industry users, vendors, and when available, the price of the product and installation and operating costs. These reviews treat principles of science and engineering underlying specific products.

EPRI BUSINESS GROUP: Energy Conversion Division

EPRI Maintenance and Diagnostic Center Course Catalog, Revision 1 TR-109511-R1

DETAILS: Final Report (120 pages)

DATE: Nov. 1998

KEYWORDS: Availability
Monitoring
Reliability
Diagnostic Techniques
Performance
Predictive Maintenance

ABSTRACT:

This catalog contains brief descriptions of courses and workshops offered during 1999 by EPRI's Monitoring and Diagnostic (M&D) Center. These courses train utility personnel on tested EPRI maintenance products and services.

DISCUSSION:

EPRI's M&D Center is located at Philadelphia Electric Company's Eddystone Station. Originally created to develop, demonstrate, and transfer the latest maintenance prediction techniques to EPRI members, the Center also offers workshops and courses. These courses are part of EPRI's Plant Maintenance Optimization (PMO) target. PMO's goal is to increase profitability for generation businesses by developing and demonstrating services and products for improved use of power plant maintenance resources.

The object of EPRI's M&D Center is:

- To instruct utility industry management and technical personnel how to use and benefit from state-of-the-art technology developed by EPRI and other industry leaders.
- To expose attendees to technologies in an actual plant situation

This catalog is updated each year; as new courses are developed, their descriptions are included in the following year's catalog. M&D Center courses are taught by recognized industry experts once a year, or as interest demands. Utility companies also can make special arrangements to conduct courses at their own or other EPRI-member facilities on a cost-reimbursable basis.

This current catalog list 32 courses, ranging from "Advanced Check Valve Monitoring & Diagnostics" to "Vibration II". A schedule lists times, places, and fees along with a 1-2 page brief description of each course. Included in the description are topical outlines, background notes, suggestions for who should attend, registration and accommodation information, and course contacts. Typical courses last 2-4 days.

These courses are intended to help reduce costs by developing and demonstrating cost-effective maintenance methods.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

Interested pulp and paper industry personnel should make arrangements through their utility company provider for participating in these courses.

Condition-Monitoring Guidelines for Rolling Element Bearings TR-100160

DETAILS: Final Report (92 pages)

DATE: Nov. 1991

KEYWORDS: Diagnostic Techniques
Predictive Maintenance
Bearings
Rotating Machinery
Vibration Monitoring

ABSTRACT:

This report contains an assessment of the extent to which the use of machinery supported on rolling element bearings affects the economy and reliability of plant operation. In most plants surveyed for this report, a sufficiently high failure rate and repair activity existed to justify the use of predictive maintenance monitoring on such machinery.

DISCUSSION:

Rolling element bearings are common in many rotating machines in fossil and nuclear plants. Typically, rolling element bearings are used in medium- to low-horsepower machinery, and fluid film bearings are used in larger, more critical machines. Rolling element bearings are replaced during fixed-interval overhauls, though they may be run to failure for inexpensive machines. In contrast to fluid film bearings, rolling element bearings produce signals at predictable frequencies when approaching malfunction. These frequency signals can be monitored to schedule rolling element bearing machine maintenance.

Twenty utility plants representing nuclear, coal-fired, and oil- or gas-fired plants were surveyed. Data was gathered on the type of rolling element bearing, lubrication method, and failure cause for different machines, as well as current maintenance practices (corrective, preventive, or predictive) during selected site visits. Finally, they developed bearing condition guidelines for applying vibration, temperature, and lubricant analyses.

Site visits and in-depth research indicated the following:

- Fatigue spalling, lubricant loss, contamination, and poor assembly accounted for more than half of all failures. Lubricant loss, overheating, and contamination pointed to problems with grease lubrication. More than 50% of rolling element bearing machines were grease-lubricated. Oil ring lubrication was the next most frequent form, followed by forced-feed lubrication.
- In coal-fired plants, two-thirds of rolling element bearing machines used corrective, run-to-failure maintenance, with preventive maintenance accounting for the remainder. About one-quarter of rolling element bearing machines in nuclear power plants used some form of predictive maintenance.

- Vibration monitoring within the operating frequency of the machine, typically under 500 Hz, was useful only for detecting imminent failure, leaving little time for planned maintenance. The high-frequency resonance technique (HFRT), 20-kHz and higher, displayed better sensitivity to early fault development.
- Monitoring temperature on the bearing outer race was useful for detecting impending failures due to lubricant depletion or over-packing. Lubricant replacement can be based on periodic checks of oil viscosity and neutrality number. Moreover, metal particle count indicative of bearing damage can be tracked using ferrography techniques.

The survey points out the potential for improved maintenance of rolling element bearing-supported plant machinery using diagnostic techniques. Survey results also indicate that standards for grease, grease packing, sealing, and bearing procurement should be developed wherever practical. Coal-handling equipment typically subject to lubricant contamination from fugitive dust, in particular, needs more attention. The EPRI Monitoring and Diagnostic Center offers courses on predictive maintenance techniques and bearing diagnostics. Fluid film bearing maintenance techniques are covered in the Bearing Failure and Repair Manual (report GS-7352).

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PREVENTIVE MAINTENANCE

Preventive Maintenance Basis: Volume 1 – Air Operated Valves TR-106857-V1

DETAILS: Final Report (Vol. 1-48 pages)

DATE: July 1997

KEYWORDS: Preventive Maintenance
Maintenance Optimization
Valves
Motors
Pumps
Failure Analysis
Component Reliability
Power Plant Reliability

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are all equally applicable to the pulp and paper industry. This report addresses Air Operated Valves.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 2 – Medium Voltage Switchgear TR-106857-V2

DETAILS: Final Report (Vol. 2-44 pages)

DATE: July 1997

KEYWORDS: Switchgear
Preventive Maintenance
Component Reliability
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Medium Voltage Switchgear.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 3 – Low Voltage Switchgear TR-106857-V3

DETAILS: Final Report (Vol. 3-40 pages)

DATE: July 1997

KEYWORDS: Switchgear
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Low Voltage Switchgear.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 4 – Motor Control Centers TR-106857-V4

DETAILS: Final Report (Vol. 4-28 pages)

DATE: July 1997

KEYWORDS: Motors
Component Reliability
Preventive Maintenance
Motor Controls
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Motor Control Centers.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 5 – Check Valves TR-106857-V5

DETAILS: Final Report (Vol. 5-32 pages)

DATE: July 1997

KEYWORDS: Check Valve
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Check Valves.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 6 – Motor Operated Valves TR-106857-V6

DETAILS: Final Report (Vol. 6-40 pages)

DATE: July 1997

KEYWORDS: Motor Operated Valves
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Motor Operated Valves.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 7 – Solenoid Operated Valves TR-106587-V7

DETAILS: Final Report (Vol. 7-30 pages)

DATE: July 1997

KEYWORDS: Solenoid Valves
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Solenoid Valves.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

**Preventive Maintenance Basis: Volume 8 – Low Voltage Electric Motors
(600V and Below)
TR-106857-V8**

DETAILS: Final Report (Vol. 8-68 pages)

DATE: July 1997

KEYWORDS: Electric Motors
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Low Voltage Electric Motors.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 9 – Medium Voltage Electric Motors (Between 1kV and 4kV) TR-106857-V9

DETAILS: Final Report (Vol. 9-82 pages)

DATE: July 1997

KEYWORDS: Electric Motors
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Medium Voltage Motors.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

**Preventive Maintenance Basis: Volume 10 – High Voltage Electric Motors
(5kV and Greater)
TR-106857-V10**

DETAILS: Final Report (Vol. 10-80 pages)

DATE: July 1999

KEYWORDS: Electric Motors
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses High Voltage Motors.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 11 – Direct Current Electric Motors TR-106857-V11

DETAILS: Final Report (Vol. 11-44 pages)

DATE: July 1997

KEYWORDS: Electric Motors
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Direct Current Motors.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 12 – Vertical Pumps TR-106587-V12

DETAILS: Final Report (Vol. 12-60 pages)

DATE: July 1997

KEYWORDS: Pumps
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Vertical Pumps.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 13 – Horizontal Pumps TR-106857-V13

DETAILS: Final Report (Vol. 13-78 pages)

DATE: July 1997

KEYWORDS: Pumps
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Horizontal Pumps.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

**Preventive Maintenance Basis: Volume 14 – Reciprocating Air
Compressors
TR-106857-V14**

DETAILS: Final Report (Vol. 14-50 pages)

DATE: July 1997

KEYWORDS: Compressors
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Reciprocating Air Compressors.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 15 – Rotary Screw Air Compressors TR-106857-V15

DETAILS: Final Report (Vol. 15-46 pages)

DATE: July 1997

KEYWORDS: Compressors
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Rotary Screw Air Compressors.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 16 – Power Operated Relief Valves TR-106857-V16

DETAILS: Final Report (Vol. 16-38 pages)

DATE: July 1997

KEYWORDS: Relief Valves
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Power Operated Relief Valves.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 17 – Power Operated Relief Valves – Pneumatic Actuated TR-106857-V17

DETAILS: Final Report (Vol. 17-40 pages)

DATE: July 1997

KEYWORDS: Relief Valves
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Pneumatic Actuated Relief Valves.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

**Preventive Maintenance Basis: Volume 18 – Pressure Relief Valves –
Spring Actuated
TR-106857-V18**

DETAILS: Final Report (Vol. 18-42 pages)

DATE: July 1997

KEYWORDS: Relief Valves
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Spring Actuated Pressure Relief Valves.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 19 – HVAC Chillers and Compressors

TR-106857-V19

DETAILS: Final Report (Vol. 19-68 pages)

DATE: July 1997

KEYWORDS: Relief Valves
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Heating, Ventilating, and Air Conditioning (HVAC) Systems Chillers and Compressors.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 20 – HVAC Dampers and Ducting TR-106857-V20

DETAILS: Final Report (Vol. 20-42 pages)

DATE: July 1997

KEYWORDS: HVAC Systems
Dampers
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Heating, Ventilating, and Air Conditioning (HVAC) System Dampers and Ducting.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 21 – HVAC Air Handling Equipment TR-106857-V21

DETAILS: Final Report (Vol. 21-56 pages)

DATE: July 1999

KEYWORDS: HVAC Systems
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Heating, Ventilating, and Air Conditioning (HVAC) Systems Air Handling Equipment.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 22 – Inverters TR-106857-V22

DETAILS: Final Report (Vol. 22-34 pages)

DATE: July 1997

KEYWORDS: Inverters
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Inverters.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 24 – Battery Chargers TR-106857-V24

DETAILS: Final Report (Vol. 24-32 pages)

DATE: July 1997

KEYWORDS: Battery Chargers
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Battery Chargers.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 25 – Valve-Regulated Battery TR-106857-V25

DETAILS: Final Report (Vol. 25-34 pages)

DATE: Dec. 1997

KEYWORDS: Batteries
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Valve-Regulated Batteries.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 26 – Nickel-Cadmium (NICAD) Battery TR-106857-V26

DETAILS: Final Report (Vol. 26-32 pages)

DATE: Dec. 1997

KEYWORDS: Batteries
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Nickel-Cadmium Batteries.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

**Preventive Maintenance Basis: Volume 27 – Liquid-Ring Rotary
Compressor and Pump
TR-106857-V27**

DETAILS: Final Report (Vol. 27-48 pages)

DATE: July 1997

KEYWORDS: Compressor
Pumps
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Liquid-Ring Rotary Air compressors.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 28 – Positive Displacement Pumps TR-106857-V28

DETAILS: Final Report (Vol. 28-47 pages)

DATE: Mar. 1998

KEYWORDS: Pumps
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Positive Displacement Pumps.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 29 – Protective Relays TR-106857-V29

DETAILS: Final Report (Vol. 29-32 pages)

DATE: July 1998

KEYWORDS: Relays
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Protective Relays.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 30 – Control Relays TR-106857-V30

DETAILS: Final Report (Vol. 30-32 pages)

KEYWORDS: Relays
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Control Relays.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 31 – Timing Relays TR-106857-V31

DETAILS: Final Report (Vol. 31-20 pages)

DATE: July 1998

KEYWORDS: Relays
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Timing Relays.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 33 – Feedwater Heaters TR-106857-V33

DETAILS: Final Report (Vol. 33-32 pages)

DATE: July 1997

KEYWORDS: Feedwater Heaters
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Feedwater Heaters.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 32 – Tube Type Heat Exchangers TR-106857-V32

DETAILS: Final Report (Vol. 32-40 pages)

KEYWORDS: Heat Exchangers
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Tube Type Heat Exchangers.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 34 – Main Condensers TR-106857-V34

DETAILS: Final Report (Vol. 34-36 pages)

DATE: July 1997

KEYWORDS: Condensers
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Main Condensers.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 35 – Main Feedwater Pump Turbines

TR-106857-V35

DETAILS: Final Report (Vol. 35-64 pages)

DATE: Nov. 1998

KEYWORDS: Turbines
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Main Feedwater Pump Turbines.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 36 – Single Stage Terry Turbines TR-106857-V36

DETAILS: Final Report (Vol. 36-44 pages)

DATE: Nov. 1998

KEYWORDS: Turbines
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Single Stage Terry Turbines.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 37 – Main Turbine EHC Hydraulics TR-106857-V37

DETAILS: Final Report (Vol. 37-65 pages)

DATE: Nov. 1998

KEYWORDS: Turbines
Turbine Control
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Main Turbine Electro-Hydraulic Control (EHC) Hydraulics.

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Preventive Maintenance Basis: Volume 38 – Station Type Oil-Immersed Transformers TR-106857-V38

DETAILS: Final Report (Vol. 38-52 pages)

KEYWORDS: Transformers
Component Reliability
Preventive Maintenance
Power Plant Reliability
Maintenance Optimization

ABSTRACT:

U.S. Nuclear plants are implementing preventive maintenance (PM) tasks with little documented basis beyond fundamental vendor information to support the tasks or their intervals. The Preventive Maintenance Basis project provides the technical basis for PM tasks and task intervals associated with 40 specific components such as valves, electric motors, pumps, and HVAC equipment. These are equally applicable to the pulp and paper industry. This report addresses Station Type Oil-Immersed Transformers .

DISCUSSION:

The PM Basis will serve the maintenance community as an essential reference for PM task selection for 40 common major components, including major mechanical, electrical, and heat transfer classes. Each PM Basis report explains 1) the approach used to develop the PM basis and the strategic considerations, 2) the recommended PM program in a concise format, including task interval recommendations, and 3) a tabular summary of degradation and failure mechanism information obtained by direct interviews.

Each report describes the technical basis behind PM tasks and the relationship between failure locations, failure mechanisms, influences on equipment degradation and timing of failures. Tasks are divided according to three categories: condition monitoring to measure the progression toward failure so that corrective action can be planned or initiated, time-directed to prevent failure by performing scheduled maintenance, and failure finding to identify a failed condition so that corrective maintenance can be initiated.

This report contains an overview of the objectives, project organization, and the process used in developing the 40 individual component PM programs and supporting technical bases. It will prove invaluable for promoting consistency in PM programs, enhancing maintenance personnel training, and will contribute to greater equipment availability and reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

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PREDICTIVE MAINTENANCE

Predictive Maintenance Primer NP-7205

DETAILS: Final Report (144 pages)

DATE: April 1991

KEYWORDS: Maintenance
Predictive Maintenance
Preventive Maintenance
Monitoring

ABSTRACT:

Successful use of a predictive maintenance program in both nuclear and fossil plants can help limit deterioration of necessary structures, systems, and components and prevent complete failure of some equipment. The Predictive Maintenance Primer provides utility plant personnel with a single-source reference to predictive maintenance analysis methods and technologies used successfully by the utility and other industries.

DISCUSSION:

Predictive maintenance presumes that all equipment may deteriorate sooner or later, thus leading to partial or complete loss of function. Predictive maintenance monitors the condition or the performance of necessary structures, systems, and components. It detects deterioration, analyzes it, and predicts future deterioration. Using these predictions, analysis act to limit deterioration and prevent complete failure. Predictive maintenance is still in its early stags of development. EPRI's Nuclear Maintenance Applications Center (NMAC) prepared this primer to assist in achieving an improved predictive maintenance program.

The Predictive Maintenance Primer provides utility plant personnel with a single-source reference to predictive maintenance analysis methods and technologies used successfully by the utility and other industries. It includes a discussion of six analytic methods (trend analysis, pattern recognition, correlation, test against limits or ranges, relative comparison data, and statistical analysis) and how they overlap and interrelate. In addition, it describes eighteen technologies that have been found useful at power plants.

This primer is meant to be a living document to be updated as additional predictive maintenance technologies and analytic methods are developed and proven. Improving and perfecting predictive maintenance practices will help meet availability, reliability, and productivity goals.

Related EPRI research is found in reports CS-5163, ES-6305, NP-6337, GS-6589-L, NP-6973 and NP-7121.

EPRI BUSINESS GROUP: Energy Conversion Division

Predictive Maintenance Program: Development and Implementation TR-108936

DETAILS: Final Report (570 pages)

DATE: Jan. 1998

KEYWORDS: Maintenance
Monitoring
Diagnostic Techniques
Equipment Reliability
Predictive Maintenance

ABSTRACT:

Many forces – the economy, competition, regulatory agencies – are pressuring electric utilities to reduce operating and maintenance (O&M) costs without cutting back on reliability or availability. Many utility managers are re-evaluating their maintenance strategies to meet these demands. To show how to reduce maintenance costs and extend the effective operating life of equipment, EPRI has organized an annual workshop around a unique management approach – Predictive Maintenance (PDM).

DISCUSSION:

In its Predictive Maintenance Guidelines (TR-103374), EPRI defines PDM as “combining and using all available diagnostic and performance data, maintenance histories, operators logs, and design data to make timely decisions about maintenance requirements of power plant equipment”. In other words, PDM uses informed engineering decisions to determine whether maintenance is required, with the ultimate objective of eliminating or delaying scheduled preventive maintenance. If repairs are needed, the predictive evaluation helps determine what corrective steps to take. As a way to increase understanding of an appreciation for PDM, EPRI’s M&D Center developed and conducts an annual workshop, PDM Program Development and Implementation. The Center also produced this set of course notes to accompany the workshop.

Objectives are:

- To help attendees understand the features and functions of a PDM program.
- To expose attendees to PDM technologies in an actual plant situation.
- To show participants how to justify and evaluate a PDM program.

EPRI’s M&D Center developed the course and course notes with input from many utilities. The workshop is structured around five main topics: (1) learning PDM basics, (2) planning, (3) designing, (4) implementing, and (5) evaluating a program. The accompanying course notes contain a complete chapter for each of these content areas.

This report includes descriptions, charts, tables, illustrations and grades used to cover the five main topics addressed during the EPRI workshops.

EPRI BUSINESS GROUP: Energy Conversion Division

Predictive Maintenance Program Implementation Experience TR-111915

DETAILS: Final Report (122 pages)

DATE: Dec. 1998

KEYWORDS: Diagnostic Techniques
Monitoring
Reliability
Availability
Predictive Maintenance

ABSTRACT:

Predictive maintenance (PDM) is a process of collecting data, assessing machinery condition, and deciding when to perform maintenance. PDM saves money and improves machinery reliability as compared to preventive or corrective maintenance. This report describes the implementation of PDM programs at Commonwealth Edison's (ComEd's) fossil power plants.

DISCUSSION:

In October 1995 ComEd of Chicago, Illinois, and the EPRI's Maintenance and Diagnostic (M&D) Center of Eddystone, Pennsylvania, joined together to develop and implement a PDM Program within the fossil division of the ComEd system. The implementation involved 10 generating stations, and it included the Fossil Operations Availability Systems Team and ComEd's System Material Analysis Department (SMAD). In order for a PDM program to be successful, it is very important that all staff levels at the plant and at the central office have an awareness of the program. This is especially important when a program that employs a new approach to maintenance decision making is being implemented. Typically, any significant change in working habits is many times resisted initially, unless "Buy-In" of those affected by the changes occurs.

This report details the steps taken to achieve an aggressive cost improvement goal through the use of predictive maintenance and to change from a corrective maintenance strategy to a predictive maintenance strategy.

PDM programs were implemented at 10 ComEd fossil generating stations. ComEd's aggressive cost reduction goals were exceeded, and substantial progress was achieved moving from a corrective maintenance strategy to a predictive maintenance strategy. The program's success can be measured by the cost-effective identification and correction of potential equipment failures at the 10 generating stations with cost benefits calculated at over \$10.6 million in the first two years of the project. These savings are an excellent indicator that a level of awareness and "Buy-In" of the PDM Programs now exists at most of the stations.

The techniques and experience described in this report can be very beneficial to anyone wishing to implement PDM into multi-plant organizations such as the pulp and paper industry.

EPRI BUSINESS GROUP: Energy Conversion Division

Predictive Maintenance Guidelines TR-103374-V2

DETAILS: Final Report (Vol. 2-150 pages)

DATE: Oct. 1997

KEYWORDS: Predictive Maintenance
Diagnostic Techniques
Rotating Machinery
Vibration Control

ABSTRACT:

This document is the second in a series of guidelines designed to help electric power utilities to develop programs that take advantage of diagnostic technologies used to detect problems in machinery. The first volume of PDM guidelines defined predictive maintenance and dealt with basic issues of program goals, procedures, costs and implementation. Volume 2 covers some of the challenges of sustaining and optimizing the PDM program.

DISCUSSION:

In 1994, the EPRI M&D Center produced the first volume of the Predictive Maintenance (PDM) Guidelines for EPRI. This volume was produced from the initial efforts of the Predictive Maintenance Advisory Group, a group of utility industry experts assembled by the M&D Center for the purposes of establishing guidelines and providing a forum for the discussion of utility PDM Programs. The PDM Advisory Group then decided to organize, conduct regular meetings, elect officers, form subcommittees and establish a charter. This document, Volume 2 of the PDM Guidelines, is the result of these meetings.

Volume 2 of the Predictive Maintenance Guidelines offers a wide range of topics developed within the follow-on PDM Advisory Group Meetings. These topics represent the key concerns of utility industry PDM personnel. The biggest challenges facing advisory group members, discussed within the meetings, are illustrated and summarized.

Predictive Maintenance is a key strategy that allows plant personnel to look for problems with machinery before catastrophic failures can occur. In addition, PDM helps get maximum utilization out of existing machinery installations by eliminating unnecessary tear down inspections. These continuing efforts help to focus on emerging PDM technologies and how these technologies impact plant operations and maintenance.

EPRI BUSINESS GROUP: Energy Conversion Division

Predictive Maintenance Guidelines: Volume 3 – PDM Implementation Plan TR-103374-V3

DETAILS: Final Report (88 pages)

DATE: Dec. 1998

KEYWORDS: Availability
Reliability
Optimization
Diagnostic Techniques
Performance
Predictive Maintenance

ABSTRACT:

Predictive maintenance (PDM) is the process of collecting data, assessing machinery condition, and deciding when to perform maintenance. PDM saves money and improves machinery reliability as compared to preventive or corrective maintenance. This guideline describes how to plan the implementation of a PDM program in a fossil power plant.

DISCUSSION:

This guideline is a part of EPRI's Plant Maintenance Optimization (PMO) development efforts. The PMO mission is to lead the industry by developing and demonstrating products and services that will improve use of power plant maintenance resources and increase profitability for generation business units/companies. This document is one of a series of guidelines designed to help establish PDM programs that take advantage of diagnostic technologies used to detect problems developing in equipment. The first volume PDM Guidelines (TR-103774-V1, August 1994) covered the basic elements of an effective PDM program. The second volume (TR-103774-V2, October 1997) included enhanced PDM techniques and procedures. A third guideline (TR-109241, November 1997) outlined the elements of a PDM assessment, which is an unbiased evaluation of a utility's existing PDM practices. This particular volume of the PDM Guidelines (TR-103374-V3, December 1998) describes how to plan the implementation of a plant-wide PDM program.

The objectives of this report are:

- To advise on the elements of a beneficial PDM program and help plan the implementation of a site-specific comprehensive PDM program.
- To help achieve lower maintenance costs and improved equipment reliability through the PDM process.

A predictive maintenance program is usually implemented into an existing set of resources at a fossil power plant. While some elements of a PDM program may already be established, they will need to be organized into an effective process. Because of this, the first step is usually to perform a PDM assessment that identifies both the existing and missing elements. The next step, planning PDM program implementation, involves creating a customized plan to meet

company-or plant-specific needs and goals. The last step is to actually complete the implementation and maintain an ongoing plant PDM process.

This third volume of the PDM Guidelines covers the 14 key elements of a comprehensive PDM program, from technical, organizational, and financial viewpoints. It provides typical findings and recommendations from a PDM assessment, which serves as a guide for planning PDM program implementation. Also included are recommended procedures for performing cost-benefit analyses of a PDM program. In all, this guideline serves as a living document – a handbook for planning a PDM program and information resource to guide PDM planning in order to achieve both short- and long-term benefits.

EPRI's Predictive Maintenance Guidelines focus on the philosophy, development, and implementation of a PDM process. This process can play an important part in achieving full equipment utilization while maintaining a high level of reliability and minimizing maintenance costs. The PDM Guidelines will help reduce catastrophic equipment failures, extend time between major outages, avoid forced outages, reduce capital expenditures, and improve overall plant maintenance planning.

EPRI BUSINESS GROUP: Energy Conversion Division

Predictive Maintenance Guidelines: Volume 4 – PDM Practices TR-103379-V4

DETAILS: Final Report (64 pages)

DATE: Dec. 1999

KEYWORDS: Maintenance
Power Plant Availability
Diagnostic Techniques
Predictive Maintenance
Reliability Centered Maintenance

ABSTRACT:

Predictive Maintenance (PDM) is the process of collecting data, assessing machinery condition, and deciding when to perform maintenance. PDM saves money and improves machinery reliability as compared to preventive or corrective maintenance. This guideline describes how to evaluate the effectiveness of a PDM program by determining the level of “Best Practices” for key PDM elements.

DISCUSSION:

This guideline is part of EPRI’s development efforts under the Plant Maintenance Optimization (PMO) Target. The PMO mission is to lead the industry by developing and demonstrating products and services that will improve use of power plant maintenance resources and increase profitability for generation business units/companies. This document is one in a series of guidelines designed to help establish PDM programs that take advantage of diagnostic technologies used to detect problems developing in equipment.

The first volume of EPRI’s PDM Guidelines (TR-103374-V1, August 1994) covered the basic elements of an effective PDM program. The second volume (TR-103374-V2, October 1997) included enhanced PDM techniques and procedures, with inputs primarily from a PDM Advisory Group of utility industry O&M personnel. A separate guideline (TR-109241, November 1997) outlines the elements of a PDM Assessment, which is an unbiased evaluation of a utility’s existing PDM practices, and recommendations for improvement. The third volume (TR-103374-V3, December 1998) includes procedures for developing a PDM implementation plan. A related report (TR-111915, December 1998) describes the M&D Center’s experience with implementing PDM programs at Commonwealth Edison’s fossil power plants. This current volume of the PDM Guidelines describes how to evaluate the progress of implementing a plant-wide PDM program and what is required to achieve “Best Practices.”

A predictive maintenance program is usually implemented using an existing set of resources at a fossil power plant. While some elements of a PDM program may already be established, they need to be organized into an effective process. Because of this, the first step is usually to perform a PDM assessment that identifies both the existing and missing elements. The next step, planning PDM program implementation, involves creating a customized plan to meet company- or plant-specific needs and goals. This is followed by actually completing the

implementation and maintenance of an ongoing plant PDM process, including tracking, measuring, and improving key program elements.

This fourth volume of the PDM Guidelines describes a unique approach developed by the EPRI M&D Center to track and numerically evaluate each of the 14 key elements in a plant-specific PDM program. The numerical measurements not only provide critical insights into the weaknesses and strengths of each key element, but the evaluation process also allows comparisons with achievable Best Practices. To gain help making these assessments, and to continually improve weaker elements, users can take advantage of evaluation methods developed by the EPRI M&D Center, which are based on extensive PDM experience. The M&D Center has structured a database of Best Practices that it intends to maintain and update, which will help users determine if they are using Best Practices in all areas. EPRI's goal is to continue collecting PDM Best Practices data and periodically updating the Database to keep it dynamic. A copy of the current Database contents is in Appendix A of these Guidelines.

Predictive maintenance has become the dominant theme for the EPRI M&D Center. The Center provides the utility industry with a broad range of PDM-related products and services. These include PDM assessment services, PDM program and technology implementation services, training courses on PDM technologies, PDM automation tools such as the O&M Workstation, and specific PDM services such as thermography surveys. Over the past 12 years, the EPRI M&D Center has gained a wealth of experience implementing PDM programs at various utilities. EPRI's Predictive Maintenance Guidelines focus on the philosophy, development, and implementation of a PDM process. This process can play an important part in achieving full equipment utilization while maintaining a high level of reliability and minimizing maintenance costs. The PDM Guidelines will help reduce catastrophic equipment failures, extend time between major outages, avoid forced outages, reduce capital expenditures, and improve overall plant maintenance planning.

EPRI BUSINESS GROUP: Energy Conversion Division

Predictive Maintenance Assessment Guidelines TR-109241

DETAILS: Final Report (108 pages)

DATE: Nov. 1997

KEYWORDS: Predictive Maintenance
Diagnostic Techniques
Rotating Machinery
Monitoring
Maintenance
Technology Assessment

ABSTRACT:

This document is the third in a series of guidelines designed to help electric power utilities develop programs that take the advantage of diagnostic technologies used to detect problems in machinery. The PDM Assessment Guidelines provide the procedures necessary to plan and implement a plant wide predictive maintenance program.

DISCUSSION:

Over the past few years, the EPRI M&D Center has worked with a number of utility companies to implement a number of machinery diagnostics and monitoring programs. From this experience, the EPRI M&D Center has learned that there are existing technologies that are effective, but they lack program coordination. Alternatively, some programs are well coordinated, but lack the use of effective technologies. The EPRI M&D Center has identified what goes into successful programs and the pitfalls of unsuccessful programs. This project is part of EPRI's Plant Maintenance Optimization development efforts, and offers (1) a procedure for assessing a plant's current level of technology utilization, (2) identifies the strengths and weaknesses of existing programs and (3) provides new opportunities for the implementation of existing technologies.

PDM Assessment was designed to support the growing number of plant reliability programs that have been established throughout the utility industry. The assessment shows that Predictive Maintenance is a key strategy that allows plant personnel to look for problems with machinery before catastrophic failure can occur. The degree of success in applying PDM is contingent not only on the diagnostics selected, but on the capabilities of the personnel that maintain, monitor, and correct the deficiencies that are found through monitoring. This and other continuing efforts help EPRI member utilities focus on emerging PDM technologies and how these technologies impact plant operations and maintenance. In addition, PDM helps utilities get maximum utilization out of existing machinery installations by eliminating unnecessary tear down inspections.

EPRI BUSINESS GROUP: Energy Conversion Division

Electric Motor Predictive Maintenance Tools and Practices: Technology Review
AP-101840-V3P3

DETAILS: Technology Review

DATE: Dec. 1995

KEYWORDS: Electric Motors
Predictive Maintenance
Maintenance Costs
Software Tools

ABSTRACT:

Fossil power plants typically base electric motor maintenance on fixed intervals of time-in-service rather than on actual motor condition. With such an approach, certain motors not scheduled for maintenance have failed unexpectedly. A predictive (condition-based) approach to motor maintenance, using commercially-available monitoring tools and EPRI's electric motor predictive maintenance (EMPM) software, can help reduce or eliminate unexpected motor failures, avoid unnecessary maintenance, focus maintenance efforts on the motors that need work, and increase motor reliability.

EPRI BUSINESS GROUP: Energy Conversion Division

Electric Motor Predictive Maintenance Program TR-108773-V2

DETAIL: Final Report (Vol. 2-248 pages)

DATE: Aug. 1999

KEYWORDS: Electric Motors
Monitoring
Predictive Maintenance
Reliability Centered Maintenance

ABSTRACT:

This final report describes and summarizes the activities to date regarding the development of the Electric Motor Predictive Maintenance (EMPM) Tailored Collaboration Program. The program was conducted by Maintenance and Diagnostics (M&D), Inc., through the EPRI M&D Center. The raw motor data (voltage, current) recorded during the test are available on CDROM (TR-108773-V2CD) by contacting the EPRI Distribution Center.

DISCUSSION:

The report describes the initial program development issues addressed by the participating utility companies including motor selection, motor traceability issues, testing methods, data collection/evaluation, software development, and documentation of the associated cost benefits. The report also describes the actual utility industry experiences while implementing such a program at their plants. Also included is a section on the research testing that was performed in a controlled environment to evaluate the effectiveness of several new technologies and their ability to detect induced faults in the test motors.

The objectives of this project were:

- To develop a beneficial Electric Motor Predictive Maintenance (EMPM) Program
- To focus on medium-to-large 4KV and above electric motors
- To set up a program where each participating utility plant selects 30 of their motors, performs test utilizing various technologies, and submits the data for incorporation into a common database.
- To develop the database in an effective and logical manner
- To determine cost/benefits

All of the original participating utility plants realized cost benefits from the program; these initial benefits can now be extended to include more of the motors in their plants. The level of participation varied from utility to utility and, not surprisingly, the amount of cost benefits realized was proportionate to the respective level of participation. More importantly, each of the participants have now been made keenly aware of the benefits of the EMPM approach to motor

maintenance; they have also been provided with the tools and procedures for the implementation of an Electric Motor Predictive Maintenance Program at their utilities.

Electric utilities have, for many years, performed maintenance on medium-to-large sized electric motors (4KV and above) on a scheduled, preventive basis (time based) or on a fix-when-broken corrective basis. However, because of the competitive nature prevailing in the Electric Power Production Industry today, and with the advent of new technologies being developed, companies are recognizing that the application of predictive maintenance strategies can reduce cost and improve equipment availability.

EPRI BUSINESS GROUP: Energy Conversion Division

Summary Report of Advanced IR NDE of Service Water Piping Systems (SWP) TR-107463

DETAILS: Application Report (62 pages)

DATE: Dec. 1997

KEYWORDS: Infrared Thermography
Nondestructive Evaluation
Erosion Corrosion
Service Water System
Predictive Maintenance
Inspection

ABSTRACT:

Infrared thermography (IR) is well established as a predictive maintenance tool for evaluation of mechanical, electronic, and electrical components. For these applications, IR is used in a passive measurement mode for detection of anomalies in the characteristic thermal pattern that is readily analyzed using passive IR techniques. For the application described in this report an active IR technique, thermal injection, was evaluated.

DISCUSSION:

Service Water Piping (SWP) systems typically do not exhibit a characteristic thermal pattern that is readily analyzed using passive IR measurement techniques. For this application, an active IR technique, thermal injection, was evaluated.

Laboratory investigation of the IR thermal injection technique established target detection capabilities for this method. Additional work concentrated on flash hood modifications to address pipe curvature effects and to extend the effective imaging field of view. Field deployment of the IR inspection system identified the need for additional modification of the flash hood to reduce its profile for inspection in tight access areas and to facilitate transport through obstacles in the plant.

The SWP system at electric power generation plants provides cooling for a variety of safety and nonsafety-related components and systems. Under accident conditions in a nuclear power plant, the SWP system provides cooling water to components and systems that are critical to a safe plant shutdown. Conventional nondestructive inspection techniques are in place for detection of erosion-corrosion damage in these systems. Other inspection techniques, such as IR NDE, continue to be evaluated in an effort to more efficiently evaluate these critical piping systems.

EPRI BUSINESS GROUP: Energy Conversion Division

A Method to Predict Cavitation and the Extent of Damage in Power Plant Piping

TR-103198-T1/T2

DETAILS: Final Report (T1-126 pages; T2-126 pages)

DATE: Dec. 1993

KEYWORDS: Cavitation
Erosion Corrosion
Equipment Reliability
Material Degradation
Piping Systems
System Reliability
Predictive Maintenance

ABSTRACT:

Cavitation erosion has been encountered in most nuclear and fossil power plants. EPRI developed a comprehensive program to understand its causes and the influence of governing parameters. This report provides a method for predicting the likelihood that cavitation will occur in piping components and its expected severity. This method can be used to evaluate candidate corrective actions.

DISCUSSION:

Cavitation erosion damage in power plant piping systems is a serious concern because it is often difficult to detect and can lead to unscheduled repairs and costly outages. With the formation and collapse of vapor bubbles, cavitation creates noise and vibration, leaving a sharp sandpaper finish that can quickly erode through the component wall.

The objective of this report was to combine valve design data, wear data, and plant operating data collected during cavitation in an empirical model for predicting the likelihood of cavitation occurring and its expected intensity.

A literature review was performed to develop a clear description of the cavitation phenomenon. Four severity levels of cavitation erosion were defined: incipient cavitation, critical cavitation, incipient damage, and choking cavitation. The predictive method selected is based on a variety of data, including flow characteristics, sound and vibration levels, and pitting rates of material specimens exposed to cavitation. These data indicate that the intensity of cavitation for each level may be represented by a third-order polynomial equation. Cavitation coefficients were developed using orifice and valve data for a baseline pressure and size. Scaling factors are provided to facilitate extrapolation to other pressures and sizes.

The method described in this report can be applied to predict the onset of cavitation erosion and estimate the extend of cavitation damage in specific plant piping systems. The predictive method currently includes orifices; butterfly, globe, cone, ball, and gate valves, and bends and elbows. Other components are excluded due to the paucity of data. Because the accuracy of the method

depends to a large extent on the amount of available test data, components are categorized according to three classes of reliability, with orifices having the highest rating of the components considered. Ongoing data collection will further improve the reliability of the predictive method. Tier 1 of this report discusses the cavitation phenomenon as well as EPRI's method for predicting its onset and extent of damage. Tier 2 contains the cavitation coefficients, which will be revised and updated as new data becomes available.

EPRI BUSINESS GROUP: Energy Conversion Division

Infrared Thermography Guide (Revision 2)

NP-6973-R2

DETAILS: Final Report (38 pages)

DATE: Feb. 1995

KEYWORDS: Infrared Thermography
Fossil-Fuel Power Plants
Predictive Maintenance

ABSTRACT:

Costly equipment outages can be reduced by implementing a comprehensive predictive maintenance program. Infrared thermography (IR), a fundamental component of such programs, uses nonintrusive techniques to monitor the operating condition of equipment and components. This revised report provides updated information to assist in implementing an effective IR program.

DISCUSSION:

IR has proved to be an effective predictive maintenance and diagnostic tool. For example, it can be used to locate areas of condenser air in-leakage, identify bad terminal lugs/connections and leaking valves, and perform surveillance checks for nozzle blockage on the containment spray ring header in a nuclear power plant. To broaden the range of IR applications, EPRI sponsored development of a guide that would address IR diagnostic capabilities. This guide was originally published in 1990 and is being revised to incorporate user input and to update information on IR equipment and vendors.

This guide, which provides a compendium of information rather than definitive standards, describes IR theory, summarizes existing and potential IR application, and offers technical information necessary for developing an effective in-house IR program. Key topics discussed in the guide including the following:

- The science of thermography
- Selection of infrared instruments
- IR applications
- Basic elements of an in-house program
- Training and certification

This revision provides updated information on commercial infrared sensing and imaging instruments including additional information to qualitative and quantitative focal plane array systems.

Although IR has been in use at commercial electric power-producing stations since the early 1970s, no current standards or universally accepted practices exist for its application. The lack of

standards and accepted practices combined with the general unawareness of IR capabilities prompted development of a comprehensive IR guide. Information in this report describes IR in sufficient detail to enable a utility engineer to effectively implement IR techniques in a predictive maintenance program.

EPRI BUSINESS GROUP: Energy Conversion Division

Infrared Thermography Anomalies Manual TR-108935

DETAILS: Final Report (48 pages)

DATE: Aug. 1997

KEYWORDS: Infrared Thermography
Predictive Maintenance
Diagnostic Techniques
Maintenance
Non-destructive Evaluation

ABSTRACT:

Infrared thermography (IRT) is a non-intrusive diagnostic technique that can play an important role in predictive maintenance programs. This manual shows how IRT can be applied in the field to detect anomalies in a wide-range of power plant systems. This activity is part of EPRI's Plant Maintenance Optimization development efforts which are intended to help reduce the costs by developing and demonstrating cost-effective maintenance methods.

DISCUSSION:

Most of the equipment found in a typical electric generating station exhibits some type of abnormal thermal pattern prior to failure. IRT is a non-invasive diagnostic technique that can detect abnormal thermal patterns by making simultaneous temperature measurements of multiple points on the surface of a piece of equipment. These data are displayed as pictures, commonly referred to as thermograms, that can be analyzed in real-time or stored electronically and analyzed later. Information from thermograms can be used to plan maintenance and avoid catastrophic equipment failures and unscheduled downtime.

After a brief introduction to the technical background of IRT, the manual describes how infrared thermography can be used to detect thermal anomalies in power plant equipment. The thermal anomalies illustrated in this document include station electrical applications, rotating equipment applications, transmission and distribution applications, and performance applications. Some of the cases are analyzed quantitatively, while others are analyzed qualitatively. Most of the cases feature a thermal image that is accompanied by a corresponding visual image. An arrow superimposed on the visual image allows the reader to match locations on the visual image with the corresponding locations on the thermal image.

The information contained in this document was acquired while using IRT to identify potential problems in the field. In each case, feedback was received from maintenance personnel involved with repair work as to the "as found" condition of the equipment.

This feedback helps refine diagnostic technique and should be an integral part of preventive maintenance. All detected anomalies should also be re-inspected with IRT after repairs are completed to verify that the problem has been corrected.

EPRI BUSINESS GROUP: Energy Conversion Division

**Infrared Thermography User's Guide (IRUG) Meeting Minutes, 1998
PC-110509**

DETAILS: Proceedings (6 pages)

DATE: Aug. 1998

KEYWORDS: Infrared Thermography
Inspection
Standards
Predictive Maintenance
Meetings
Technology Utilization

ABSTRACT:

This report presents the meeting minutes from the eighth Infrared Thermography User's Group (IRUG) meeting hosted by The Southern Company and held from July 28 through July 31, 1998 in Atlanta, Georgia. The information in this document summarizes the presentations and discussions from that meeting. The meeting focused on the use of infrared technology and how it can benefit the electric utility industry and its customers.

EPRI BUSINESS GROUP: Energy Conversion Division

Infrared Thermography Anomaly Assessment TR-111916

DETAILS: Final Report (54 pages)

DATE: Dec. 1998

KEYWORDS: Infrared Thermography
Nondestructive Evaluation
Predictive Maintenance
Cost Benefit Analysis

ABSTRACT:

Infrared Thermography (IRT) is a non-intrusive diagnostic technique that has become an important tool in the establishment of predictive maintenance programs. By presenting specific case histories, this report shows how IRT can be applied in the field to detect anomalies in a wide-range of power plant systems and result in corrective actions with real dollar cost benefits.

DISCUSSION:

Most of the equipment found in a typical electric generating station exhibits some type of abnormal thermal pattern prior to failure. IRT is a non-invasive diagnostic technique that can detect these abnormal thermal patterns by making simultaneous temperature measurements of multiple points on the surface of a piece of equipment. These data are displayed as pictures, commonly referred to as thermograms, that can be analyzed in real-time or stored electronically and analyzed later. Information from thermograms can be used to plan maintenance and avoid catastrophic equipment failures and unscheduled downtime. This report extends the case histories previously reported in the "Infrared Thermography Anomalies manual" (EPRI report TR-108935) and also relates to "Infrared Thermography Developments for Boiler, Condenser and Steam Cycle" (EPRI report TR-109529).

This report is part of EPRI's Plant Optimization (PMO) developmental efforts. The PMO mission is to lead the industry in developing and demonstrating products and services that will improve utilization of power plant maintenance resources and increase profitability for generation business units/companies.

After a brief introduction to the technical background of IRT, the report describes several infrared thermography case histories where thermal anomalies were detected in various types of power plant equipment. The thermal anomalies illustrated in this document include station electrical applications, rotating equipment applications, transmission and distribution applications, and performance applications. Some of the cases are analyzed quantitatively while others are analyzed qualitatively. Most of the cases feature a thermal image that is accompanied by a corresponding visual image. An arrow superimposed on the visual image allows the reader to match locations on the visual image with the corresponding locations on the thermal image.

The information contained in this document was acquired while using IRT to identify potential problems in the field. In each case feedback was received from maintenance personnel involved

with repair work regarding the “as found” condition of the equipment. This feedback helps refine diagnostic techniques and should be an integral part of preventive maintenance. All detected anomalies should also be re-inspected with IRT after repairs are completed to verify that the problem has been corrected. In addition, cost benefit analyses should be made to demonstrate to management the projected dollars saved by applying IRT and setting up a comprehensive IRT program.

EPRI BUSINESS GROUP: Energy Conversion Division

Infrared Thermography Field Application Guide TR-107142

DETAILS: Final Report (92 pages)

DATE: Jan. 1999

KEYWORDS: Infrared Thermography
Predictive Maintenance
Non-destructive Evaluation
Transmission Lines
Distribution Lines
Substations

ABSTRACT:

Infrared thermography (IR) is widely used as part of a predictive maintenance program for inspection of a variety of plant mechanical and electrical components. The non-contact, remote inspection capabilities of this technology make it extremely appealing for on-line, in-service inspection applications. By observing and analyzing the thermal signature of an operating component, the thermographer is able to provide valuable information about the continued operability of that component.

Implementations and maintenance of an Infrared Thermography program have provided the utility industry with tremendous paybacks in the form of lowered operating costs and improved availability. Continued expansion of these programs to include additional components will yield additional benefits.

DISCUSSION:

EPRI Report NP-6973, Infrared Thermography Guide, Revision 2, provides guidance to the utility thermographer for using IR as a predictive maintenance tool. It provides information on the IR theory of operation, IR equipment operation and selection, inspection techniques, inspection application examples, training and certification, and key elements of an in-house IR program.

Information for inclusion in the Infrared Thermography Field Application Guide was solicited from utility industry thermographers and other recognized industry experts. General information and specific examples are presented for each application area. It is intended that the information presented in this report will supplement the previously released Infrared Thermography Guide, Revision 2.

This report provides a brief review and refresher tutorial on heat flow basics and infrared radiation theory, along with a tutorial on infrared nondestructive inspection using passive and active IR techniques. The IR applications for substation and transmission and distribution lines are discussed in terms of key requirements for a successful program and are supplemented with sample images.

Infrared thermography has been proven to be a valuable predictive maintenance tool for utility industry inspection programs. This report also illustrates how IR is developing as a tool for nondestructive inspection. IR programs are continually growing in scope and effectiveness. By providing guidance for the implementation of proven IR techniques and by exploring the feasibility of newly developed techniques power plants can continue to improve plant performance and availability.

EPRI BUSINESS GROUP: Energy Conversion Division

5

MAINTENANCE MANAGEMENT & OPTIMIZATION

Assessing Maintenance Effectiveness **TR-107759**

DETAILS: Technical Note (27 pages)

DATE: Dec. 1996

KEYWORDS: Maintenance
Predictive Maintenance
Performance
Maintenance Assessment
Maintenance Practices

ABSTRACT:

Assessing the effectiveness of maintenance practice requires a consistent set of measures that will quantify successful practices and provide an opportunity for improvements. This tech note presents a set of measures that could be used for temporary as well as continuous evaluation of maintenance practices used at nuclear power plants.

DISCUSSION:

Determining the impact of changes in practices and techniques requires some sort of measuring instrument. The measuring instrument must be based upon values that are acceptable and agreed upon by people that will use these values. The values have to be tied to some fairly repeatable standards that can be obtained in a routine fashion. Currently, processes are implemented and a plant department is tasked to look at the cost benefit of implementing certain practices. These measurements are not intended to focus on cost as a general factor but to look at what technical benefits can be obtained from implementing practices. However, there is little data that provides guidance or recommends an approach to this task. This report is the first attempt at providing guidance in this area and suggestions that can be used for comparison between power plants.

A set of measures to assess maintenance effectiveness has been presented. The report presents recommendations for plants to determine which measures will be useful according to their plant objectives. These measures are geared toward maintenance activities in particular but can be used for other activities in general.

This document provides a tool that can be used to evaluate maintenance activities. Plants have made substantial improvements in maintenance practices, and the report recommends ways to measure these improvements. The measures presented in this document are not meant to be the

final work but a primer for maintenance assessment practices. Plants are encouraged to use this report as an implementation document for the concept of maintenance performance measures. The measures will require revision and updating as the industry gains more experience with the overall concept.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

While this report focused on nuclear power plants, the results are equally applicable to any power plant, such as those in the pulp and paper industry.

Improving Maintenance Effectiveness Guidelines: An Evaluation of Plant Preventive and Predictive Maintenance Activities TR-107042

DETAILS: Final Report (114 pages)

DATE: Mar. 1998

KEYWORDS: Preventive Maintenance
Predictive Maintenance
Maintenance
Maintenance Assessment

ABSTRACT:

Effective maintenance programs can ensure reliable performance of plant systems, structures, and components (SCCs). Special performance requirements and increased competition in the utility industry demand a well thought-out maintenance strategy that is supported by a balanced mix of maintenance activities and techniques to achieve reasonable equipment reliability and availability.

DISCUSSION:

Over the past few years, utility companies have experimented (with varying levels of success) with changes in their maintenance practices and programs. A certain level of preventive maintenance (PM) has always been required to operate nuclear power plants; however, achieving an optimal mix of PM activities remains a challenge for some nuclear plant operators. Reliability-centered maintenance (RCM) and other customized versions of this methodology have been used to adjust maintenance practices for certain SCC's. Most nuclear plant operators have recognized that dependence on planned and periodic maintenance alone does not provide the level of performance desired by most nuclear plant operators.

Objectives of this report were to:

- To provide a picture of maintenance optimization processes used in the nuclear industry
- To present alternative strategies that can be used by power plants to assist the optimization process
- To review and discuss the current predictive maintenance (PDM) tools being used in most nuclear power plants

Current maintenance practices used at most nuclear power plants have incorporated some type of predictive maintenance activity into their maintenance programs. However, predictive maintenance practices for the most part are not the result of a fully developed strategy, but are the consequences of trying to use the most current technology. Even with the lack of overall strategic planning, most sites have maintenance programs that function well and have been fairly successful in controlling maintenance costs, while achieving a respectable level of equipment performance. Many of the programs were implemented with the intent to meet prescribed

equipment operational and performance goals. By improving use of current maintenance practices, power plants should be able to maintain reliable operations and achieve lower maintenance costs through more effective use of technology.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

While this report is focused on nuclear power plants, the results are equally applicable to any power plant operation.

Maintenance Work Management Practices Assessment TR-106430

DETAILS: Interim Report (6 pages)

DATE: April 1997

KEYWORDS: Reliability
Maintenance Optimization
Best Practices
Systems Analysis
Maintenance Assessment

ABSTRACT:

EPRI's Plant Maintenance Optimization (PMO) mission is to lead the industry by developing and demonstrating products and services for improved utilization of power plant maintenance resources and increased profitability for generation business units/companies. This interim report covers the first six generation stations that have undertaken Maintenance Assessments to identify possible improvements in maintenance practices and quantify their potential benefits.

DISCUSSION:

EPRI's Plant Maintenance Optimization program is intended to help reduce the cost of power production by improving human and technical systems in fossil power plants. Improvements increase revenues as equipment becomes more available for production and decrease costs as less parts and labor are needed for repair. A Value-Based Maintenance Grid and associated evaluation criteria have been developed to be a framework to evaluate the cost efficiency of work maintenance practices at fossil power plants. This interim report summarizes Maintenance Assessments using this methodology of six of a planned 12-15 generation stations.

The report describes assessment results from six power plants. The assessment process includes gathering benchmark data, interviewing plant personnel, making field observations, and conducting audits of plant procedures and documents. Plant personnel are involved in every phase of the process with all information collected during interviews kept anonymous in order to encourage full participation. Assessments are based on the Value-Based Maintenance Grid, which compares plant practices with industry best practices. After the Grid has been further tested and improved, EPRI plans to issue the Grid description for use by member utilities.

People and work processes areas most often identified for improvement in the assessments were scheduling of work, performance measurement, reporting, problem-solving, accountability, and internal customer satisfaction. Technical system areas most often identified for improvement were such maintenance technologies as predictive maintenance and streamlined reliability-centered maintenance. Notably, because plant staffs participated in every phase of the assessment process, improvement efforts began during the evaluation itself. This report provides results for recommendations and estimated of return on investment that could be expected from a fully implemented Maintenance Work Management Improvement Effort based on the 6 plant projects.

The assessment methodology described in this report can identify maintenance management practice improvements with a potential to significantly increase revenues and decrease costs at fossil power plants. To realize these benefits, however, users need to make a real commitment to the process. A serious assessment of plant practices involves costs and effort that can only be justified if suggested improvements are implemented.

EPRI BUSINESS GROUP: Energy Conversion Division

Maintenance Work Management Improvement: Improving Culture and Work Process

TR-109734

DETAILS: Final Report (64 pages)

DATE: March 1998

KEYWORDS: Reliability
Maintenance Optimization
Fossil-Fuel Power Plants
Best Practices

ABSTRACT:

EPRI's Plant Maintenance Optimization (PMO) mission is to develop and demonstrate products and services for improved use of power plant maintenance resources and increased profitability. Based on a series of work management improvement projects, EPRI plans to develop a best practices guideline. As part of this effort, this document details how to improve fossil power plant work culture and work processes.

DISCUSSION:

The cost leverage of favorable fuel contracts alone is not enough of an advantage to keep fossil power stations competitive in an open market. Enhancement of non-capital resources, such as work culture and work processes, also is needed to help plants maintain their advantage as low-cost energy producers. EPRI's experience has shown that work management improvement projects enhance work processes and work culture in fossil power plants.

Objectives of this report were:

- To improve human and mechanical system reliability throughout fossil power stations.
- To define and reinforce station values, vision, mission, and direction.
- To develop a system of accountability.

Improvement projects make changes for the better. Typically, non-fuel O&M costs have dropped by more than 11 percent and availability from a five-year average in the low 80th percentile has climbed to the upper 90th. Forced outages also have decreased, with a five-year Equivalent Forced Outage Ration (EFOR) average falling from 7.5 percent to a current year-to-date average of just over 4 percent. The end of an improvement project, however, does not mean the improvement process is over. With effective improvement structures in place, fossil power stations are prepared for continuous improvement.

EPRI BUSINESS GROUP: EPRIGEN Group

Maintenance Work Management – Best Practices Guidelines: Maintenance Assessment and Improvement TR-109968

DETAILS: Final Report (56 pages)

DATE: Jan. 1998

KEYWORDS: Maintenance Optimization
Reliability
Operation
Best Practices
Planning
Fossil-Fuel Power Plants
Maintenance Assessment

ABSTRACT:

This report on maintenance work management best practices is part of EPRI's Plant Maintenance Optimization (PMO) development efforts. Based on a series of assessment and improvement projects, the report describes the process and typical results.

DISCUSSION:

Deregulation has prompted a drive to better manage operation and maintenance (O&M) of fossil power plants. To help its member utility companies make the transition and become more competitive in the new era of deregulation, EPRI has initiated PMO development efforts. These efforts are intended to help reduce production costs by developing and demonstrating cost-effective maintenance methods. This report is part of that program.

The report identifies three basic steps to achieve maintenance best practices: (1) A **Maintenance Assessment** that results in an (2) **Improvement Plan** whose completed projects are kept viable through brief progress reviews, or (3) **Reinforcement**. While the basic process is similar from plant to plant, results are highly individualized. Organizations that achieve the best practices do so through a process of customization and adaptation during each of the three basic steps.

Every plant has its own unique set of work management best practices. The process by which plants identify and achieve their own best practices takes effort, time, and money. Experience has shown that outside, expert facilitation is an important key to success; internal programs take longer and do not generally achieve the same level of success. For more information on maintenance work management best practices, refer to these EPRI reports: Plant Maintenance Optimization (TR-108949-R1) summarizes the assessment and improvement process; Maintenance Work Management Practices Assessment (TR-106430) outlines results from the first six assessments; Maintenance Work Management Improvement: Improving Culture and Work Process (TR-109734) describes the improvement process based on plant projects; and, Value-Based Maintenance Grid (TR-108937) details the assessment grid.

EPRI BUSINESS GROUP: EPRIGEN Group

Computerized Maintenance Management System Best Practices Guideline TR-111464

DETAILS: Final Report (106 pages)

DATE: Oct. 1998

KEYWORDS: Maintenance Management
Maintenance Optimization
Computerized Maintenance System

ABSTRACT:

A computerized maintenance management system (CMMS) tracks maintenance work and stores electronic work orders. This system is at the heart of maintenance work processes, work analysis and measurement, and several plant support processes. The greatest value can be obtained from CMMS technology when it is integrated with plant organization and work processes. This guideline report describes the best practices for selection and implementation of a new CMMS at an electric utility.

DISCUSSION:

The project is part of EPRI's Plant Maintenance Optimization (PMO) development efforts. The PMO mission is to develop and demonstrate products and services that will improve application of power plant maintenance resources and increase profitability for generation business units/companies. This best practices guideline summarizes a series of CMMS selection and implementation projects performed with utility companies of different sizes and with various CMMS.

This report breaks CMMS implementation into the following eight steps:

- Perform process reengineering to realize maximum benefit from a CMMS.
- Determine system requirements in terms of replacing the existing CMMS and interfacing the new CMMS to existing systems.
- Plan CMMS implementation, including numerous system preparation activities.
- Justify purchase by enumerating tangible and intangible benefits of the CMMS.
- Implement process changes to improve the efficiency and effectiveness of the maintenance organization.
- Prepare the CMMS in terms of equipment hierarchy issues and failure codes.
- Train users on the CMMS equipment.

New CMMSs are now in operation at 13 sites. Financial benefit projections indicate that return of the initial investment will be realized within 2-3 years; a return of three times the system investment, including internal labor, will be realized in the first 5 years.

CMMS technology will automate maintenance work practices in fossil power plants and help them become competitive in the deregulated power market. A number of EPRI projects have developed and demonstrated the tools, expertise, and experience to successfully integrate CMMSs into plant maintenance organizations. Related EPRI reports address CMMS selection (TR-108938) and maintenance work process integration (TR-110272) at Wisconsin Public Service as well as CMMS selection (TR-109728) at Cinergy.

EPRI BUSINESS GROUP: Energy Conversion Division

Reliability Centered Maintenance (RCM) Workstation for Power Delivery: Software User Manual CM-108076-R1

DETAILS: Final Report (170 pages)

DATE: Dec. 1997

KEYWORDS: Maintenance Management
Preventive Maintenance
Predictive Maintenance
Maintenance Optimization
Maintenance Costs
Power Plant Reliability

ABSTRACT:

The overall goal of Reliability Centered Maintenance (RCM) is to improve the economic posture of a power plant by promoting cost-effective application of maintenance resources. EPRI's RCM Technical Reference for Power Delivery provides essential technical data and guidance for conduction RCM studies of power delivery equipment and systems. It serves as the "handbook" of RCM for the utility industry power delivery sector.

DISCUSSION:

Preventive maintenance is perhaps the single largest controllable cost of a utility operation. Careful planning and good management are essential to achieve an optimal balance between cost of maintenance and service reliability. Traditional maintenance programs rely heavily on time-directed maintenance and manufacturer recommendations to preserve equipment operation. RCM addresses problems of traditional maintenance programs by focusing resources on preservation of function as opposed to individual equipment operation. RMC addresses problems of traditional maintenance programs by focusing resources on preservation of function as opposed to individual equipment operation. RCM also promotes use of predictive techniques and recognizes that some failure can be more cost-effectively handled through corrective maintenance. This project used results of a previous substation effort to expand and refine the material in developing appropriate guidance and references for all power delivery, and included technical examples of RCM studies for transmission and distribution equipment.

This technical reference presents a compendium of resources that are indispensable for those engaged in RMC studies of power delivery equipment and systems. The technical reference is a valuable tool for individuals involved in optimizing maintenance resources – it contains both guidance in applying RMC methods and appropriate data references suitable for use with or without RCM analysis software.

The technical reference materials are also available in a software version, the RMC Technical Reference for Power Delivery. A companion software product, the RMC Workstation for Power Delivery, provides a computerized environment for conducting and documenting RCM studies. The workstation product allows users to conduct RCM studies using methods and generic data in

the technical reference. Thus, the two software products are compatible from the standpoints of philosophy, process, and technology. Minimum system requirements are a 486/50 PC with 8 megabytes of RAM and 15 megabytes free hard disk space.

This technical reference and its companion software products are a response to industry needs for guidance in performing maintenance optimization studies using RCM methodology. Several trial applications of RCM have shown potential for substantial savings in maintenance costs (averaging 5 percent to 20 percent) while providing quantifiable improvement in service reliability. Related EPRI products under development include an RCM-based model of a Living Preventive Maintenance (PM) Program, an approach to vegetation management based on RCM philosophies, a comprehensive maintenance management tool called Maintenance Management Workstation (MMW), and a transmission field inspection and maintenance tool called Transmission Inspection & Maintenance System (TIMS).

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Streamlined Reliability-Centered Maintenance (SRCM) Program for Fossil-Fired Power Plants TR-109795-V1

DETAILS: Final Report (Vol. 1-82 pages)

DATE: March 1998

KEYWORDS: Power Plant Availability
Maintenance Optimization
Reliability-Centered Maintenance
Power Plant Reliability

ABSTRACT:

Following EPRI's philosophy to use and expand existing technology if it makes economic sense, the Institute's Plant Maintenance Optimization Target has adopted a reliability-centered maintenance (RCM) process called Streamlined RCM, or SRCM. SRCM provides a cost-effective process to determine the optimum maintenance strategy for plant systems and equipment based on importance to business objectives. SRCM maintains all the basic steps of traditional RCM.

DISCUSSION:

The evolution into a nonregulated industry has prompted a drive to control operation and maintenance (O&M) programs among electric utility companies. For fossil-fired plants, controlling O&M includes the transition from reactive maintenance to a preventive/predictive maintenance strategy. To help its member utility companies make the transition and become more competitive, EPRI has initiated Plant Maintenance Optimization development efforts to help reduce production costs by developing and demonstrating cost-effective maintenance methods. This project is part of that program.

By using a logical step-by-step approach to determine the maintenance strategy for plant/systems, utility companies are able to document the basis for the maintenance program, more effectively manage change to the plant maintenance program, and focus resources on doing the right task at the right time on the right equipment. This report describes how all of the SRCM tools and processes work together. Accompanying this process is software, program management, system and component templates, implementation support, training, and living program development.

Experience within the utility industry shows that some plants who have had essentially no formal plant maintenance program are using SRCM to create a program for the first time, while other plants have used SRCM to optimize their existing program. All utility plants anticipate a reduction in unscheduled breakdown maintenance. Other intangible benefits include improved communication between key plant staff concerning system functions, equipment failure causes, and their significance. Additionally, most plants that have applied SRCM have computed a payback of less than one year.

EPRI BUSINESS GROUP: EPRIGEN Group

Streamlined Reliability-Centered Maintenance (SRCM) Implementation Guidelines

TR-109795-V2

DETAILS: Final Report (Vol. 2-130 pages)

DATE: Dec. 1998

KEYWORDS: Maintenance
Optimization
Performance
Predictive Maintenance
Reliability-Centered Maintenance

ABSTRACT:

Following EPRI's philosophy of using and developing existing technology where it makes economic sense, EPRI has adopted a reliability-centered maintenance (RCM) process called streamlined RCM or SRCM that maintains and improves all the basic steps of traditional RCM. SRCM provides a cost-effective process to determine the optimum maintenance strategy for plant systems and equipment based on their importance to business objectives.

DISCUSSION:

Deregulation and increasing competition have prompted a drive to control operation and maintenance (O&M) programs among electric utility companies. For fossil-fired plants, controlling O&M includes the transition from reactive maintenance to a preventive/predictive maintenance strategy. To help its member utility companies make the transition and become more competitive, EPRI has initiated development efforts intended to help reduce production costs by developing and demonstrating cost-effective maintenance methods. This project is part of that program.

Volume 1 of this report, described the development status of SRCM for fossil plants at the end of 1997. For Volume 2 of this report, the project team compiled guidelines for the implementation of SRCM. The guidelines include an outline of the SRCM process, an account of current utility industry participation, and a description of SRCM project tools currently available or under development. The team also analyzed the benefits of SRCM at three utilities.

By using SRCM's logical step-by-step approach to determine the maintenance strategy for plant/systems, plants are able to document the basis for the maintenance program, more effectively manage change to the plant maintenance program, and focus resources on doing the right task at the right time on the right equipment. This report describes how all of the SRCM tools and processes work together and provides information on the status of utility industry projects and tool development. Several tools have been completed to enhance the performance and maintenance of SRCM analysis. Both system level and component level templates have been developed to provide efficiency and consistency in analysis. A Living Program module in the SRCM Workstation has been developed to assist and automate the updating of the initial SRCM analysis.

As of the end of 1988, 22 utility companies have participated in the SRCM program. Some plants that have had essentially no formal plant maintenance program are using SRCM to create a program for the first time, while other plants have used SRCM to optimize their existing plant maintenance program. All utility industry plants anticipate a reduction in unscheduled breakdown maintenance. Other intangible benefits include improved communication between key plant staff concerning system functions, equipment failure causes, and their significance. Additionally, most plants that have applied SRCM have established a payback of less than one year.

EPRI BUSINESS GROUP: EPRIGEN Group

Value-Based Operations and Maintenance Practices TR-104853

DETAILS: Final Report (60 pages)

DATE: Jan. 1995

KEYWORDS: Decision Analysis
Decision Making
Operating Costs
Optimization
Fossil-Fuel Power Plants

ABSTRACT:

Utility companies can maximize the net corporate value of their operating and maintenance practices through a systematic approach that employs decision analysis techniques and marginal-value analysis. In a case study, that confirmed the merit of the value-based approach, Duke Power Company developed and tested decision trees for specific predictive maintenance scenarios.

DISCUSSION:

As power markets open to competition, fossil plant operators face increased pressure to reduce operation and maintenance (O&M) costs. Traditional O&M decision methods—which rely primarily on routine scheduling and outage inspection data—can lead to overly conservative decisions that yield reliable generation, but not necessarily at least cost. To help maximize the economic value of O&M decisions, EPRI’s Fossil Assets Management (FAM) project is developing rigorous methods—based on probabilistic and marginal-value analyses—for determining the systemwide corporate value of candidate operational and maintenance alternatives.

The case study at Duke Power, involving maintenance strategy for a boiler feedwater pump, helped confirm the value of this approach for making O&M decisions. The full account of Duke’s application and the decision trees featured in this report will provide a guideline for those wishing to use this approach for similar decisions. All the models developed under this project are structured to account for failure or degradation modes, the cost of such events, and the associated uncertainties in failure and cost estimation.

EPRI BUSINESS GROUP: EPRIGEN Group

Value-Based Maintenance Grid for Assessing Work Management TR-108937

DETAILS: Final Report (170 pages)

DATE: Feb. 1999

KEYWORDS: Fossil-Fuel Power Plants
Maintenance Management
Technology Assessment
Optimization
Equipment Reliability

ABSTRACT:

The Value-Based Maintenance Grid is a tool that assesses maintenance processes in fossil power plants. Reliability Management Group (RMG) and EPRI jointly developed the grid in 1995. It is based on RMG's Reliability Management Grid, a tool RMG has used successfully in other competitive industries such as manufacturing and refining.

DISCUSSION:

This project is part of EPRI's Plant Maintenance Optimization (PMO) development efforts. The PMO mission is to lead the industry by developing and demonstrating services and products that improve use of power plant maintenance resources and increase profitability. The Value-Based Maintenance Grid is the basis for performing maintenance assessments, a popular project with EPRI members since the grid's inception in 1995.

The Grid has 10 rows with 88 cells and 493 criteria. It includes elements associated with the work process, technology, and people. Work process includes work identification, planning, scheduling, completion, and documentation. Technology includes predictive maintenance and reliability-centered maintenance. People elements include work culture issues such as leadership and accountability. Together these criteria comprehensively describe elements of optimum maintenance. The definitions and criteria in the grid are a framework for assessing compliance with good work management.

Developing the Value-Based Maintenance Grid started a successful series of research projects. To date, EPRI members have performed eight maintenance assessment projects and three maintenance improvement projects based on this grid. For a summary of six of these projects, see EPRI report TR-106430.

EPRI BUSINESS GROUP: EPRIGEN Group

Cost Benefit Analysis for Maintenance Optimization TR-107902

DETAILS: Final Report (84 pages)

DATE: Feb. 1999

KEYWORDS: Cost Benefit Analysis
Steam Generators
Steam Turbines
Predictive Maintenance
Preventive Maintenance
Software Tools
Maintenance Optimization

ABSTRACT:

The ability to gauge the cost-effectiveness of maintenance tasks is of crucial importance in the increasingly competitive electric utility industry. This report describes a computerized cost benefit analysis module (CBAM) that analyzes maintenance cost at the component, system, unit, and plant levels.

DISCUSSION:

As part of its on-going efforts in the area of preventive maintenance, EPRI has participated in the development of software tools to facilitate the implementation of advanced methodologies such as Streamlined Reliability Centered Maintenance (SRCM). This software is part of EPRI's Plant Maintenance Optimization (PMO) development efforts for fossil power plants. The PMO mission is to lead the industry by developing and demonstrating products and services for improved utilization of power plant maintenance resources and increased profitability for generation business units.

This project developed a software package that provides a systematic and quantitative process for estimating and accumulating the cost benefit of performing a modified set of preventive maintenance tasks in preference to the current preventive maintenance tasks. The project team developed and tested the Cost Benefit Analysis Module as a user-friendly tool to guide in making consistent cost benefit analyses for modifying a preventive/predictive maintenance program based on recommendations from an SRCM analysis.

The CBAM is a versatile analysis package that allows the user to enter maintenance task data directly or to import data after performing Streamlined Reliability Centered Maintenance analyses. The user can define all of the costs associated with a particular piece of equipment:

- The cost of each existing preventive maintenance task
- The cost of corrective maintenance
- The cost of each recommended task

The user then assigns values to the factors that determine these costs such as labor, administration, materials, services, failure rates, preventive maintenance frequency, and replacement power. The CBAM uses these inputs to accumulate the cost benefits of alternative maintenance strategies.

The CBAM software runs on any PC running under Windows™ 3.0 or higher. As is typical for Windows-based applications, “Copy” and “Paste” functions are available to ensure efficiency and consistency. A complete User’s Manual for the CBAM software is included in an Appendix to this report.

This software was originally developed to calculate cost benefits after performance of SRCM analysis. However, the software can effectively perform cost calculations and compare maintenance options in a stand-alone mode. CBAM can also import the results of SRCM analysis. It is expected that CBAM will be integrated into the SRCM workstation currently in development. Other EPRI work on SRCM is described in EPRI reports TR-106503, TR-105502, and TR-105582.

EPRI BUSINESS GROUP: Energy Conversion Division

Prototype Compact Computer Aid for Maintenance: Joint EPRI-CRIEPI Human Factors Studies TR-104323

DETAILS: Final Report (88 pages)

DATE: Dec. 1994

KEYWORDS: Nuclear Power Plants
Human Factors Engineering
Pumps
Valves
Human Performance
Maintenance Management

ABSTRACT:

The Compact Computer Aid for Maintenance (CCAM)—a rugged, handheld computer—facilitates data collection, calculation, and trending by nuclear plant engineers and mechanics. This easy-to-use instrument offers a cost-effective intervention for reducing the frequency and severity of errors associated with overhauling the main feedwater pump and main steam valve. The features of CCAM support many other maintenance applications as well.

DISCUSSION:

Front-end analyses identified areas where errors occurred in connection with main feedwater pump overhaul and where some type of intervention would be possible. These errors included (1) those made during calculations, (2) inappropriate repair site decisions due to insufficient data, and (3) incorrect actions due to difficulty in communicating data or specifications between mechanics and engineers. Ultimately, the scope of the CCAM intervention was expanded to include valve maintenance and seismic monitor calibration.

CCAM involves a system consisting of desktop and handheld computer components. The desktop computer is used to manage the CCAM system and database, while the handheld computer is used on the plant floor for data collection and retrieval and as a calculation aid. By design, CCAM is a rugged, IBM-compatible computer using static RAM as a removable storage media. With a specialized disk drive, the desktop computer can transfer and receive data files from the handheld unit, thus supporting an integrated maintenance information system. Users of prototype CCAM indicated that it frequently contributed to a reduction in errors and facilitated communication between engineering and craft personnel. To a lesser extent it also increased efficiency. Users rated the hardware and software as very easy to use and noted that application of CCAM proved superior to the standard work practice for accomplishing a given task. All participants in the evaluations indicated that they would definitely recommend CCAM to other plant personnel.

This project is part of a larger EPRI-CRIEPI joint research program to reduce human errors and increase productivity in U. S. and Japanese nuclear power plants. Overall, CCAM provides (1) computerized support for calculations and data collection on the plant floor, (2) historical

docket or trend data to support repair site decisions by engineers, and (3) a mechanism to facilitate communications between mechanics and engineers.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

Although the CCAM instrumentation and computer program was developed to meet the needs of nuclear power plants, the system is equally applicable to other fossil fuel and other industrial power plants such as those found in the pulp and paper industry.

Maintenance Job Cards: Joint EPRI-CRIEPI Human Factors Studies TR-104602

DETAILS: Final Report (116 pages)

DATE: Dec. 1994

KEYWORDS: Nuclear Power Plants
Human Factors Engineering
Pumps
Valves
Maintenance Management

ABSTRACT:

The EPRI-CRIEPI Maintenance Job Cards are designed as a handy reference for plant personnel who initially diagnose equipment problems. Seven categories are included in the set—troubleshooting, valve maintenance, alignment, pump maintenance, general maintenance, V-belts and sheaves, and rigging.

DISCUSSION:

A previous EPRI-CRIEPI project identified rugged, handheld information aids—Job Cards—as having significant potential for reducing the frequency and severity of errors associated with overhauling the main feedwater pump and other types of centrifugal pumps. Front-end analyses revealed a number of functional areas where significant errors had occurred, including improper torquing, faulty rigging, inadequate inspection, incorrect readings, and failing to meet technical standards. Maintenance workers will benefit from having ready access to concise, graphic-based information aids that supplement the normal complement of governing work documents. The aim of the Job Cards is to provide mechanics with easily accessible, readable, and comprehensive materials to aid memory, provide general information, guide troubleshooting, supplement training, and orient workers.

Objection of this project were to:

- Determine content requirements and format specifications of the Job Cards.
- Develop prototype versions of the Job Cards on the most important topics.
- Implement the prototype Job Cards at two test sites.
- Evaluate the usability and usefulness of the Job Cards at each site.
- Make recommendations concerning the implementation of Job Cards on an industrywide basis.

A literature review was conducted to determine the aspects of job aids that proved successful in previous military applications. Task analysis was performed to identify the critical elements associated with pump and valve overhauls. On-site observations and interviews with end-users were conducted to identify required information content, topics, and organization as well as

preferences for layout, style, size, and packaging. Post-implementation questionnaires were administered to users and supervisors at two sites to gauge the impact (both objective and subjective) of Job Card use on productivity, ease of performance, error correction, and confidence.

Based on the initial interviews, the Job Cards were organized into nine functional categories, including general maintenance; pumps, valves, rigging, troubleshooting, alignment, V-belts and sheaves, documents, and system information. Surveys of end-users showed the Job Cards were well accepted by most users and received high marks for usability and usefulness. Although Job Card content was customized for the two trial-use plants, feedback showed that over half of the Job Cards could be implemented as-is in a number of plants, whereas another one-third would require only minor changes to be used at other plants. These Job Cards are included in the NMAC published set that contains seven categories—troubleshooting, valve maintenance, alignment, pump maintenance, general maintenance, V-belts and sheaves, and rigging. The pocket-sized cards are conveniently organized in a wire-o-bound set and color-coded by category for easy reference.

EPRI BUSINESS GROUP: Energy Conversion Division

**Advanced Technology Systems (ATTS) Authoring Manual: Joint
EPRI-CRIEPI Human Factors Studies
TR-104743**

DETAILS: Final Report (96 pages)

DATE: Dec. 1994

KEYWORDS: Training
Computer Simulation
Maintenance Management

ABSTRACT:

The ATTS package can help utility personnel develop quality troubleshooting courseware modules. The system—which includes a user’s manual and authoring software on disk—applies the technologies of intelligent tutoring systems, simulation, and multimedia.

DISCUSSION:

A previous EPRI-CRIEPI project identified training as an appropriate intervention to enhance troubleshooting proficiency. The first application domain was motor-operated valves (MOVs) (EPRI report TR-103368). Simulation-oriented tutoring was identified as the method most suited to help utility maintenance personnel gain a more complete understanding of equipment systems in both operations and diagnosis areas. This finding agreed with a previous EPRI project that demonstrated the effectiveness of computer simulation to provide diagnostic training in the area of diesel generators. At present, utility companies have tools to develop and modify training that involves factual knowledge, such as storyboard instruction materials, exam questions, and graphics/text/animation. However, they do not have tools to easily develop and modify training that involves complex system simulations, embedded expert training and advice, and tailoring of information to individual student needs. The ATTS Authoring System, described in report TR-104746, was designed to fill this void.

The ATTS Authoring System—which includes a user’s manual and authoring software on disk—allows instructors to create simulation-based intelligent tutoring systems involving interactive displays, test problems, expert procedures, and instructional strategies. The authoring system produces student courseware that may then be distributed and run on other similar IBM PC platforms. The software includes on-line help information as well as sample projects.

Requirements for the software include IBM-compatible 80386 or higher computer with 8 MB of RAM, at least 9 MB of hard disk space, a 256-color SVGA monitor, and a mouse. Other capabilities such as videodisc, Video for Windows, and sound cards are supported but optional.

The results of the ATTS Authoring System workshop indicated favorable acceptance of the system based on its capability, interface, and operation, which allows instructors to tailor training to the needs of individual students. Overall, workshop attendees enthusiastically used the ATTS and indicated their plans for employing the system at their respective utility company.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

This project was developed to aid nuclear power plants but is equally applicable to fossil fuel and other industrial type power plant operations.

The Maintenance Engineer Fundamentals Handbook: An EPRI Course TR-106853

DETAILS: Final Report (163 pages)

DATE: Nov. 1996

KEYWORDS: Maintainability
Maintenance Management
Life Extension
Preventive Maintenance
Training

ABSTRACT:

Most operating nuclear plants were built 20 years ago and were designed 30 years ago at a time when most of the reliability engineering effort went into the nuclear heat source, the reactor, the vessel, the nuclear fuel, and its control system. Very little has been invested for reliability of other equipment (valves, pumps, etc). Add aging to the picture and one can see why maintenance is so important today to maintain the safety of these plants. At the same time, there is a need to control costs or even decrease them to survive in an increasingly competitive environment. The solution is to get smarter, and invest in brainpower to decrease both the residual failures and the prevention costs. This document provides course material to teach Maintenance Engineering to plant engineers and provides them with the tools to make winning this challenge possible.

DISCUSSION:

After the design and construction phases are over, the safety and economic performance of a nuclear unit are determined by the quality of its operation and by a combination of reliability and availability of the systems that constitute the whole unit. Obtaining that combination requires the most advanced level of skills of the various organizations that together are in charge, generally Engineering and Maintenance in the U. S. industry, considering the extraordinarily high standards applicable in this case.

This handbook is aimed at giving Maintenance Engineers (in Engineering, System Engineering, or Maintenance Departments of nuclear stations) a good start in their personal development effort by assembling a state-of-the-art fundamentals package with the goal that this initial push will send them in the right direction, accelerate their self-improvement process, as well as provide them with the desire to reach further.

Maintenance has long been considered, world-wide, as a second-class type of activity, far behind Design and Operation. This is no longer true. The value of a good maintenance program in making an industry safe and profitable is now widely recognized. What is not yet fully understood is that Maintenance has progressed a great deal in the past 30 years and is now a fully developed science, requiring education as well as the more traditional attributes, which are common sense and experience. This handbook provides a foundation for that education.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

This handbook was prepared to assist in the Maintenance of Nuclear power plants, but address primarily, power plant components common to any fossil-fuel or other industrial type power plants.

6

WELDING TECHNIQUES

State-of-the-Art Weld Repair Technology for High-Temperature and Pressure Parts AP-13592

DETAILS: Final Report (Vol. 1-309 pages; Vol. 2-346 pages; Vol. 3-106 pages; Vol. 4-93 pages; Vol. 7-50 pages)

DATE: Jan. 1998

KEYWORDS: Fossil-Fuel Power Plants
Welding
Piping
Maintenance
Maintenance Costs
Welding Repair

ABSTRACT:

This assembled package contains State-of-the-art Weld Repair Technology for High Temperature and Pressure Parts Volume 1 (TR-103592-V1); Volume 2 (TR-103592-V2); Volume 3: Turbine Casing, Piping, and Header Utility Survey, and Bibliography (TR-103592-V3); Volume 4: Weld Repair of Pipe/Header Girth Welds (TR-103592-V4); and Volume 7: Weld Repair of Aged Piping – A Literature Review (TR-103592-V7).

These reports describe a cooperative utility/EPRI program that focused on improving the level of understanding of various weld repair techniques now employed in fossil power plants and examining methods and alternatives that can aid in extending the life of high temperature components.

EPRI BUSINESS GROUP: Energy Conversion Division

**State-of-the-Art Weld Repair Technology for High-Temperature and Pressure Parts Repair Guidelines: Volumes 1 and 2
TR-103592-V1/V2**

DETAILS: Final Report (Vol. 1-309 pages; Vol. 2-346 pages)

DATE: Jan. 1994

KEYWORDS: Welding
Life Assessment
Component Reliability
Life Extension
Maintenance

ABSTRACT:

More than half of the current electric power industry fossil plant fleet will exceed 25 years in age over the next decade. Consequently, it will be more difficult to maintain these units for safe and reliable operation. The costs associated with repairing or replacing equipment to provide needed capacity continue to increase, and therefore, addressing component life assessment and extension becomes a significant utility issue. The tools to perform the detailed inspections needed to assess remaining component life have been developed and are being applied to deal with service-related degradation. The key question for these aging units becomes, how can unit capacity be preserved most economically.

High temperature high pressure components such as header piping, reheat and main steam piping, and turbine casings are examples where early degradation might be anticipated because they operate at temperatures and pressures that can lead to creep or thermal degradation. This guide addresses the methodologies for when and how to repair or replace the damaged components. The materials presented in these two volumes represent both a compilation and an evaluation of state-of-the-art information that emphasize repair experiences.

EPRI BUSINESS GROUP: Energy Conversion Division

**State-of-the-Art Weld Repair Technology for High Temperature and Pressure Parts: Volume 3: Turbine Casing, Piping, and Header Utility Survey, Vendor Survey, and Bibliography
TR-103592-V3**

DETAILS: Final Report (Vol. 3-106 pages)

DATE: Nov. 1996

KEYWORDS: Welding
Welding Repair
Turbines
Maintenance
Life Extension

ABSTRACT:

As fossil power plants age, companies are forced to perform more and more repairs on such components as turbine casings, main and reheat piping, and headers components that have experienced high temperature degradation. This report presents information from two surveys on the weld repair technologies currently used by utility companies and repair organizations to extend the life of high temperature, high pressure components.

DISCUSSION:

The electric utilities industry is focusing increasing attention on maintenance and repair issues as much of the domestic fleet of fossil fuel plants has now reached 25 years of age or greater. In particular, high temperature degradation of components such as turbine casings, main and reheat piping, and headers has prompted many to search for repair methodologies to extend the lives of these components. This survey was conducted to assist in identifying many of the welding repair methodologies currently being employed by vendors and utility companies.

This report includes a survey of utility plant repair vendors, and original equipment manufacturers (OEMs) to assess state-of-the-art welding repair technology used for repair of high-temperature components such as main and reheat piping, headings and turbine casings. The report also includes a bibliography on turbine casing repairs to assist in locating repair data and information for turbine casings and related components.

According to the 28 utility companies who participated in the survey, nearly two-thirds of all weld repairs to turbine casings and related components are performed by a repair vendor or by the OEM. Steam chests were the single most often repaired component, with valve bodies, nozzle chambers, and bolt/stud holes also listed. Many utility companies discussed the use of various nickel-based welding filler wires for temporary repairs (1-3 years life expectancy). Interestingly, 40% of all repairs appear to have resulted in subsequent cracking. Nearly 60% of respondents reported the use of specialized welding techniques such as temperbead welding or low stress (peening) methods. Girth weld repairs accounted for over 90% of all weld repairs performed on piping/headers, while seam welds accounted for the remaining 10%. The shielded metal arc welding process was reported as the process of choice for most vendors and utility

companies. Approximately 60% of those responding reported that piping/header repairs are performed by in-house staff, while a similar percentage reported utilization of vendors. Some 25% reported the use of both in-house staff and vendors.

This survey indicated that specialized welding techniques such as temperbead welding or low stress welding (peening) methods are commonly applied to repair turbine casings by vendors and utility companies in lieu of postweld heat treatment. However, until recent changes in at least one of the codes, temperbead welding was not recognized for piping and header repair. Recent changes should assist in performing cost-effective weld repairs without the need of high temperature (1100 degrees Fahrenheit, 593 degrees Centigrade) postweld heat treatment. Information from the survey on welding preheated, interpass, and postweld heat treatment temperatures; welding filler metals; and various welding processes suggest that comparable welding methods are used to repair CrMo and CrMoV high temperature components throughout the power industry.

EPRI BUSINESS GROUP: Energy Conversion Division

State-of-the-Art Weld Repair Technology for High Temperature and Pressure Parts: Volume 4: Weld Repair of Pipe/Header Girth Welds TR-103592-V4

DETAILS: Final Report (Vol. 4-93 pages)

DATE: Nov. 1997

KEYWORDS: Welding
Welding Repair
Maintenance
Predictive Maintenance
Life Extension
Life Assessment

ABSTRACT:

Optimization of weld repair technologies can assist in reducing costs and lengthening the remaining life of components. This cooperative utility industry/EPRI program focused on improving the level of understanding of various weld repair techniques now employed in fossil power plants and examining methods and alternatives that can aid in extending the life of high temperature components.

DISCUSSION:

Maintaining older power plants in a safe and reliable fashion will become increasingly difficult over the next decade as many plants now exceed 25 years of operation. Detailed inspections are necessary to assess component condition and to assist in predicting remaining lives for older components such as piping, headers, and turbine casings. Highly stressed locations, such as girth weldments in main steam and hot reheat lines, header weld connections, longitudinal seam welds, hanger lugs, and radiographic plugs, are typical areas that receive attention. Often the results of inspections warrant decisions concerning the integrity of existing weldments and decisions associated with repair or replacement.

This report was aimed at providing state-of-the-art guidelines for condition assessment and repair of aged welds in piping and headers; to quantify the life extension achieved by weld repairs to aged piping and headers; to evaluate the effect of prior aging on the performance of weld repairs; to evaluate alternatives to postweld heat treatment.

The overall results of this program provide substantial evidence that service-aged piping systems can be successfully weld-repaired with and without postweld heat treatments and that life extension by several decades may be achievable under the right design and repair conditions. Weld repairs performed on degraded ex-service welds resulted in restoration or improvement of tensile and creep properties for both levels of degradation. The degree of improvement appeared to be associated with the prior condition of the base material with the most improvement occurring for the more severely degraded condition tests. Extrapolation of isostress rupture tests (found to be more conservative than Larson-Miller extrapolations) predicted estimated remaining life approximating 30 years for the first level of degradation and 18 years for the second level.

Microhardness test results within the heat affected zone of each weldment indicate that the temperbead weld repairs produced only slightly harder peak hardness values than those measured for the fully postweld heat-treated repairs. Temperbead weld repairs consistently produced higher impact properties than those measured for the postweld heat-treated weldments.

Volumes 1 and 2 of this report provide repair guidelines highlighting life assessment; run, repair, and replacement decisions; and repairs. Volume 3 documents comprehensive utility industry and vendor surveys on turbine casing, piping and header repairs and provides a bibliography on casing repairs.

Interest in weld repair and remaining life prediction of various high energy piping components is due in part to a number of isolated weld failures that have occurred in long seam piping and in part to cost reduction programs associated with deregulation. Twenty utility companies participated in this project to examine and compare weld repair methodologies employed on piping, header, and turbine casing components. The program demonstrated that weld repairs performed with and without postweld heat treatment are viable repair options that should be considered when component damage is verified. Of particular interest are the results associated with temperbead-type repairs. No detrimental effects were observed for either of the two temperbead weldments: in fact, in certain categories such as toughness, considerable improvement was realized.

EPRI BUSINESS GROUP: Energy Conversion Division

State-of-the-Art Weld Repair Technology for High-Temperature and Pressure Parts: Volume 5: Weld Repair of 1-1/4Cr-1/2Mo Piping Girth Welds TR103592-V5

DETAILS: Final Report (Vol. 5-57 pages)

DATE: Oct. 1998

KEYWORDS: Welding
Welding Repair
Predictive Maintenance
Life Extension
Component Reliability
Materials Aging
Life Assessment

ABSTRACT:

Optimization of weld repair technologies can assist in reducing costs and lengthening the remaining life of components. This cooperative utility industry/EPRI program focused on improving the level of understanding of various weld repair techniques now employed in fossil power plants and examining methods and alternatives that can aid in extending the life of high temperature components.

DISCUSSION:

Maintaining older power plants in a safe and reliable fashion will become increasingly difficult over the next decade as many plants now exceed 25 years of operation. Detailed inspections are necessary to assess component condition and to assist in predicting remaining lives for older components such as piping, headers, and turbine casings. Highly stressed locations, such as girth weldments in main steam and hot reheat lines, header weld connections, longitudinal seam welds, hanger lugs, and radiographic plugs, are typical areas that receive attention. Often, the results of inspections warrant decisions concerning the integrity of existing weldments and decisions associated with repair or replacement.

This report provides state-of-the-art guidelines for condition assessment and repair of aged welds in piping and headers; documents current industry practice and experience with respect to weld repair of piping and headers; quantifies the life extension achieved by weld repair to aged piping and headers; evaluates the effect of prior aging on the performance of weld repairs; and evaluates alternatives to postweld heat treatment.

The overall results of this program provide substantial evidence that service-aged piping systems can be successfully weld-repaired with and without postweld heat treatments. Estimates of remaining life under 6.6 ksi (45.5 Mpa) design conditions using Larson-Miller extrapolation of 28 to 45 years have been obtained, for the PWHT and temperbead repairs respectively. Temperbead repairs resulted in projected remaining lives that were consistently higher than PWHT repairs regardless of the extrapolation procedure used. The most conservative isostress extrapolation procedure still results in a projected remaining life of 12.4 years at 1000 degrees

Fahrenheit. Both types of weld repairs meet the tensile strength requirements of ANSI B31.1 code. Microhardness test results within the heat affected zone of each weldment indicate that the temperbead weld repairs produced only slightly harder peak hardness values than those measured for the fully postweld heat-treated repairs. Temperbead weld repairs consistently produced higher impact properties than those measured for the postweld heat-treated weldments. Volumes 1 and 2 of this report provide repair guidelines highlighting life assessment; run, repair, and replacement decisions; and repairs. Volume 3 documents comprehensive utility industry and vendor surveys on turbine casing, piping, and header repairs and provides a bibliography on turbine casing repairs. Volume 4 documents weld repair studies on aged 2-1/4-1Mo piping/header material.

This report demonstrates that weld repairs both with and without postweld heat treatment are viable options that should be considered when component damage is verified. Of particular interest are the results associated with temperbead type repairs, which resulted in improved impact roughness and area rupture life.

EPRI BUSINESS GROUP: Energy Conversion Division

State-of-the-Art Weld Repair Technology for High-Temperature and Pressure Parts: Volume 7: Weld Repair of Aged Piping – A Literature Review
TR-103592-V7

DETAILS: Final Report (Vol. 7-50 pages)

DATE: June 1998

KEYWORDS: Fossil Fuel Power Plants
Welding
Welding Repairs
Piping
Maintenance Costs
Life Extension

ABSTRACT:

Optimization of weld repair technologies can assist in reducing costs and lengthening the remaining life of components. This cooperative utility industry/EPRI program focused on improving the level of understanding of various weld repair techniques now employed in fossil plants and examining methods and alternatives that can aid in extending the life of high temperature components.

DISCUSSION:

Maintaining older power plants in a safe and reliable fashion will become increasingly difficult over the next decade as many utility industry plants now exceed 25 years of operation. Detailed inspections are necessary to assess component condition and to assist in predicting remaining lives for older components such as piping, headers, and turbine casings. Highly stressed locations, such as girth weldments in main steam and hot reheat lines, header weld connections, longitudinal seam welds, hanger lugs, and radiographic plugs, are typical areas that receive attention. Often the results of inspections warrant decisions concerning the integrity of existing weldments and decisions associated with repair or replacement.

Report objectives were:

- To provide state-of-the-art guidelines for condition assessment and repair of aged welds in piping and headers
- To document current industry practice and experience with respect to weld repair piping and headers
- To quantify the life extension achieved by weld repairs to aged piping and headers
- To evaluate the effect of prior aging on the performance of weld repairs
- To evaluate alternatives to postweld heat treatment

A review of several worldwide studies has confirmed that aged high temperature piping can be successfully weld-repaired to gain additional life in excess of several decades. The key aspects of successful weld repair include excavation and removal of all repair creep cavitation damage, elimination of external bending stresses and implementation of good welding practice. From merely a creep rupture point of view, PWHT has been concluded to be superfluous by several authors. Temperbead repairs appear to offer a promising alternative to PWHT repairs from a creep, tensile and toughness standpoint. Choice of the repair process ultimately is dictated by many considerations such as toughness, notch sensitivity, residual stresses and hydrogen embrittlement susceptibility. Several reports suggest that GTAW repairs may outperform SMAW repairs with or without PWHT. Volumes 1 and 2 of this report provide repair guidelines highlighting life assessment; run, repair, and replacement decisions; and repairs. Volume 3 documents comprehensive utility and vendor surveys on turbine casing, piping, and header repairs and provides a bibliography on turbine casing repairs. Volumes 4 and 5 document weld repair studies on aged 2-1/4Cr-1Mo and 1-1/4Cr-1/2Mo piping/header materials respectively. Volume 5 documents weld repair studies on casing needs.

Interest in weld repair and remaining life prediction of various high energy piping components is due in part to a number of isolated weld failures that have occurred in long steam piping and in part to cost reduction programs associated with deregulation. Twenty utilities companies participated in this project to examine and compare weld repair methodologies employed on piping, header, and turbine casing components. The program demonstrated that weld repairs performed with and without postweld heat treatment are viable repair options that should be considered when component damage is verified. Of particular interest are the results associated with temperbead-type repairs, which resulted in improved impact toughness and stress rupture life. Findings from a review of literature (this Volume 7), confirm the results of EPRI's own investigations.

EPRI BUSINESS GROUP: Energy Conversion Division

NOREM Applications Guidelines: Procedures for Arc Welding of NOREM Hardfacing Alloys TR-107231

DETAILS: Final Report (192 pages)

DATE: Dec. 1996

KEYWORDS: Welding
Welding Repairs
Valves
Arc Welding
Maintenance

ABSTRACT:

NOREM is a cobalt-free hardfacing alloy that provides outstanding resistance to both adhesive (galling) wear or cavitation-erosion wear. Wire products and welding procedures have been developed for depositing NOREM™ using a number of standard techniques. These developments enhance the attractiveness of using the NOREM alloys for field repairs of installed components such as valves and hydropower components.

DISCUSSION:

An earlier report described progress in developing GTAW and PTAW procedures for depositing NOREM (TR-105816). However, utility personnel requested development of other techniques that are commonly used to perform field repairs. Therefore, these studies were undertaken to develop gas tungsten arc welding (GTAW), shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and submerged arc welding (SAW) techniques for NOREM wire products. Also information generated by valve suppliers for plasma transferred arc welding (PTAW) was compiled.

Report objectives were:

- To develop NOREM product specifications and welding procedures for arc welding processes that yield multiple-layer, crack-free overlays with minimal preheating requirements.
- To assist utility companies and valve repair organizations in independently qualifying welding procedures.
- To measure the galling wear resistance and cavitation-erosion wear resistance of specimens prepared using these welding procedures to confirm that the outstanding wear resistance of the NOREM alloys has been maintained.

Researchers successfully used GTAW to deposit sound weld overlays on SA-516 carbon steel and Type 304 stainless steel piping without any preheating. Metal-core wire that used prealloyed gas atomized powder as filler material and contained a lower nitrogen content than was investigated earlier, consistently provided sound welds and greater flexibility to the welder. The

low-nitrogen wire and rod could be used to perform a local weld repair. Powder with the higher nitrogen content was successfully deposited by two groups using PTAW with a modest preheat of 200 degrees Fahrenheit. The GTAW composition was successfully used as a basis for developing GMAW, SMAW, and SAW welding consumables and procedures with the desired features. Wear measurements showed these changes in alloy composition did not adversely affect the wear resistance of the NOREM alloys.

Laboratory evaluations and loop tests under simulated nuclear reactor operating conditions of small valves hardfaced with NOREM show that its performance matches or exceeds that of the long-established cobalt-based alloys (Stellites™). Over 400 valves with NOREM hardfacing have been purchased or installed by some 30 nuclear utility companies. The need for a NOREM product form and welding procedures suitable for diverse field applications led to the initiation of this program. This study led to procurement specifications and a deposited NOREM chemistry that is appropriate for different welding techniques. The NOREM alloy now is not only “welder friendly”, but also exhibits wear resistance equivalent to that of cobalt-base hardfacing alloys. NOREM should be considered for applications in both nuclear valves and fossil plant valves. Because of its outstanding resistance to cavitation-erosion damage, NOREM should also be considered as an alloy for performing field repairs of hydropower components.

EPRI BUSINESS GROUP: Energy Conversion Division

State-of-the-Art Weld Repair Technology for Rotating Components TR-107021-V1

DETAILS: Final Report (Vol. 1-402 pages)

DATE: Jan. 1997

KEYWORDS: Steam Turbines
Rotors
Welding
Welding Repair
Life Extension

ABSTRACT:

Deregulation of the power industry, increased competition, enhanced environmental regulations, and aging or degraded equipment continue to place greater economic pressures on utility companies. Weld repair of rotors and discs offers a viable means of extending the life of in-service rotors and discs. This report provides comprehensive repair guidelines for the utility industry.

DISCUSSION:

Aging or degraded equipment, when associated with a major component such as rotor or disc, can have a significant effect on plant generating capacity and revenues due to costly weld repairs and extended plant shutdowns. In 1994, several utility companies and EPRI entered into a tailored collaborative effort to examine turbine rotor and disc repair issues. This repair guideline (Volume 1) is one product from this effort. A related and complementary product is Volume 2: Repair of Steam Turbine Blading.

The repair guideline provides a single comprehensive resource that describes all major forms of weld repairs for steam turbine rotors and discs. It includes information pertinent to repair of nuclear and fossil steam turbine rotors and discs, whether they are for low-, intermediate-, or high-pressure service. Specific repair evaluation methodologies and repair practices/processes are described and guidance is presented where relevant. Special considerations such as insurance, commercial, technical, and quality assurance also appear in the guideline. Furthermore, the volume discusses steps for formulating a successful repair plan. It also presents specific repair cases (based on form of damage) along with their benefits and risks, lays out inspection criteria, and summarizes costs and risk management. Finally, the results of a comprehensive vendor survey highlight repair vendor and OEM capabilities, facilities, and past experience.

The results of this effort have provided a valuable and comprehensive repair guideline that will assist in welded repairs of high-, intermediate-, and low-temperature steam turbine rotors and discs. The guideline can be used to address various forms of low-, and high-temperature degradation, including fatigue, creep, corrosion, thermal damage, and embrittlement. Furthermore, the guideline examines other non-service related forms of damage/degradation, such as manufacturing flaws, and provides repair methodologies. Specific criteria and guidance appear for repair, including welding preheat and postweld heat treatment considerations; welding

and filler metal procedures and qualification assistance; and, application of specifications. This guideline will permit users to work more closely with OEMs, consultants, insurers, and repair vendors to assure quality work.

EPRI BUSINESS GROUP: Energy Conversion Division

**State-of-the-Art Weld Repair Technology for Rotating Components:
Volume 2: Repair of Steam Turbine Blading
TR-107021-V2**

DETAILS: Application Report (Vol. 2-318 pages)

DATE: Dec. 1997

KEYWORDS: Steam Turbines
Life Extension
Welding
Welding Repair
Maintenance

ABSTRACT:

The utility industry is faced with greater and greater economic pressures resulting from deregulation of the power industry, increased competition, enhanced environmental regulations, and aging or degraded equipment. Because of these economic pressures, many have developed internal repair capabilities for a variety of components ranging from piping to valves to diaphragms. One of the many components in which utility companies have demonstrated considerable success more recently, and have begun to realize significant savings, is in the repair of steam turbine blading. This guidelines was assembled to assist those who elect to work with original equipment manufacturers (OEMs) and repair vendors to perform blade repairs by providing them with the necessary information and background to closely interface with these organizations to assure successful turbine blade weld repairs.

This repair guideline, is one of a two-set volume. Volume 2 begins with an overview of the various materials utilized for steam turbine blading applications and the filler metals commonly used to join them. Next, it examines the critical dimensions and tolerances that must be controlled during any welding repair process regardless of the location. Each of the damage mechanisms typically associated with turbine blades is reviewed including: fatigue, surface corrosion, stress corrosion cracking, corrosion assisted fatigue, creep, and foreign object damage. Damage such as materials defects and improper repair methods are also presented.

The focal point of the guidelines is the four sections which address repairs performed for: airfoils, erosion shields, tenons and coverbands (shrouds), and for lashing lugs and tie-wires. Specific descriptions of each repair process are provided including discussions on: critical measurements and how they are performed, preparation of the repair area, welding processes and approaches utilized, preheat and postweld heat treatment criteria, fixturing, cold twisting, machine/grinding, final inspections, and acceptance criteria. The final two topics covered in the guideline relate to moment weighing and sequencing and to frequency (vibration) testing. Following repair, blades are often subjected to these tests to assure successful performance of each individual row of blades and of the entire turbine. The results of this guideline provide users with a valuable resource which will assist in welded repairs of steam turbine blading used for high-, intermediate-, and low-pressure steam turbine applications. This guideline will permit

users to work more closely with OEMs, repair vendors, consultants, and insurers to assure cost-effective, quality work.

A related and complementary product of this program is “Volume 1, Weld Repair of Steam Turbine Discs and Rotors”.

EPRI BUSINESS GROUP: Energy Conversion Division

On-Line Seal Welding of Pipe Cracks

TR-108133

DETAILS: Final Report (23 pages)

DATE: Mar. 1997

KEYWORDS: Piping System
Stress Corrosion Cracking
Fatigue Cracking
Welding
Welding Repairs
Maintenance

ABSTRACT:

The repair of through-wall cracks (caused by, for example, stress corrosion cracking or fatigue) in typical non-isolable nuclear service piping systems is costly and often not practical. Typical repair methodology frequently limits the use of localized isolation due to work area conditions such as radiation levels, accessibility, or plant operation conditions. This report establishes a reliable process for seal welding the through-wall pipe leak, allowing an external overlay repair to be performed per Code Case N-504.

DISCUSSION:

Conventional repair methods often require isolating the degraded pipeline to remove the flaw prior to the weld repair. However, in many cases it is necessary to repair a component without taking the degraded system off-line or by utilizing localized isolation methods due to work area restriction. As an alternative repair method, weld overlay repairs without removing the flaw have been accepted per Code Case N-504, as long as the leak has been stopped and moisture is not present.

This report establishes a reliable process of sealing a through-wall pipe leak with pressure and provides basic guidelines for on-line and in situ seal welding for stainless steel piping.

The on-line seal welding repair method offers an alternative repair approach to non-isolable nuclear service piping systems. The approach offers an immediate response and significantly reduces the requirements of a typical repair that requires isolation. The repair methodology requires minimal planning, tooling, and implementation to provide a cost-effective weld repair.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

While this report addresses a nuclear power plant problem, the results, welding procedures, etc. are equally applicable to any service water piping system such as those found in the pulp and paper industry.

Temperbead Welding Repair of Low Alloy Pressure Vessel Steels: Guidelines TR-103354

DETAILS: Final Report (256 pages)

DATE: Dec 1993

KEYWORDS: Maintenance
Welding
Welding Repair
Life Extension

ABSTRACT:

Optimum use of temperbead weld repair of low alloy pressure vessel steels permits welding on low alloy steel without the need for postweld heat treatment, thus saving significant repair costs and making some otherwise impractical repairs feasible. The results of this study support easing the ASME Code requirements for the temperbead process in order to make the procedure easier and cheaper to use.

DISCUSSION:

Earlier EPRI-supported research on the temperbead repair of pressure vessel steels resulted in ASME Code Case N-432 authorizing use of gas-tungsten arc welding temperbead repair. However, code restrictions limited its use, and specified welding parameters did not give adequate control.

The objective of this report was to develop temperbead welding procedures that can be used for controlled deposition; to obtain data on resulting weld properties that justify lower preheat temperatures, a reduced number of weld layers, and elimination of the postweld hydrogen bake.

The results of this work will make it much easier to repair low alloy pressure vessel steel components using the temperbead process. A conventional postweld heat treatment at approximately 1125 degrees Fahrenheit is often completely impractical in a nuclear reactor pressure vessel. This work will make it possible to use temperbead welding repair in wider applications and significantly reduce cost and outage time for a repair. The data in the report will add confidence in the use of the process and should lead to further, more realistic relaxation of codes and regulatory requirements.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

This report addresses pressure vessels in nuclear power plants, but the welding process and techniques are applicable to any power plant facility.

Justification for Extended Weld-Overlay Design Life TR-NP-7103-D

DETAILS: Topical Report (132 pages)

DATE: Jan. 1991

KEYWORDS: Stress Corrosion Cracking
Stainless Steels
Welding
Welding Repair
Life Extension

ABSTRACT:

Austenitic stainless steel piping used in nuclear power plant boiling water reactor (BWR) application has exhibited intergranular stress corrosion cracking (IGSCC) in operating plant service. Weld-overlay repair, originally used as an interim IGSCC mitigation measure, has now proved suitable for long-term repair on welded stainless steel components.

DISCUSSION:

IGSCC of austenitic stainless steel piping in BWR plants has created a serious availability problem in recent years. Mitigation measures, such as weld-overlay repair, have been developed to increase plant availability associated with IGSCC. Although weld-overlay repair has been used widely as an interim mitigation measure, extensive research now qualifies this repair for long-term service.

The objectives of this report were:

- To examine and compile experimental, analytic, and operating experience with weld-overlay repairs.
- To use data obtained to provide a technical justification for long-term operation following a weld overlay.

Review of available information reveals that extensive experimental, analytic, and operating experience with weld-overlay repair strongly supports the adequacy of such repairs as long-term mitigation measures for affected piping. This report illustrates that ASME code—required margins to failure are restored by application of the weld-overlay repair. Laboratory studies further demonstrate that with controlled ferrite and carbon levels, the structural integrity of the weld-overlay is not likely to be degraded by IGSCC and crack growth into the overlay. Moreover, the weld-overlay process produces a compressive residual stress distribution in the inner portion of the repaired component wall, inhibiting additional IGSCC initiation and growth. Developments in inspection of weld overlays show that the weld overlay and a portion of the underlying base metal can be reliably examined using suitable volumetric inspection techniques.

Weld-overlay repair for austenitic stainless steel piping has proved a valuable technique for mitigating the consequences of IGSCC in BWR components. Results of the analyses,

experimental work, and plant operation with overlays demonstrate the adequacy of these repairs as long-term measures. NRC has concurred with the acceptability of the weld overlay as a long-term repair option, provided that these repairs meet certain criteria for design basis, materials, and inspectability, as defined in NUREG-0313, Revision 2.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

Results of this report are applicable to any austenitic stainless steel piping in any power plant or industrial facility.

**Proceedings: Welding and Repair Technology for Power Plants: Second International Conference
TR-107719**

DETAILS: Proceedings (1006 pages)

DATE: Jan. 1997

KEYWORDS: Turbines
Welding
Welding Repair
Boilers
Life Extension

ABSTRACT:

The conference on welding and repair technology for power plants included presentations of case histories, emerging welding technologies, and demonstrated repair techniques and approaches. These proceedings provide technical information discussed at the conference in the repair of turbine rotors, disks, blades, piping, steam generators, headers, reactor pressure vessel internals, valves, pumps, and other components.

DISCUSSION:

Aging or degraded power plant components and materials have prompted the utility industry to focus more attention on maintenance and repair issues over the past decade. Issues such as life expectancy of required components; avoidance of time-consuming postweld heat treatments; repair guidelines for aging components and pumps/valves; and repair procedures for critical high-temperature locations in rotors, blades, headers, and piping are among the many important emerging issues utility companies face today. EPRI, utility companies and vendors worldwide have been carrying out research and application activities on these and related issues. A need exists to consolidate this experience and identify current limitations and future needs of welding technology for the utility industry.

This conference reviewed emerging technologies for welding and repair of power plant components, including issues such as life extension repair approaches, postweld heat treatment alternatives, prior service effects, and materials properties. 265 participants attended the conference, which addressed key welding and repair issues for power plant components, including turbine blades, rotors and discs, headers, piping, valve and pumps, pressure vessels, steam generators and turbine casings.

The conference provided a forum for transferring emerging, state-of-the-art technologies to address these issues. Areas covered included repair methods and techniques, advanced welding technologies, prior service effects, performance, materials properties, case histories, and postweld heat treatment alternatives. Specific emphasis was placed upon emerging technologies related to steam turbine repair and refurbishment for components such as rotors, discs, and blades.

EPRI BUSINESS GROUP: Energy Conversion Division

Weld Repair of Class 2 and 3 Ferritic Piping TR-108131

DETAILS: Final Report

DATE: Sept. 1997

KEYWORDS: Corrosion
Welding
Welding Repair
Erosion Corrosion
Microbial Corrosion
Piping Systems

ABSTRACT:

Numerous piping systems for nuclear power plants were constructed with carbon steel piping under the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, Class 2 and Class 3. These systems can suffer from a number of degradation mechanisms, including microbiologically influenced corrosion (MIC), erosion-corrosion (EC) damage, or general corrosion. Sections III and XI of the ASME Code do not prohibit use of external weld overlays to repair internal wall thinning. Neither, however, do these ASME Code sections provide specific guidance for weld overlay repair installation. This lack of specific guidance has resulted in broad differences of opinion as to the viability of weld overlay repairs. The United States Nuclear Regulatory Commission (USNRC) issued Generic Letter 90-05 (GL90-05), "Guidance for Performing Temporary Non-Code Repair ASME Code Class 1, 2, and 3 Piping." GL90-05 currently requires that all permanent repairs be conducted in accordance with ASME Code requirements.

In order to resolve the issue on guidance, a series of weld overlay repairs were fabricated and tested at the EPRI Repair and Replacement Applications Center (RRAC) under the direction of the ASME Task Group on Alternate Rules for Repair of EC Damage. These overlay repairs were installed on carbon steel piping coupons using AWS E7018 electrodes. A variety of flaw sizes, weld installation parameters, and weld configurations were employed. The repair mockups were pressure tested, and the tests results were used to develop proposed rules for incorporation into Section XI of the ASME Code. Finite element analysis was performed to benchmark the test results and to provide guidance for applying weld overlay repairs in the field. These tests demonstrate that external weld overlay is a viable repair alternative for internal wall thinning.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

The welding repair techniques described in this report are not only applicable to nuclear power plant piping systems, but to any fossil fuel or industrial power plant as well.

Weld Overlay of Waterwall Tubing, Alternative Materials and Distortion TR-112643

DETAILS: Interim Report (60 pages)

DATE: Dec. 1999

KEYWORDS: Corrosion
Maintenance
Welding
Welding Repair
Fossil Fuel Boilers
Boiler Tubing

ABSTRACT:

This report investigates alternative filler materials for waterwall overlay applications that are less costly than current overlay materials and that closely match the thermal expansion characteristics of the base material. The report also analyzes current welding practices and develops alternative approaches to minimize distortion and residual stresses.

DISCUSSION:

The rate of wall thickness losses (wastage) of fireside waterwall tubing in fossil-fired utility boilers has been a concern of maintenance personnel for many years. Recent conversion by many utilities companies to low NO_x burners for compliance with Clean Air Act requirements has increased waterwall wastage rates up to 120 mils (3 mm) a year in some boilers. To slow down this corrosion rate, utility plants have been overlaying existing waterwalls with corrosion-resistant weld materials or replacing waterwall panels with new panels that have been overlaid in the factory. Though less costly than replacement panels, the field overlay process is a very expensive mitigation technology that leaves high residual stresses in the waterwall tubing. Additionally, thermal expansion difference between the base material and the weld overlay material cause high thermal expansion stresses.

A welding filler metal was found that is less costly and that matches thermal expansion characteristics of the waterwall tubing material. Alternatives to the power supplies currently used by welding contractors were evaluated and found to provide superior welding characteristics.

Typical waterwall corrosion overlay applications can encompass as much as 5000 square feet (46.5 square meters) of waterwall tubing surface in a utility industry boiler. The alternative material suggested by this report could typically save 25 percent over currently used overlay materials. The material savings alone could amount to \$250,000 on one project. Distortion control and thermal expansion stress mitigation will also make the repairs performed utilizing procedures in this report more durable, allowing for longer service life of existing waterwall tubing.

EPRI BUSINESS GROUP: Energy Conversion Division

LASER Welding Survey for Power Generation Industry TR-110355

DETAILS: Final Report (66 pages)

DATE: April 1998

KEYWORDS: Fossil Fuel Boilers
Welding
Welding Repairs
Heat Treatment
Service Life

ABSTRACT:

EPRI has developed technology for laser weld repair of steam generator tubes in light water reactors. This technology has promise for other specialized welding and heat treatment applications in the power generation industry.

DISCUSSION:

During the past decade, laser welding technology has become an increasing part of repair, replacement, and refurbishment options available to the industry. Combined with both low-loss transmission capabilities and with robotics for work in hostile environments, lasers have found new opportunities in industries such as automotive and electronics. Only limited use of this technology has been applied to date in the power generation industry. Recently, EPRI developed a new approach for repair of steam generator tubes in pressurized water reactors using a continuous wave Nd:YAG laser. In the laboratory, this technology has successfully produced a structural metallurgical bond by applying a weld overlay to the inside surface of the steam generator tube. The process has recently received the American Society of Mechanical Engineers (ASME) Code approval (Code Case N-576).

The purpose of this report was (1) to provide information to the electric utility industry regarding recent advances in laser welding technology for the power generation industry and, (2) to obtain utility industry input regarding research needs for which this laser technology could be applied economically.

Utility companies participating in this project most favored application for the EPRI-developed laser process was as a tool for performing weld overlay repairs, either in waterwall or boiler tube applications or in heat exchanger applications. They also identified lasers for applications in which different weld metals, typically not compatible, could be welded. Specific candidates for laser repair included waterwall refurbishment, feedwater and condenser tube repair, valve hardfacing, turbine blade refurbishment, and control rod drive or control rod housing repairs in nuclear plants. Laboratory studies indicated that the EPRI-developed laser technology was adaptable for each of these cases.

EPRI BUSINESS GROUP: Energy Conversion Division

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BOILERS & AUXILIARIES

State-of-the-Art Maintenance and Repair Technology for Fossil Boilers and Related Auxiliaries CS-4840

DETAILS: Final Report (212 pages)

DATE: March 1987

KEYWORDS: Maintenance
Boiler Tubes
Auxiliary Systems
Fossil-Fuel Fired Boilers

ABSTRACT:

Continuous, reliable operation of fossil-fired boilers depends on effective maintenance practices. This report presents information on state-of-the-art techniques that utility personnel can perform quickly and at low cost.

DISCUSSION:

An increasing number of utility companies are deferring the retirement of existing fossil fuel power plants to satisfy capacity requirements. This places greater demands on the maintenance staff to keep aging units, particularly boilers and auxiliaries, in service at an acceptable level of availability. To perform their diverse responsibilities and thus meet these demands, plant personnel must have ready access to information on advanced maintenance techniques.

This report lists 18 maintenance tasks, which are examined in depth. Eight of these tasks address pre-outage planning and tube repairs; three tasks pertain to boiler tube maintenance; and the remaining seven tasks are associated with the repair and maintenance of air heaters, ash hoppers, burners, expansion joints, pulverizers, and sootblowers. The report lists between two and 15 state-of-the-art techniques for each task, with illustrative photographs and explanatory diagrams. For example, the boiler tube repair section on slag removal tasks features five methods of removal—high pressure water lances, shotguns, dynamite charges, rappers, and waterblowers. A bibliography section and a reference section provide sources for obtaining additional information on the techniques discussed.

More than half of the utility industry \$4 billion annual budget for fossil plant maintenance is spent on boilers and auxiliaries. This report is the first step in a program to reduce this huge maintenance expense through improvements in the tools and methods available to the industry.

By documenting the current state-of-the-art in boiler maintenance techniques, it provides a baseline for evaluating the merits of future improvements. The report also serves as a reference manual for training entry-level maintenance personnel. In a follow-on effort (EPRI project RP2604-02), work will begin on development of guideline manuals for field-welding procedures, welding quality control measures, rigging and scaffolding practices, and sootblower operation and maintenance. These manuals will complement work being completed under EPRI's ongoing life extension program (project RP2596).

EPRI BUSINESS GROUP: Nuclear Power Group

Acoustic Coal Chute Flow Monitor: Technology Review AP-101840-V3P1

DETAILS: Technology Review (Vol. 3)

DATE: Dec. 1995

KEYWORDS: Coal Handling
Coal Quality
Coal-Fired Boilers
Acoustic Monitoring
Monitors
Moisture

ABSTRACT:

At pulverized-coal-fired generating units, high coal surface moisture and compaction often slow or halt the flow of coal from bunkers to pulverizers or mills. High ash content in western coals and the presence of foreign objects in coal piles may also render flow erratic. Normally, coal flowing through the system creates acoustic energy at an easily-monitored level unless the chute becomes clogged. Using a nonintrusive, acoustic coal chute flow monitor (CCFM), operators of pulverized-coal-fired boilers can detect coal flow stoppage early enough to take corrective action and thereby avert load swings, thermal transients, and interruptions in unit operation. If coal flow stops, suitably-equipped CCFM systems can automatically activate air hammers and restore coal flow before thermal input to the boiler drops.

EPRI BUSINESS GROUP: Energy Conversion Division

Feedwater I&C Maintenance Guide TR-105663

DETAILS: Final Report (344 pages)

DATE: Nov. 1995

KEYWORDS: Control Equipment
Electric Equipment
Valves
Predictive Maintenance
Preventive Maintenance

ABSTRACT:

The feedwater control system maintains nuclear reactor or steam generator water level during plant operation. Feedwater control system problems have been a significant factor in automatic plant shutdowns and lost generation. This guide provides recommendations to improve the operation of the feedwater control system.

DISCUSSION:

The feedwater control system performs a vital role in power generation by maintaining nuclear reactor or steam generator level within the desired range. Despite stringent performance requirements, feedwater control systems are often susceptible to numerous potential single failures. Also, degradation of control system components can occur quickly because of the relatively harsh and demanding environment around the feedwater pumps. Improvements in design and maintenance are needed to support reliable plant operation.

This guide provides detailed typical system descriptions for the major types of nuclear power plants, including those with digital feedwater control systems. Design changes that have improved system reliability are described, ranging from minor design changes to full-scope digital replacements. Maintenance practices that are considered vital to proper equipment operation are discussed. Diagnostic testing to detect degraded component performance is described. Performance monitoring methods are also explained in detail.

The feedwater control system continues to cause unplanned plant shutdowns due to component failures and inadequate system performance. Obsolescence of the installed control system components has contributed to system problems. Although much has been written regarding feedwater control systems, there has not been a single reference source that discusses a variety of methods for improving feedwater control system performance. This guide will serve as a valuable source of information for plant personnel who are evaluating their feedwater control system to determine how to improve its performance.

EPRI BUSINESS GROUP: Nuclear Power Group

NOTE:

While this report addressed nuclear power plants, these maintenance guides are equally applicable to fossil plant feedwater systems such as those in the pulp and paper industry.

Infrared Thermography Developments for Boiler, Condenser, and Steam Cycle

TR-109529

DETAILS: Final Report (82 pages)

DATE: Dec. 1997

KEYWORDS: Infrared Thermography
Maintenance
Diagnostic Techniques
Performance
Reliability
Availability

ABSTRACT:

This report is part of EPRI's Plant Maintenance Optimization efforts. It describes development and testing of infrared thermography (IRT) tools and techniques to demonstrate their effectiveness in determining boiler internal thermal patterns, condenser air-in leaks, and heat-rate performance improvements.

DISCUSSION:

The development and application of infrared thermography techniques for detection of mechanical and electrical equipment in power plants and switchyards has proven to be very beneficial to maintenance procedures, particularly predictive maintenance programs. As a result, the infrared technologies developed in the early phases of EPRI's program have been applied to valve and boiler external leaks, and the results of these studies have been included in a Thermography Interim Report (unpublished). These and other results on the application of IRT to the examination of power plant equipment have been published in TR-108935, "Infrared Thermography Anomalies Manual." The extension of these techniques to include boiler and condenser internal happenings—and the effect of valve leaks on heat-rate performance—is the focus of this report. EPRI's Plant Maintenance Optimization development program is intended to help reduce cost of production by developing and demonstrating cost-effective maintenance methods.

Objectives of this report were:

- To develop infrared thermography techniques for observing thermal activities and patterns inside boilers.
- To develop tools able to operate in these relatively hostile environments.
- To search the literature for any related technical information.
- To conduct analyses to ensure success and minimize risks.
- To develop infrared technologies to determine condenser air-in leakage.
- To develop infrared thermography techniques to assist in improving heat-rate performance.

This report verified that the developed infrared thermography tools and techniques were effective in observing heat patterns inside boilers, air-in leakage in condensers, and in detecting avoidable steam leaks that affect steam cycle efficiency and overall performance.

EPRI BUSINESS GROUP: Energy Conversion Division

Proceedings: Third International Conference on Boiler Tube Failures in Fossil Plants TR-109938

DETAILS: Proceedings (660 pages)

DATE: April 1998

KEYWORDS: Boiler Tubes
Fossil-Fuel Fired Boilers
Power Plant Availability
Failure Analysis
Nondestructive Evaluation
Creep

ABSTRACT:

Boiler tube failures remain the leading cause of fossil steam plant availability loss. These conference proceedings address the state-of-the-art practices and techniques in the United States and other countries for reducing boiler tube failures.

DISCUSSION:

The equivalent unavailability factor due to boiler tube failures (BTF) in the U. S. is about 3 percent. A disturbing feature is that since 1992, the factor has been increasing from a minimum of about 2.5 percent, which was reached after eight years. Most failures are repeat failures resulting from the same root cause. EPRI has sponsored two previous conferences to assist in developing optimum BTF reducing technology (EPRI Reports CS-5500 and TR-100493).

Objective of the conference was to evaluate and exchange technical information on established BTF analysis, prevention, and understanding in fossil-fired power plants.

These proceedings contain the papers, discussions, and survey results from the conference. Some key points are:

- Major strides have been made since the last conference in 1991 in understanding the mechanisms and root causes of all the leading BTF. However, it appears, because of all the changes taking place in the industry, that corporate boiler tube failure reduction programs are not being maintained, resulting in a serious deterioration in unavailability.
- The leading causes of BTF are long-term overheating/creep in superheaters and reheaters, and corrosion fatigue in waterwalls and economizers. As the boilers get older, the time dependent creep mechanisms are expected to dominate.
- Almost 90 percent of utility companies are recording failures by location. However, only around 60 percent address the root cause of failures.

- Around 40 percent of utility companies consider they have a management supported, boiler tube failure reduction program (BTFRP), but 65 percent do not have a corporate philosophy signed by upper management. In addition, 65 percent are dissatisfied with their BTFRP.
- Over 60 percent of utility companies do not train their BTFRP staff, and over 70 percent never or seldom train their operators in BTF prevent.

EPRI BUSINESS GROUP: Nuclear Power Group

Mitigation of Fireside Corrosion in Low NO_x Boilers: A State-of-the-Art Assessment of Materials Solutions

TR-112823

DETAILS: Topical Report (104 pages)

DATE: Sept. 1999

KEYWORDS: Corrosion
Fossil Fuel Boilers
Burners
Protective Coatings

ABSTRACT:

The use of low-NO_x burner systems in coal-fired boilers has resulted in an increase in water-wall corrosion. In response, existing protective coating technologies have been substantially improved and new technologies developed. This report summarizes the state-of-the-art for protective boiler coatings, surveying all major technologies and noting improvements to be expected in the near future. Available performance and cost details are included.

DISCUSSION:

EPA regulations mandate significant reductions in NO_x emissions for utility boilers. The preferred, lowest-cost method to achieve these reductions is through the use of burner systems that minimize NO_x formation. Such burner systems, especially systems with overfire air ports (OFAs), create reducing zones in the lower furnace. Wastage rates ranging from 40 to 100 mils/yr (1-2.5 mm/yr) in supercritical boilers and 20 to 30 mils/yr (0.5-0.75 mm/yr) in subcritical boilers have been reported. EPRI corrosion studies, reported in TR-111152, indicate that the high wastage rates are mainly due to FeS-rich deposits on the boiler walls, which create very reducing conditions locally. EPRI combustion fluid dynamic modeling studies further indicate that the area covered by FeS-rich deposit can be significantly reduced by fine-tuning air/fuel ratios of individual burners or burner levels. However, for some boilers there will remain areas with unacceptably high corrosion rates. This report describes commercially available protective coating technologies for reducing these corrosion rates. The report also describes results of a preliminary EPRI investigation of the potential problem of increases in superheater and reheater corrosion, which have been observed in some boilers after installation of low-NO_x burners.

Conclusions noted in the report include the following:

- Coating technologies to combat water-wall corrosion have improved significantly in the last two to four years. Technologies suitable for both shop and field applications are now available that will provide effective protection for at least five years, and in many cases much longer.
- Due to intense competition, the price of most technologies has remained steady or declined over the past two to four years.

- In situ repair is always less expensive than installation of replacement panels. Thus, it is important to monitor water-wall wastage and take remedial action before tubes become too thin to be repaired.
- The use of low-NO_x burner systems frequently results in some carburization of superheater and reheater tubing. However, increases in corrosion appear infrequent so far. In one well-documented boiler, no increases in superheater corrosion were found after installation of a low-NO_x burner system, although carburization was observed.

This report shows that problems associated with excessive water-wall corrosion due to low-NO_x burner systems have largely been brought under control. Previous EPRI studies have revealed the root cause of the excessive corrosion and indicated ways to minimize the damage (see TR-111152 and TR-111155). For areas that will suffer from unavoidable corrosion, coating technology has been refined to provide reliable protection. This protection can be implemented at a reasonable cost, provided corrosion is monitored and action is taken before the tubes are too thin to repair.

EPRI BUSINESS GROUP: Energy Conversion Division

Operation and Maintenance Guidelines for Draft Fans TR-101698

DETAILS: Final Report (500 pages)

DATE: Jan. 1993

KEYWORDS: Fans
Maintenance
Operation
Inspection
Welding

ABSTRACT:

The reliability, efficiency, and safety of draft fans in fossil fuel power plants depend on effective operating and maintenance practices. These guidelines systematically present state-of-the-art techniques that utility personnel can use in operation, maintenance, troubleshooting, inspection, and weld repair of major fan components and auxiliary systems.

DISCUSSION:

Draft fans are among the leading causes of fossil unit forced outages. In recent years, utility companies have found it necessary to replace fan rotors—particularly on cycling units—due to chronic cracking problems. Occasionally, the failures are catastrophic and lead to extended fan outages to await delivery of long-lead replacement parts. Previous EPRI fan-related projects have focused on failure cause identification (report CS-3199), field test procedures (CS-1651), foundation analysis (CS-4746), pressure and flow pulsation analysis (CS-1444), noise reduction (CS-3260 and CS-3262), design and procurement (CS-3431), erosion control (CS-6068), and centrifugal fan monitoring (GS-7409).

These guidelines are organized in sections covering the major comprehensive topics of fan operation, maintenance, troubleshooting, wheel inspection, and weld repairs. Each section makes extensive use of road maps as a systematic means to list and describe step-by-step procedures. In addition, the document contains nearly 300 diagrams and photographs. Operation includes subsections on training, written procedures, startup, shutdown, parallel operation, on-line monitoring, and performance/auxiliary power optimization. Maintenance covers prestartup, in-service, and out-of-service checks for 15 fan components and auxiliary systems. Wheel inspection specifies a program to identify cracking and erosion damage before it escalates to the level of a major problem. Weld repair outlines procedures for performing field repairs to fan components.

These guidelines are intended for use in developing and refining operation and maintenance procedures for large draft fans in power plant applications, regardless of whether the application is forced draft, induced draft, booster, gas recirculation, primary air, or pulverizer exhaust. The guidelines are generic in nature and are intended to supplement, rather than substitute or supersede, specific operation and maintenance requirements and procedures provided by fan and auxiliary manufacturers.

EPRI BUSINESS GROUP: Energy Conversion Division

Condition Monitoring of Fans With Rolling Element Bearings CS-5606

DETAILS: Final Report (104 pages)

DATE: March 1988

KEYWORDS: Vibration
Diagnostic Techniques
Fans
Bearings
Monitoring
Rotating Machinery
Predictive Maintenance

ABSTRACT:

Data on high-frequency vibration caused by the impacts of bearing pits and spalls can help schedule equipment maintenance. One data collection technique, developed through long-term monitoring of combustion air axial fans at the Pennsylvania Electric Company Homer City station, helps plant personnel anticipate failures of draft fan antifriction bearings by several months.

DISCUSSION:

The vibration meters routinely used to monitor rotation equipment in utility power plants measure the overall waveform and collect detailed spectral data in bands containing several of the running speed frequency (0-1 kHz). However, most vibration metering systems are insensitive to higher frequencies. Data on less energetic but nevertheless significant frequencies in the 30-50 kHz range would aid detection of rub and bearing damage in fans, pumps, motors, and compressors, particularly those with rolling element (antifriction) bearings.

After conducting a review of bearing monitoring technology, investigators designed a vibration monitoring system for the Pennsylvania Electric Company Homer City station. Over a three-year period, the system—which included a permanently mounted velocity probe and accelerometer in addition to handheld sensors—collected data on 18 rolling element bearings in two forced draft and two primary air axial fans. For each bearing the system provided spectral data on frequencies as high as 100 kHz and on signal level. Examination of three bearings removed for maintenance corroborated the vibration data. Several data analysis techniques identified failure progression indicators, which the team compared to a typical fault detection criteria used with standard vibration meters. The investigators also recommended techniques to detect and estimate fault severity.

Low-frequency data from the permanently mounted velocity probe and accelerometer correlated well, but data from handheld sensors in the system were inconsistent. Structural casing vibrations unrelated to the bearing increased the magnitude of signals from handheld sensors, which could lead to premature bearing replacement. Examination of bearings replaced on the basis of signals from such devices revealed only minor spalling with no threat of impending failure, confirming

the low-frequency monitoring is not appropriate for detection of bearing damage. Fan deterioration data suggest that information provided by permanently mounted accelerometers, which monitor the decibel level in higher (30-50 kHz) frequencies, can help predict bearing failures several months in advance. The high-frequency signals from these instruments are insensitive to noise problems and unaffected by changes in fan operation.

High-frequency monitoring is a useful technique for scheduling maintenance of rolling element bearings in axial draft fan; aircraft derivative gas turbines; and low-horsepower fans, pumps, and motors.

EPRI BUSINESS GROUP: Energy Conversion Division

Guidelines for the Use of Refractories in Circulating Fluidized-Bed Combustors

GS-7304

DETAILS: Final Report (144 pages)

DATE: May 1991

KEYWORDS: Circulating Fluidized-Bed Combustion
Failure Analysis
Maintenance
Refractories
Pulverized Coal

ABSTRACT:

This manual provides preliminary guidelines for refractory practice in circulating fluidized-bed combustors (CFBCs). The guidelines are based on early refractory experiences in CFBCs and information from related processes, mainly in the oil refining industry.

DISCUSSION:

Refractory use in traditional pulverized-coal boilers is insignificant. Therefore, operators and engineers are generally not familiar with the design, operation, and maintenance of refractory-lined process vessels. The CFBCs, a relatively new type of boiler designed to operate on low-grade fuels, uses refractory-lined combustors, cyclones, ducts, and other components. Accelerated wear and premature failure of refractory linings have been reported in several instances. EPRI commissioned an experienced refractory engineer to investigate the failures and to provide guidelines that will familiarize utility engineers with refractory usage.

The resulting guidelines briefly describe refractory installation techniques in general and treat refractory practice for CFBCs in greater detail. Key topics discussed are lining design and refractory selection, installation inspection and startup, failure analysis and repair techniques.

At the time these guidelines were developed, CFBC technology had only recently been introduced into the United States. Refractory practice was, therefore, in its infancy. Continued operation of refractory-lined CFBCs and supporting research will most likely result in improved refractory performance in the future and more-detailed guidelines for refractory usage. These guidelines must be considered preliminary. It is EPRI's intention to update the guidelines periodically on the basis of additional operating experience and the results of its investigation on refractory wear in CFBCs.

EPRI BUSINESS GROUP: Energy Conversion Division

Guidelines for the Prevention of Economizer Inlet Header Cracking in Fossil Boilers GS-5949

DETAILS: Final Report (208 pages)

DATE: Nov. 1989

KEYWORDS: Economizers
Cracking (Fracturing)
Thermal Fatigue
Cycling Operation
Fossil-Fuel Fired Boilers
Power Plant Availability

ABSTRACT:

Fossil boiler economizer inlet headers and tubes are susceptible to thermal-fatigue cracking, especially in cycling operation. Using these guidelines, power plants can monitor, evaluate, and control the frequency and magnitude of thermal excursions thereby extending pressure-part life and avoiding forced outages.

DISCUSSION:

As fossil boiler cycling operation became common industry practice, plants began to experience leaks in economizer inlet tubes at the toe of tube-to-header filler welds. Inspection of the failures revealed (1) longitudinal cracks on the inside surfaces of the tubes and bore holes and (2) longitudinal and circumferential ligament cracks on the inside surfaces of the headers. Economizer inlet header crack repairs could not be justified economically, and unless cracked headers were analyzed and proven safe and reliable for operation, new headers were necessary.

A literature survey and visits to 13 domestic and foreign utility companies, as well as leading boiler manufacturers and inspection service organizations, obtained information on header cracking experience, inspection/analysis techniques, and crack prevention/control solutions. They organized the results of their investigation into step-by-step guidelines focusing on (1) headers most susceptible to damage, (2) header condition, (3) tests to correlate operating parameters with cracking experience, (4) optimized operating procedures (5) serviceability evaluations, and (6) design modifications for replacement headers.

- The root cause of cracking is associated with feeding cold water into a hot economizer inlet header during transient boiler operating conditions.
- Headers most susceptible to cracking are those with a high number of operating cycles, a ligament size of 1-3/8 in. or less measured on the inside surface, flue gas exposure, and severe thermal cycles caused by slug feeding during transient operation.
- Thermal-fatigue cracking is detectable by visual, ultrasonic, and other inspection methods. Cracked headers can be monitored to determine the through-wall temperature gradients that develop during transient operation.

- Revised operating methods, such as a trickle feeding and off-line economizer recirculation, reduce temperature gradients and high stresses. Lower thermal stresses result in extended header service life.
- Several leak-before-break analyses have predicted failure by leakage, but because catastrophic failure remains a possibility, each header must still be evaluated for its unique conditions. If replacement is necessary, improved designs that minimize stress risers are available.

These guidelines will assist in preventing cracks in economizer inlet headers of new units and controlling cracks in older units. There is currently no non-destructive examination technique that can be used from outside the header to determine the size of ligament cracks. The results of this project have been integrated into boiler tube failure (BTF) prevention program (EPRI Report GS-6467).

EPRI BUSINESS GROUP: Energy Conversion Division

**Corrosion Fatigue Boiler Tube Failures in Waterwalls and Economizers:
Volumes 1-4
TR-100455-V1/V2/V3/V4**

DETAILS: Final Report (Vol. 1-224 pages; Vol. 2-188 pages; Vol. 3-446 pages;
Vol. 4-284 pages)

DATE: May 1992

KEYWORDS: Power Plant Availability
Boiler Tubes
Failure Analysis
Water Chemistry

ABSTRACT:

Corrosion fatigue is the major source of boiler tube failures, which remain the leading cause of fossil steam plant availability loss. Information is now available from ten fossil plants to provide valuable guidance on identification and control of these failures.

DISCUSSION:

Volume 1, Field Survey Summary, describes and illustrates 24 possible corrosion fatigue sites and the relationships between the number of corrosion failures and unit operation, boiler water chemistry, and chemical cleaning. Volume 2, Laboratory Corrosion Fatigue Studies, contains data on initiation and propagation of corrosion fatigue cracks and shows a large dependence on dissolved oxygen and other chemical parameters. Volume 3, Field Monitoring and Theoretical Stress Analysis, contains the field monitoring results on three boilers and detailed stress analyses of predominant cracking locations. Volume 4, Summary Report and Guidelines for Corrosion Fatigue Evaluation, brings all the results together in an influence diagram that defines the relative effects of stress, boiler chemistry, and operating regime.

This project has made a major step toward understanding the root cause of corrosion fatigue failures. Use of Volume 1 will allow correct identity of this mechanism and, based on the 24 locations described, the determination of any other boiler locations prone to repeat cracking. The initial influence diagram will assist in assessing whether a repair technique or a major modification will permanently eliminate the cracking.

EPRI BUSINESS GROUP: Energy Conversion Division

Waterwall Wastage in Low NO_x Boilers: Root Causes and Remedies TR-111155

DETAILS: Final Report (106 pages)

DATE: Oct. 1998

KEYWORDS: Nitrogen Oxides
Burners
Sulfidation
Corrosion
Boilers

ABSTRACT:

Several boilers, retrofitted with low-NO_x burner systems that employ external staging, have experienced severe waterwall corrosion. This study has demonstrated that iron sulfide rich deposits are the main cause of excessive corrosion. Methods to reduce iron sulfide deposition and, thus, reduce corrosion have been identified and patented by EPRI.

DISCUSSION:

EPA regulations require significant reductions in NO_x emissions for utility boilers. The preferred method to achieve this is using burner systems with reduced NO_x formation. Such burner systems create reducing zones in the lower furnace, especially systems with overfire airports (OFAs). Waterwall wastage has been observed in a significant number of boilers retrofitted with low-NO_x systems that employ OFAs or some other means of external staging. The problem is most severe in supercritical boilers using relatively high-sulfur coals, but subcritical boilers and boilers firing low-sulfur coals are not immune. Wastage rates are typically up to 20 mils/yr (0.5 mm/yr) for subcritical boilers and 40-80 mils (1-2 mm/yr) for supercritical boilers. Prior to this study, the conventional perception was that the corrosion was caused by H₂S in severely non-stoichiometric flue gas, containing up to 12 percent CO. However, laboratory studies indicate that corrosion rates observed in the field are much higher than those caused by H₂S at levels (500-1500 ppm) usually found in boilers retrofitted with low-NO_x burner systems.

The study obtained the following key results:

- Severe waterwall corrosion in boilers retrofitted with low-NO_x/OFA systems is most likely to occur in areas where deposits rich in iron sulfide are present.
- Combustion modeling can pinpoint the source of FeS deposits and indicate burner system modifications that minimize FeS deposition.
- The project developed a corrosion model to predict corrosion rates caused by FeS deposits. Predicted corrosion rates agree well with those found in service.
- Corrosion caused by H₂S in the flue gas cannot be neglected, but is generally less than 20 mils/yr (0.5 mm/yr) for supercritical boilers. Modeling studies indicate that measures to reduce FeS deposition also may reduce H₂S levels near the furnace wall.

This study has clearly demonstrated that FeS deposits are the main culprits causing excessive waterwall wastage. Thus, waterwall wastage is not intrinsic to low-NO_x burner systems. CFD modeling suggests several avenues to reduce FeS deposits and associated corrosion without increasing NO_x emissions. The main approach is to make burner system modifications that prevent or reduce FeS deposition on furnace walls. Modeling of a T-fired furnace shows that this can be done inexpensively by adjusting the fuel/air distribution into various burners to increase FeS oxidation. Field demonstrations are now in progress to verify that this concept works in practice as well as in theory. Details of the corrosion and modeling studies are reported separately in EPRI reports TR-111152 and GC-111049.

EPRI BUSINESS GROUP: Energy Conversion Division

Boiler Condition Assessment Guideline TR-111559

DETAILS: Final Report (132 pages)

DATE: Dec. 1998

KEYWORDS: Fossil-Fuel Power Plants
Life Assessment
Nondestructive Evaluation
Operations Research
Maintenance
Fossil-Fuel Fired Boilers

ABSTRACT:

The increasingly competitive environment for power generation is requiring that utility companies manage their operating plants to achieve least-cost generation. Reducing operating and maintenance costs is one element in that effort. Achieving such cost reduction while still maintaining plant safety and reliability requires a clear picture of the condition of key plant components. This guideline document provides a structure for performing condition assessment activities for major boiler components as a significant part of the overall plant assessment.

DISCUSSION:

Existing EPRI reports and tools provide a sound technical basis for performing condition assessment activities for boiler components. This current work serves to consolidate and summarize the extensive EPRI database to create a starting point for utility personnel to develop the condition assessment actions required for their fossil power plant boilers. The boiler continues to represent the largest source of forced outages in the industry and is a proper focus for condition assessment. In the context of this report and in the bulk of EPRI work on this topic, condition assessment actions are performed on a continuing basis to support maintenance planning, operations, and long-term management of generation assets. The guideline retains the EPRI recommended three-level structure for performing condition assessment. The iterative character of this approach allows utility companies to optimally match the cost of condition assessment efforts with the value of having such information. As has also been done in the past, the guidelines start with roadmaps to identify the sequence of actions required to perform condition assessment. Information on damage mechanisms, nondestructive evaluation options, analysis and disposition bases, and damage prevention opportunities is included in tabular form to support the roadmap. More detailed levels of information are, of course, available in the referenced EPRI reports upon which this current guideline is based.

Extensive EPRI and worldwide research has clearly defined the damage mechanisms for major boiler components. This means to perform condition assessment are generally straightforward and only require the organization and execution of appropriate work.

This guideline will assist in that activity by consolidating material from multiple sources into a single, streamlined document that can serve as the boiler component condition assessment program plan.

EPRI BUSINESS GROUP: Energy Conversion Division

Guidelines for Chemical Cleaning of Fossil-Fueled Steam-Generation Equipment TR-102401

DETAILS: Final Report (680 pages)

DATE: Jan, 1993

KEYWORDS: Boilers
Boiler Tubes
Tube Deposits
Chemical Cleaning
Power Plant Availability
Water Chemistry

ABSTRACT:

The quality of water and steam is central to ensuring fossil plant component availability and reliability. These comprehensive guidelines on chemical cleaning of heat transfer surfaces will help achieve these goals.

DISCUSSION:

In 1984, EPRI published a Manual on Chemical Cleaning (EPRI report CS-3289). Since then, new solvents and methodologies have been developed, the superheater and reheater circuits now need to be cleaned, and the aspects of waste disposal have drastically increased the cost of a chemical clean.

This report develops comprehensive guidelines on chemical cleaning of steam-generating equipment.

The project team surveyed approximately 60 domestic and international utility companies as well as boiler and turbine manufacturers and chemical cleaning companies. They then compiled the new information developed since the original manual was published. On the basis of their findings, the team assembled a completely new guideline document. The EPRI Fossil Plant Cycle Chemistry Group of 22 utility companies and five manufacturers reviewed the material, as did the Chemical Cleaning Subcommittee of the EEI Chemistry Committee.

The guidelines describe in detail the methods for determining the need for chemical cleaning, the solvent selection process, the planning and execution aspects, and the waste minimization and disposal process. The individual sections and appendixes also discuss:

- Hazards and safety precautions
- Chemical cleaning procedures for boiler, superheater and reheater tubing, and other cycle components
- Methods for determining deposit weight
- The chemistry of organic and inorganic solvents

- Specifications for chemical cleaning

One of the EPRI fossil plant cycle chemistry goals is to extend the period between chemical cleans and ultimately eliminate the need for cleaning. These guidelines will assist in reaching this goal by keeping the complete cycle cleaner. They will also reduce the risk of damage resulting from chemical cleans that are performed incompletely or improperly and increase the safety of plant personnel.

EPRI BUSINESS GROUP: Energy Conversion Division

Boiler Chemical Cleaning Wastes Management Manual TR-101095

DETAILS: Final Report (164 pages)

DATE: Aug. 1992

KEYWORDS: Boiler Tubes
Chemical Cleaning
Waste Disposal
Waste Management
Pollution Control

ABSTRACT:

Boiler chemical cleaning wastes pose potentially difficult waste management problems. This manual presents a number of different strategies for managing these wastes during water-side cleaning of utility boilers.

DISCUSSION:

Over time, the internal surfaces of boiler tubes collect mineral deposits. These deposits interfere with heat transfer from the hot combustion gases to the water and steam inside the tubes, reducing boiler efficiency. Utilities typically clean these tube interior surfaces every two to five years. The type of cleaner used depends on the types of deposits, boiler type and tube metallurgy, relative cost, and previous boiler cleaning experience. Previous EPRI work found that boiler chemical cleaning wastes (BCCWs) can contain high concentrations of heavy metals as well as inorganic compounds not commonly present in other power plant liquid effluents (EPRI report CS-5281). Some of these wastes are difficult to treat to required water quality discharge limits, and some are classified as hazardous under the Resource Conservation and Recovery Act. This manual expands on the previous EPRI study by examining several waste management options.

This report describes the chemical composition and regulatory status of boiler chemical cleaning wastes; and summarizes boiler chemical cleaning waste management options.

Researchers used existing literature and past EPRI reports to determine the chemical makeup of the wastes. They then investigated the regulatory status of the various components and identified several management options. For each option, the research team prepared a technology description, along with an evaluation of the effectiveness of the option and its cost. The researchers used actual field data in the effectiveness and cost evaluations whenever possible; in some cases, they used laboratory or literature data.

Laboratory screening tests showed that permanganate treatment or natural degradation in ash ponds followed by sulfide addition are effective methods for removing metals from citric acid wastes. No chemical treatment method tested was suitable for EDTA (ethylenediamine tetraacetic acid)-based cleaning wastes. Emissions-monitoring studies were conducted at two utility companies that routinely evaporate wastes, an often-used practice. Emissions of metal

compounds from the cleaning wastes at a coal-fired boiler were found to be insignificant compared with the normal plant emissions. At an oil-fired generating unit, about 50 percent of the metals contained in the waste could not be accounted for. (Further investigation will be required to clear up this anomaly.) No significant changes in normal operating conditions were observed at either generating plant during evaporation.

Laboratory studies of BCCW reuse in a bench-scale flue gas desulfurization system showed that five types of waste could be successfully recycled as a supplement for makeup water. The chemistry of the scrubbing solution results in precipitation of the metals, which are subsequently removed with scrubber sludge. Toxicity Characteristic Leaching Procedure tests on the sludge did not show any of the metals to be leachable.

Successful management of boiler chemical cleaning wastes requires a knowledge of the regulatory requirements and the technical options available. From a pollution-prevention point of view, options that minimize waste production—such as source reduction, substitution, or recycling—are preferred. These options include reduced cleaning frequency (through improved boiler-cycle chemistry); decreasing the volume of chemicals used; and changing cleaning chemicals to less-corrosive, less-toxic, or more-easily-treatable compounds. EPRI's Manual on Chemical Cleaning of Fossil-Fueled Steam Generation Equipment (report CS-3289) is a good source of information on cleaning frequency and procedures. (A revised version of this document is expected to be published by the end of 1992).

This report is one in a series created to help manage low-volume and noncombustion waste streams. EPRI report CS-5281 discusses treatment options and costs for 10 waste streams. EPRI report GS-7052 describes management schemes for 16 wastes. Risk management for BCCW and other noncombustion wastes is being investigated.

EPRI BUSINESS GROUP: Environment Division

Ultrasonically Assisted Cleaning: TechCommentary Vol. 9, No. 1 TC-102982-V9P2

DETAILS: Technical Commentary

DATE: Jan. 1993

KEYWORDS: Ultrasonic Cleaning
Chlorofluorocarbons
Deposits

ABSTRACT:

This Technical Commentary characterizes ultrasonic technologies as a “new wave” in industrial cleaning. They can achieve a higher standard of cleanliness, improved production efficiency, and reduced use of chlorofluorocarbons (CFCs) and volatile organic compounds (VOCs). Ultrasonic cleaning is based on the principle of sound waves traveling through a liquid and subjecting it to alternating periods of negative and positive pressure, and is used in cleaning technologies ranging from consumer products to high-tech industrial cleaning systems. The article describes how the process differs from conventional cleaning processes; explains cavitation; gives examples of industrial applications; describes how the process cleans; and discusses equipment, conditions, and supplies. Advantages are reduced emissions, reduced process times, less expensive chemicals, reduced consumption of cleaning chemicals, improved quality, safety, and adaptability. Disadvantages are certain limitations, and the installation of new equipment. Technical considerations include: type and condition of the substrate; type of debris and ease of removal; part exposure; and solution recapture and separation. Capital and operational costs are considered. Alternate technologies and other applications are briefly discussed.

EPRI BUSINESS GROUP: Energy Conversion Division

8

TURBINES, CONDENSERS & HEAT EXCHANGERS

Large Steam Turbine Repair: A Survey NP-7385

DETAILS: Final Report (100 pages)

DATE: July 1991

KEYWORDS: Steam Turbines
Life Extension
Welding
Welding Repair
Stress Corrosion
Reliability

ABSTRACT:

Repairs to large steam turbines containing unacceptable defects can be performed using mechanical and weld repair techniques. This report documents a number of turbine repairs and provides detailed guidelines that simplify the repair/replacement decision and associated requirements.

DISCUSSION:

Large steam turbines have experienced service failures in a far shorter time than the original design life. Because of the need for continued operation, utility companies face decisions of whether to repair or replace major components, such as large steam turbines. With replacement turbines becoming more difficult to obtain in a timely, cost-effective manner, utility companies are increasingly considering repair options to maintain the service worthiness of their steam turbines.

Objectives of this report were:

- To document the state-of-the-art regarding available technology for repair of rotating steam turbine components.
- To provide a list of experienced vendors who offer assistance in various phases of the repair/replacement cycle.

A vendor survey revealed that repairs to turbines containing unacceptable flaws can be accomplished using mechanical or weld repair techniques. Through weld repairs to turbines have been made in Europe since 1930, no standard repair procedures are in place because most

turbines require unique approaches. The choice of repair strategy depends on specific requirements, such as plant downtime, turbine materials, technical merits, insurability of the repair, and cost. Turbine locations amenable to mechanical and weld repairs include the blade attachment region, keyway, shaft, and journal. Mechanical repairs have also been performed on the disk face and rotor bore. Whereas mechanical repairs can readily be performed in situ, most vendors considered in situ weld repairs impractical and not cost-effective. At the time of this survey, only a few repair organizations were prepared to address weld repairs on site. Overall, vendors noted that personal communication among the owner, repair organization, and insurer were important to successful and timely completion of the repair.

This report provides information on vendors with proven experience who can assist in resolving repair/replacement challenges. The report also identifies engineering and fabrication techniques available for evaluating the suitability of a specific component or component location for a given repair. In particular, the “reverse engineering” approach, described in this report, offers a tool to use in evaluating turbines and making the repair/replacement decision. Because a variety of techniques are available to address a given repair, it is important to evaluate repair/replacement decisions based on plant considerations, technical merits, and economics.

EPRI BUSINESS GROUP: Energy Conversion Division

Steam Turbine Hydraulic Control System Maintenance Guide TR-107069

DETAILS: Final Report (221 pages)

DATE: Dec. 1996

KEYWORDS: Turbine Controls
Maintenance
Preventive Maintenance
Predictive Maintenance
Valves

ABSTRACT:

Steam turbine hydraulic control system maintenance problems have been a significant factor in plant power reductions, shutdowns, and lost generation. This guide provides recommendations to improve the reliability of the hydraulic components and fluid.

DISCUSSION:

Although considerable effort has been expended in improving system reliability, failures resulting in lost generation and high maintenance cost still plague the industry. This guide provides maintenance recommendations for system hydraulic components and fluids and identifies design changes and maintenance practices that have improved reliability on an individual basis.

This guide provides a summary of turbine control hydraulic component and hydraulic fluid problems with the associated failure modes and analysis. Successful predictive and preventive maintenance programs are identified. Maintenance practices to maintain fluid quality are presented.

The turbine hydraulic control system continues to cause unplanned plant shutdowns due to component failures and inadequate control system performance. Obsolescence of the installed control system components has contributed to system problems. This guide will serve as a valuable source of information for plant personnel that are evaluating their hydraulic system to determine how to improve performance.

EPRI BUSINESS GROUP: Energy Conversion Division

High-Temperature Bolting Life Prediction and Life Assessment TR-113529

DETAILS: Final Report (102 pages)

DATE: Aug. 1999

KEYWORDS: Turbine Valves
Bolts
Predictive Maintenance
Stress relaxation
Creep
Non-destructive Evaluation
Life Assessment
Diagnostic Techniques

ABSTRACT:

Informed run/replace decisions for high-temperature bolting require nondestructive evaluation (NDE), life assessment, and life prediction. This report gives an improved, analytical life prediction method based on stress relaxation calculation of accumulated creep strain and measured bolt length.

DISCUSSION:

High-temperature turbine cylinders and valve covers are jointed using studs/bolts. Because of the high cost of bolt replacement, it is clear that replacements should be made only when the bolt is near its end of life. Based on utility industry experience, there is a large population of high-temperature turbine and valve studs/bolts approaching end of life; this situation requires a method to identify bolts susceptible to failure and to perform remaining life calculations. This report developed and validated an improved analytical creep life predictive method for high-temperature bolting.

The life prediction method uses creep behavior, an incremental calculation procedure, and the strain hardening flow rule to predict the stress relaxation behavior. Creep constitutive equations were developed using a two-parameter material model for three bolt materials: 1CR-1/4V, 1CrMoVTiB, and 12Cr-1Mo-1W-1/4V. The failure criterion was an accumulated inelastic or creep strain limit of 1 percent. This failure criterion is consistent with a ductility exhaustion approach for creep failure at the thread root.

For validation, the calculated results were compared to the results of uniaxial stress relaxation testing, bolt model testing, and service experience. For the uniaxial tests, good agreement was found between the observed calculated relaxation properties for 12C4-1Mo-1W-1/4V. For bolt model tests, the calculated values for accumulated inelastic strain as a function of cycles were in good agreement with those measured for 1CrMoVTiB steel. For service-exposed bolts, the current length of HP turbine inner cylinder and stop valve bolts were measured. The initial bolt length was estimated as the nominal specified and was used to calculate the accumulated creep strain. Because of this uncertainty in initial length, the observed creep strain was considered

unreliable. The temperature of the stop valve studs were measured. The measured temperature at the mid-point of the valve studs was uniform and approximately 55-60 degrees Fahrenheit below the nominal steam temperature of 995 degrees Fahrenheit. There was a temperature gradient of approximately 30 degrees Fahrenheit along the length of the stud.

This report provides an overview of the complex issues involved in life assessment and prediction of high-temperature bolts. The analytical procedure developed in this study coupled with other industry-wide NDE and measurement procedures is expected to provide broad guidelines for bolting life assessment. By integrating remaining life prediction and field measurements, this method can produce significant economic O&M benefits for utilities.

EPRI BUSINESS GROUP: Energy Conversion Division

General Electric Electrohydraulic Controls (EHC) Electronics Maintenance Guide

TR-108146

DETAILS: Final Report (210 pages)

DATE: Dec. 1997

KEYWORDS: Turbine Controls
Maintenance
Electronic Equipment
Power Electronics
Predictive Maintenance
Preventive Maintenance

ABSTRACT:

Steam turbine electrohydraulic control system maintenance problems have been a significant factor in plant power reductions, shutdowns, and lost generation. This guide provides recommendations to improve the reliability of the electronic circuits and components of General Electric EHC systems.

DISCUSSIONS:

Although considerable effort has been expended in improving EHC system reliability, failures resulting in lost generation and high maintenance costs still plague the industry.

This guide provides information that can be used to improve EHC maintenance practices and procedures. The guidelines are geared toward providing system engineers and/or maintenance supervisors with the information and guidelines needed to improve site-specific maintenance procedures and processes. This guide contains:

- Descriptions of the electronic systems in EHC.
- Data on system and electronic component failure history for each type of GE-EHC. The history is evaluated to identify trends and document the causes, components, and subsystems involved in the events.
- Summaries of current maintenance practices used by the utility industry.
- Guidelines on the maintenance and operation of the systems, which are based on the history of the system electronics and on current utility practices.

The turbine hydraulic control system continues to cause unplanned plant shutdowns due to component failures and inadequate control system performance. Obsolescence of the installed control system components has contributed to system problems. The guide will serve as a valuable source of information for plant personnel who are evaluating their control system to determine how to improve performance.

EPRI BUSINESS GROUP: Energy Conversion Division

Terry® Turbine Controls Guide NP-6909

DETAILS: Final Report (770 pages)

DATE: Sept. 1990

KEYWORDS: Steam Turbines
Turbine Controls
Maintenance
Preventive Maintenance
Predictive Maintenance

ABSTRACT:

This guide provides background and specific recommendations on implementing an effective maintenance or upgrade program for Terry turbine controls. In addition, it represents a resource for addressing industry control issues related to Terry turbines.

DISCUSSION:

Although utility industry experience with Terry turbines has been positive, control adjustments have sometimes been required. This technical guide—which covers only Terry turbine controls, such as the trip system, throttle valve linkage, and governors—is designed to provide a broad range of personnel with information on the setup and operation of these controls systems.

The technical repair guide for Terry turbine controls offers comprehensive instructions on optimum methods for repair, maintenance, adjustment, and troubleshooting of Terry turbine controls. Moreover, it includes an engineering description of operation and prevalent failure mechanisms, preventive and predictive maintenance guidelines, repair and adjustment methods, and spare parts recommendations. Specifically, this guide is an up-to-date, stand-alone reference manual, with sufficient drawings and descriptions to affect most required maintenance on the control not including site-specific appurtenances.

Individual plants can use this guide to review maintenance practices related to Terry turbine controls and to develop improved procedures. The guide, which may also assist in upgrading all or portions of control systems, contains an easy-to-use matrix that allows users to customize a manual to their specific component.

EPRI BUSINESS GROUP: Energy Conversion Division

Terry® Turbine Maintenance and Troubleshooting Guide TR-105874

DETAILS: Final Report (354 pages)

DATE: Dec. 1995

KEYWORDS: Maintenance
Life Extension
Steam Turbines
Predictive Maintenance
Monitoring

ABSTRACT:

This guide provides plant engineering and maintenance personnel with a comprehensive reference source covering all facets of turbine system maintenance. The document complements the NMAC Terry® Turbine Controls Guide, NP-6909, and contains the most complete assemblage of information available on maintenance of the turbine, its steam supply system, and its various components and devices.

DISCUSSION:

This document offers component-level guidelines and tips for performing all normally required inspection and maintenance, with particular emphasis on procedures and components not fully covered in the original turbine instructions. Where the controls guide addressed only the various governor packages used by several Terry turbine configurations, this guide provides assembled information on maintaining Terry turbine systems in commercial nuclear power plants, including auxiliary feedwater, reactor core isolation cooling, and high-pressure coolant injection applications.

Terry turbine maintenance has been targeted as an area of increasing interest. System engineers, and plant maintenance personnel will find the information in this guide valuable in planning and scheduling required preventive and corrective maintenance, and also in troubleshooting performance problems identified during routine surveillance testing. Users will benefit by using the information to develop and implement effective performance monitoring and system predictive maintenance programs. Individual utility plants can use this guide to review their specific maintenance practices and develop new or improved procedures, where applicable.

EPRI BUSINESS GROUP: Energy Conversion Division

Terry® Turbine Controls Maintenance Guide, Revision 1 TR-016909-R1

DETAILS: Final Report (276 pages)

DATE: Sept. 1998

KEYWORDS: Turbine Controls
Maintenance
Predictive Maintenance
Steam Turbines

ABSTRACT:

This Terry® Turbine Controls Maintenance Guide, Revision 1, and the Terry Turbine Maintenance and Troubleshooting Guide (TR-105874) provide a comprehensive reference set covering all facets of equipment inspection, predictive maintenance, and corrective maintenance. These volumes represent the aggregate knowledge of industry experts in the field and offer valuable supplemental information to that provided by the original equipment manufacturer. Maintenance and troubleshooting techniques offered in these guides will assist plant personnel in refining and optimizing both their operations and maintenance procedures and their training programs relative to this equipment.

DISCUSSION:

The Terry Turbine Controls Guide (NP-6909) was originally prepared and distributed in 1990 in response to utility industry interest in improving the available information relative to maintenance of this equipment. Following the dissolution of the original equipment manufacturer, Terry Steam Turbine Co., operators of Terry turbines found themselves facing a void with respect to the availability of specific technical information and expertise for this equipment.

Since that time, field use has shown NP-6909 to be an invaluable technical resource for the plant maintenance professional. In 1994, development of a companion document (TR-105874) to address the remainder (the non-control system portion) of the Terry turbine, as installed in commercial nuclear power reactors, was undertaken. Development of TR-105874 suggested the need to update and reorganize information contained in NP-6909 into a more compatible and user-friendly format.

The resulting guide provides end users with a complete guide to control issues for all major plant applications of the Terry turbine. The revised document is divided into two major sections: the first provides technical guidance for HPCI applications, while the second addresses RCIC and AFW applications, which are similar. The document includes both new and updated drawings, as well as predictive maintenance and troubleshooting information.

As the pool of original knowledge relative to Terry turbine systems continues to naturally diminish, this guide, in conjunction with TR-105874, will represent an increasingly more important resource for plant engineering, maintenance and training personnel. EPRI believes that

these two documents represent the best accumulation of existing information on the subject. Through their use, users should be able to significantly improve and optimize their existing plant predictive, preventive, and corrective maintenance programs related to this equipment, thereby achieving increased reliability and availability at decreased cost.

EPRI BUSINESS GROUP: Energy Conversion Division

Turbine-Generator Maintenance Outage Interval Extension: Turbo-X Version 1.0a User's Manual CM-110998

DETAILS: User Manual (86 pages)

DATE: Oct. 1998

KEYWORDS: Maintenance
Steam Turbine-Generators
Fossil-Fuel Power Plants
Outages
Inspection

ABSTRACT:

In the industry's growing competitive climate, utility companies are seeking new and innovative technologies for safely maximizing intervals between major turbine-generator (T-G) inspections and overhauls. EPRI's newly developed Turbine Outage Extension (Turbo-X) System provides key status reports reflecting the on-line health of T-G critical components in terms of life consumption, performance degradation, and probability of failure. Information obtained via Turbo-X provides a means of justifying the extension of T-G operations between inspections and overhauls.

DISCUSSION:

Monitoring and predictive maintenance programs in place at most U. S. plants are limited to off-line diagnosis and analysis. These "after the fact" approaches tend to be labor intensive and heavily dependent on human interpretation. Moreover, they may not offer critical details on T-G component life consumption based on actual operating history. A financial interpretation is also often missing, divorcing the economic decision makers from the engineers responsible for T-G operation and maintenance. EPRI's Turbo-X system links technical planning with financial management aspects of T-G operation. This report describes a decision analysis tool that combines engineering, economic, and risk analysis to provide guidance for planning and extending T-G overhauls and inspections.

Level 1 of EPRI's Turbo-X system combines industry-based risk assessment data with unit-specific experience to determine an optimal time for unit overhaul based on the unit's net present value (NPV). Levels 2 and 3 modules, available later, can be customized for plant-specific T-G components and O&M procedures. The final overhaul interval identified by Turbo-X takes annual unit capacity and operational factors into consideration. This analysis ensures the failure history data based on actual operating hours fits properly into any future decision, given the budget limits, forced outage rates, and safety limits.

This Turbo-X user's manual details key development concepts as well as installation, program layout and menus, an example program, and actual program operation. Turbo-X runs on Windows NT 4.0 or above and Microsoft Windows 95 or later system. It requires a VGA graphics card, 15 MB RAM, Microsoft mouse or other Windows-compatible device, and 10 MB

hard disk space. The respective guidelines and decision logic within Turbo-X are fully automated and accessible to the financial planner. Turbo-X will not intrude on any plant control or instrumentation system.

To provide some perspective of the benefits of the results of this report, it is noted that the average major utility industry turbine overhaul is performed approximately every five years and requires about six weeks to complete, resulting in more than 260,000 lost MWh. The potential economic benefits associated with interval extension can be sustained as long as reliability is not compromised. By extending these outages from 5-yr. intervals to 10-yr. intervals, a typical plant would eliminate two overhaul periods of 5-7 wks each over a 20-yr. time span. This would result in substantial savings in O&M and replacement power costs. For example, shifting from a 5-yr. to an 8-yr. outage maintenance interval, a 2400-MW plant with four T-G units would save an estimated \$62 million (\$17 million NPV). Shifting from a 6-yr. to a 10-yr. maintenance outage interval would save \$168 million (\$42 million NPV). EPRI's Turbo-X system can help achieve such savings by linking technical planning for T-G maintenance with prudent financial management.

EPRI BUSINESS GROUP: Energy Conversion Division

Heat Exchangers: An Overview of Maintenance and Operations

TR-106741

DETAILS: Final Report (57 pages)

DATE: March 1997

KEYWORDS: Heat Exchanges
Heat Transfer
Preventive Maintenance
Predictive Maintenance

ABSTRACT:

In the past, EPRI has conducted a voluminous amount of research on heat exchangers. This document draws on this experience and presents the information applicable to the maintenance and operation of heat exchangers, with an eye to providing tips on how to avoid the most common problems. This document provides practical suggestions for startup and shutdown, improvement of performance, problems and fixes with over capacity, failure mechanisms and their prevention, and many other topics of interest to power plant personnel. Because the majority of heat exchangers in power plants are the shell-in-tube type, these have been discussed in greater detail.

DISCUSSION:

A large number of heat exchangers are used in any power generating facility. Heat exchangers can be of various designs and construction. The effect of inefficient heat exchangers can range from being a slow economic drain on the generation facility to completely shutting it down. This Tech Note is intended to provide an overview of the basic operation and maintenance needs of heat exchangers.

This document presents information necessary for plant engineers and maintenance staff to diagnose and possibly correct inefficient operation of heat exchangers. Suggestions given here will be helpful in avoiding most of the common maintenance and operational problems. This report is designed as an aid for the maintenance and operation personnel who are already familiar with the equipment and systems at their facility; therefore, detailed technical descriptions of the various types of heat exchangers are not included here. References have been made to other reports and documents for such specific information. Also, information available in Codes and Standards has been referred to but is not repeated here.

EPRI BUSINESS GROUP: Energy Conversion Division

Heat Exchanger Workstation: Technology Review AP-101840-V3P4

DETAILS: Technology Review (Vol. 3)

DATE: Dec. 1995

KEYWORDS: Heat Exchangers
Feedwater Heaters
Condensers
Maintenance
Equipment Availability
Software

ABSTRACT:

Heat exchanger problems, such as those encountered with feedwater heaters (FWHs), condensers, and balance-of-plant heat exchangers, can cause significant availability losses and heat-rate penalties in fossil-fueled and nuclear power plants. Effective maintenance and performance analyses of heat exchangers can play an important role in supporting power plant efficiency and availability. EPRI's Heat Exchanger Workstation (HEW) is a software package designed to assist in the maintenance and operation of plant heat exchangers. HEW-FWH, the feedwater heater component of HEW, is also available. The software incorporates graphical, database, and knowledge-based-system tools, calculation procedures, and a hypertext reference module, and provides a complete environment for FWH record keeping, performance analysis, and troubleshooting.

EPRI BUSINESS GROUP: Energy Conversion Division

Basic Eddy Current Theory an Application with Emphasis in Heat Exchanger Examination, Version 1.0 AP-107468

DETAILS: Final Report (42 pages)

DATE: April 1998

KEYWORDS: Eddy Current Testing
Heat Exchanger
Non-destructive Testing
Software
Life Assessment

ABSTRACT:

EPRI has developed a software application to aid in the training of eddy current Level I and II NDE personnel. The software provides the individual participants with a self-paced interactive tool for the delivery of NDE instruction.

DISCUSSION:

Studies show that people retain about 20% of what they see, 40% of what they see and hear, and 70% of what they see, hear, and do. These statistics explain why interactive computer-based training has become a successful option for increasing numbers of companies and why the EPRI NDE Center has begun developing multimedia programs that address the current training needs for utility companies. Employees can see, hear, and do training at their own computers, at their own convenience and pace, while saving their companies thousands of dollars in travel costs and time away from their jobs.

Objective of this report were:

- To provide a better understanding of eddy current electromagnetic techniques as applied to balance-of-plant (BOP) heat exchanger tubing through an interactive resource
- To develop a simple-to-use, self-paced, Windows-based software application for the purpose of training NDE eddy current Level I and II personnel
- To allow eddy current Level I and II candidates to be trained in-house at their own pace

The EPRI NDE Center has developed a comprehensive eddy current technology to train NDE eddy current Level I and II personnel and has produced interactive computer-based training (CBT) software to allow them to be trained in-house at their own pace. CBT provides a flexible, interactive, multimedia training tool. The course, Basic Eddy Current Theory and Application with Emphasis in Heat Exchanger Examination,” is intended to meet industry training requirements for Level I and II eddy current personnel.

Eleven modules are included in the course incorporating text, animation, hypertext, hyperlinks, sound, and on-line quizzes. They are: Module 1. Basic Electrical theory, Module 2. Eddy Current

Test Coil Principles, Module 3. Coupling Effects with Test Materials, Module 4. Eddy Current Coil Design and Circuits, Module 5. Eddy Current Instruments, Module 6. Reference Standards, Module 7. Impedance-Plane, Module 8. Heat Exchanger Design and Operation, Module 9. Eddy Current Inspection Considerations, Module 10. Eddy Current Inspection and Analysis Techniques Applied to Nonferromagnetic Tubing, Module 11. Electromagnetic Inspection Techniques Applied to Ferromagnetic Tubing.

This product allows in-house training without incurring costs associated with traveling to an out-of-town training facility. This software product complements EPRI's NDE personnel testing software, "NDE Personnel Qualification Testing Software, version 1.0" (AP-108317-CD). With the above two products, a user can now train Level I and II candidates, create the required test questions, and grade individual tests automatically.

EPRI BUSINESS GROUP: Energy Conversion Division

Eddy Current Testing of Service Water Heat Exchangers for Engineers Guideline TR-110392

DETAILS: Final Report (114 pages)

DATE: Feb. 1999

KEYWORDS: Heat Exchangers
Eddy Current Testing
Non-destructive Testing
Service Water Systems
Life Assessment

ABSTRACT:

Service water (SW) heat exchangers experience tube failures due primarily to inside diameter (ID) pitting and flow-induced fretting wear at tube-to-tube support plate intersections. Eddy current is a fast volumetric tube wall examination technique performed from inside a tube to test and maintain structural integrity of the installed tubing. Because the service water heat exchanger tubing examination is not mandated under the ASME Code or the Regulatory Guide requirements, eddy current examination practices vary from one contract vendor to another. This document provides utility engineers with a well-defined uniform examination guideline for inspecting service water heat exchanger tubing.

DISCUSSION:

This report provides utility engineers responsible for service water heat exchangers with a guideline document that will enable the cognizant engineer to become more familiar with eddy current examination practices, secure qualified inspection vendors, plan and implement timely on-site eddy current tubing examinations, evaluate eddy current examination results, and make timely run/repair/replace decisions on tested heat exchanger components.

This finalized guideline document details the following major topics relating to the testing of SW heat exchangers:

- Eddy current examination flow path
- Eddy current examination plan
- Eddy current examination report
- Run/repair/replace decision
- Tube plugging criteria calculation
- Remaining heat exchanger life
- Eddy current bid specification

Service water heat exchangers play a vital role in life cycle management of operating plants. Periodic inspection of these components is necessary to maintain and extend the operability of existing plants. Frequently, plant component/system engineers rely on outside inspection vendors to perform eddy current examination of installed heat exchanger tubing. This guide will assist utility engineers with understanding eddy current capabilities and limitations and how it is used to maintain the integrity of installed tubing. It will help guide the cognizant utility engineer in preparing a bid specification, securing the most qualified vendor, monitoring on-site eddy current examination activities, performing needed tube repairs, and estimating remaining heat exchanger operating life.

EPRI BUSINESS GROUP: Energy Conversion Division

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MOTORS & GENERATORS

Electric Motor Predictive and Preventive Maintenance Guide NP-7502

DETAILS: Final Report (120 pages)

KEYWORDS: Electric Motors
Induction Motor
Maintenance
Preventive Maintenance
Predictive Maintenance

ABSTRACT:

Electric motor failure could result in lost capacity as well as excessive repair and maintenance costs. This guide provides information on establishing an effective maintenance program to help prevent unexpected motor failures, costly downtime, and unnecessary maintenance costs. Specifically, the guide summarizes technical data relative to four basic power plant motor types and associated components.

DISCUSSION:

Maintenance recommendations proposed by electric motor vendors have sometimes encouraged many overly conservative maintenance practices. These practices have led to excessive maintenance activities and costs that have not provided an extra margin of operability. Current work was prompted by a need to determine appropriate maintenance techniques and tasks for specific applications based on the type and size of electric motors and components.

This guide summarizes technical data on the four basic types of power plant motors and their components; it correlates failure causes, symptoms, and modes. The guide further addresses the significant causes of motor failures and outlines methods to optimize service life and minimize maintenance costs through appropriate preventive maintenance programs. Test and maintenance recommendations for different motor sizes and types are arranged to allow clear comparison of motor reliability with function and cost effectiveness. Throughout the guide, easy-to-read charts and tables chronicle the data.

On the basis of information provided in this guide, maintenance personnel can customize their programs for specific motors according to service applications and operating conditions. To assist in this effort, the guide includes a glossary of terms, regreasing guidelines for motors with antifriction bearings, and oil-monitoring guidelines for electric motors with oil bath bearings.

This guide provides a foundation for an effective electric motor maintenance program with simple, but viable, testing routines that increase assurance of efficient motor operation. In all, the guide simplifies selection of predictive and preventive maintenance tasks to help maintenance personnel plan motor repairs during scheduled outages and avoid costly unexpected failures. Related EPRI reports include GS-7352, Manual of Bearing Failure and Repair; NP-3357, Condition Monitoring of Nuclear Plant Electrical Equipment; and CS-5328, Signature Analysis, Rotating Equipment Monitoring.

EPRI BUSINESS GROUP: Energy Conversion Division

Guide for Rewinding and Reconditioning Medium Voltage Electric Motors: Volume 17 EL-5036-V17

DETAILS: Final Report (Vol. 17-282 pages)

DATE: June 1996

KEYWORDS: Electric Motors
Induction Motors
Rewinding
Stators
Maintenance

ABSTRACT:

When medium-voltage motors fail, plant personnel have to oversee repair and rewinding. This guide provides a short-course approach to medium voltage motor repair, with sample specifications and check-off sheets to help the nonspecialist get the best service from the repair shop. The guide can also serve as a technical reference for the specialist.

DISCUSSION:

The 16 previous volumes of EPRI's Power Plant Electrical Reference Series provide practical information on a variety of design, operation and maintenance issues relating to motors, generators, transformers, and electrical auxiliaries in both nuclear and fossil power plants. This volume provides a guide for the rewinding and recondition of 2300, 4000, 6600, and 13,200 V motors.

This guide is written for electric utility engineers concerned with the repair and rewinding of electrical motors in the 250 to 10,000 HP range. The guide emphasizes stator coils, their function, design, and manufacture. It includes information on losses and motor ventilation as these factors affect coil temperature. The medium-voltage motors covered in the guide require form-wound coils made of pre-insulated rectangular magnet wire. The guide discusses insulation components and systems as well as production testing during coil making and rewinding. It also covers windings and winding connections.

The guide has two parts. Part I, addressed to utility personnel who are responsible for motor repair, is a short course in medium voltage repair, with sample specifications and check-off sheets for 2300, 4000, 6600 and 13,200 V motors. It includes a technical guide for motor repair and a summary of the essentials of a repair shop quality control program.

Part II is addressed to the motor specialist and provides an in-depth discussion of motor theory as it relates to windings, winding insulation, coil design, coil manufacturing, and increasing motor output. Also included is a review of the quality standard of the Electric Apparatus Service Association (EASA).

This guide is designed to help utility personnel become better informed consumers of motor repair services. It can also be useful to repair professionals. Part II of the guide provides much technical information not conveniently available elsewhere. EPRI conducts courses based on this guide on medium voltage electric motor repair.

EPRI BUSINESS GROUP: Energy Conversion Division

Proceedings: Utility Motor and Generator Predictive Maintenance and Refurbishment Conference
TR-104625

DETAILS: Proceedings (340 pages)

DATE: Nov. 1994

KEYWORDS: Electric Motors
Electric Generators
Monitoring
Turbine Generators
Predictive Maintenance
Windings

ABSTRACT:

An abstract was not available. Some of the topics included in the contents are: (1) detecting equipment and on-line monitoring of partial discharges; (2) large motor insulation systems life extension; (3) monitoring and expert diagnosis of electrical auxiliary systems; (4) generator field thermal sensitivity and turbine generator rotor thermal unbalance; (5) rotor shorted turns; (6) copper dusting in large steam turbine driven generator rotors; (7) on-line measurement of rotor wedge temperatures; (8) on-line detection and location of stator winding interturn faults; (9) neural networks for plant condition monitoring; (10) air-cooled turbo generators for combined cycle operation; (11) testability and quality assurance for large air-cooled generator stator windings; (12) repair and rewind of electric utility motors; (13) stator cooling degradation by corrosion products; (14) on-line thermal monitoring on a 900 MW Turbogenerator.

EPRI BUSINESS GROUP: Energy Conversion Division

Main Generator On-Line Monitoring and Diagnostics TR-107137

DETAILS: Final Report

DATE: Dec. 1996

KEYWORDS: Diagnostic Technique
Predictive Maintenance
Electric Generators
Monitoring

ABSTRACT:

The monitoring of large electric turbine generators has become a topic of interest and investigation in the electric utility industry due to pressure to extend plant life and reduce operating costs. This is particularly true in the nuclear power industry because the costs and consequences of losing a unit are more significant than for fossil or hydro plants. This document provides information about common generator monitoring, diagnostics, sensors, and instrumentation.

DISCUSSION:

Improving the amount or type of monitoring is one possible way to extend generator life. Improved monitoring will allow more foresight in machine operation through a better knowledge of the machine's condition and will avoid major failures before they occur due to early warning of degradation or problems.

This report provides a guide to the repair of medium-voltage motors for utility plant managers and other personnel who may not have extensive experience or training in the area; contains a compendium of technical resource information for the motor specialist.

A description of the various monitoring philosophies is given, starting from simple monitoring with alarms, up to elaborate "expert systems" with on-line trending and diagnostic capabilities. A description of common generator and auxiliary system sensors and instrumentation is provided. Information is furnished on the types of monitoring devices, what they measure or sense, and the possible interpretations of the readings.

In addition to the common sensors, there are numerous specialized monitoring devices or systems that provide information about specific generator problems that can occur. Descriptions are provided on each of the known systems.

To make decisions regarding generator monitoring, equipment engineers need an in-depth understanding of monitoring systems and specialized monitoring devices available.

This EPRI effort was designed to provide utility engineers with information necessary to increase their knowledge and awareness of existing monitoring systems, as well as to identify potential needs or benefits of monitoring upgrades.

EPRI BUSINESS GROUP: Energy Conversion Division

Guidelines for the Procurement of On-Site Clip Replacement and Repairs of Water-Cooled Generators

TR-107680

DETAILS: Final Report (111 pages)

DATE: Jan. 1997

KEYWORDS: Electric Generators
Corrosion
Crevice Corrosion
Stators
Maintenance

ABSTRACT:

In May of 1991, General Electric (GE) recommended special maintenance tests to detect water leaks caused by clip-to-strand corrosion in the stator windings of GE water-cooled generators. This report provides guidelines for the procurement of repairs caused by this leak-producing mechanism.

DISCUSSION:

Clip-to-strand corrosion occurs in the water-cooled stator windings in large GE steam turbine generators because, as manufactured, the braze design of the windings allows water to become trapped in a spongy, phosphorous-rich region between winding strands. Phosphoric acid forms in this zone. The acid attacks the copper directly and also leads to the formation of a galvanic cell that consumes the copper of the clip. Over time, a crevice or tunnel results with eventual leakage. Since this leak-producing mechanism is built into the stator bars, it is just a matter of time before all coils develop leaks, though the timing and seriousness of the leaks will vary from machine to machine.

There are three basic strategies for handling leaks caused by clip-to-strand corrosion. One is watchful waiting: monitoring the oxygen content of stator cooling water and the rate of hydrogen discharge from the stator water cooling water storage tank. A second strategy is to repair only leaking bars. A third approach is to undertake a global repair of all stator bars during a planned outage, whether the bars are leaking or not. The best approach depends on the importance of the machine, its leaking characteristics, and the economics of continued partial repairs versus global repair.

The report lists the companies that perform repairs to GE generators and describes the approaches to clip repair they employ. Criteria are given for evaluating the four repair methods in use. The report includes sample specifications for partial and global repairs.

Besides providing comprehensive background information on the problem and technical specifications on repair procurement, the report discusses the economics of clip repair. EPRI has developed a computer program called SLEAK that facilitates finding the optimum monitoring or repair options for a specific generator. SLEAK, which runs on a PC, enables users to make

justifiable economic decisions based on user-specific scenarios for generators with confirmed or suspected stator winding leaks. Users can rank the options according to several different own criteria.

EPRI BUSINESS GROUP: Energy Conversion Division

Emergency Diesel Generator Bearing Monitoring Using HFED Techniques TR-107251

DETAILS: Final Report (103 pages)

DATE: Dec. 1996

KEYWORDS: Bearings
Diesel Generator
Maintenance
Predictive Maintenance
Diagnostic Techniques
Vibration

ABSTRACT:

Maintenance for emergency diesels, generators, and related equipment must be performed within plant technical specifications, which limits the time available to perform required maintenance and to return the equipment to service. Predictive diagnostic techniques that monitor changes in operation are desirable to assist timely planning and implementing corrective actions.

High-frequency envelope detection or HFED is a diagnostic tool that can detect the presence of component degradation in high noise signatures. HFED is an advanced diagnostic technique that has been successfully demonstrated to provide meaningful data for generator bearings that can be trended via energy numbers and statistical parameters.

DISCUSSION:

Equipment condition at a nuclear facility had prompted engineers to seek alternative techniques to further evaluate, understand, and possibly trend the condition of their emergency diesel generator. A similar condition existed prior to a bearing replacement eight years earlier and, upon inspection, the bearing showed no evidence of wear. Overhaul of any diesel component affects equipment and plant availability. Removing the diesel from service was not only an availability issue, but also a major work and cost effort. An attempt was made to apply high-frequency envelope detection (HFED) methods to detect and monitor generator bearing conditions.

This document provides a summary of the diagnostic techniques, an application of the techniques, and the testing results. This guide can assist utility personnel in applying a similar technique in their diesel generator predictive maintenance program.

EPRI BUSINESS GROUP: Energy Conversion Division

Diesel Engine Analysis Guide

TR-107135

DETAILS: Final Report (134 pages)

DATE: Sept. 1992

KEYWORDS: Diesel Engines
Diagnostic Techniques
Predictive Maintenance
Maintenance
Monitoring

ABSTRACT:

This guide provides a thorough background on diesel engine analysis including combustion, vibration, and ultrasonic analysis theory. Interpretation of results is also provided. This guide is intended to enable nuclear or any power plant utility personnel to make informed decisions regarding the nature and use of diesel engine analysis, including how to set up an effective program, how to establish analysis guidelines, how to make use of the resulting data to plan maintenance, determine the causes of off-design operating conditions, and warn of potential component failures.

DISCUSSION:

Diesel engine analysis has not seen consistent widespread use in part because utility personnel interested in establishing an engine analysis program have not had a single comprehensive source for technical guidance to establish and evaluate it. At many of the locations where engine analysis has been used, it has been successful in identifying engine problems before these problems progressed to catastrophic failure. For example, engine analysis has successfully identified bent connecting rods, cracked cylinder heads, scuffed cylinder liners, leaking fuel injectors and valves, and collapsed valve lifters. In addition, engine analysis can and has been used successfully to identify problems in diesel engines in other industries such as detonation, cylinder load imbalance, faulty fuel injection, leaking valves and piston rings, worn or scored cylinder liners, worn rocker arms, defective valve lifter worn cams, and damaged wrist pins. Engine analysis techniques were first used to support engine design and development efforts. Diesel engine analysis has been used in the marine, rail, and pipeline industries for many years and has proven cost-effective and successful. It has been used to tune engines, to improve fuel efficiency, to support predictive maintenance methods, to assist with problem diagnosis, and to support longer maintenance intervals.

This guide includes a thorough background on diesel engine combustion, vibration, ultrasonic analysis, theory, interpretation of results, guidance on identifying specific modes of degradation, and examples of specific engine combustion, vibration, and ultrasonic analyses for diesel engines in nuclear standby service. In addition, troubleshooting guidance and a discussion of acceptance guidelines are reviewed. Also, engine analysis programs, equipment costs, equipment selections, and setups are covered.

EPRI BUSINESS GROUP: Energy Conversion Division

10

SUBSTATIONS, TRANSFORMERS & SWITCHGEAR

Guidelines for the Life Extension of Substations TR-105070-R1CD

DETAILS: Final Report

DATE: March 1998

KEYWORDS: Circuit Breakers
Substations
Transformers
Switches
Life Extension
Maintenance

ABSTRACT:

A structured life extension program can help make equipment replacement/refurbishment decisions that ensure safe, reliable, cost-effective operation of transmission substation equipment. These guidelines—now available for the first time on CD-ROM—support current utility practices and industry standards, while forming a basis for establishing a maintenance and condition assessment program. The CD provides an Adobe Acrobat™ version of the original document published in 1995, plus the 1997 addendum in a single file. The 1997 update was developed from utility industry responses to follow-up survey of 500 report recipients. The updated guidelines address transformer oil testing and load tap changer assessment and include revised information on surge arresters.

DISCUSSION:

These comprehensive guidelines, prepared primarily by and for the utility industry, will help establish systematic maintenance and testing practices for evaluating the condition of older substations.

These guidelines incorporate the experience of utility, consulting, and equipment engineers to offer a cross section of utility practices for extending the life of substation equipment. Equipment covered in the guidelines includes power transformers, circuit breakers, switches, relay and control systems, bus and structures, dc systems, grounding systems, surge arresters, control cables, and bushings. The 1997 update to the guidelines provides additional information on transformer oil testing and load tap changer assessment as well as revised information on surge arresters. The guidelines define generic approaches to maintenance of substation equipment and systems, condition assessment of major equipment, and decision making regarding refurbishment

or replacement options. Incorporated in the guidelines are discussions of such areas as the type of maintenance applied to subject equipment, routine maintenance and inspection procedures, common tests performed as a part of a condition assessment program, reasons for tests and use of test results, factors to be considered when deciding on replacement/refurbishment, and costs associated with the process. Pertinent references are provided at the end of each section.

Utility substation maintenance practices are undergoing an evolution in terms of utility treatment of substation electrical equipment. The driving force in the rapidly changing area is economics. While the utility industry comprises many companies, widely diverse in size and geographic location, certain issues are common to all utilities. Utility maintenance practices have typically centered on maintaining equipment to achieve the highest reliability. This method led to maintenance on a periodic basis regardless of the type of equipment or its previous test results. While effective, this approach required a large amount of resources. Further, as equipment aged, the maintenance required to achieve the same level of reliability increased. Utilities companies—now operating with reduced resources in a competitive marketplace—are searching for new strategies to meet their reliability goals, including condition assessment and reliability-centered maintenance. These guidelines represent the outcome of EPRI’s search for new strategies, and are specifically designed to help proactively reevaluate current practices in the context of plant-specific situations.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Proceedings: Substation Equipment Diagnostics Conference V11 TR-113481

DETAILS: Proceedings (440 pages)

DATE: Aug. 1999

KEYWORDS: Circuit Breakers
Data Transmission
Substations
Transformers
Underground Transmission
Diagnostic Techniques

ABSTRACT:

Advanced diagnostic sensors and systems are needed to provide reliable and accurate information for determining the condition of major transmission substation equipment. The seventh EPRI Substation Equipment Diagnostics Conference highlighted the work of researchers, universities, manufacturers, and utilities companies in producing advanced diagnostic equipment for substations.

DISCUSSION:

Utilities companies must continue to provide equal or better electric power service to their customers even as they continue to reduce their maintenance and operations staffs. To ensure reliable operation, the performance of major equipment in substations—including transformers, circuit breakers, relays, disconnect switches, batteries, insulators, and control equipment—must be accurately and reliably monitored. The seventh EPRI conference on substation equipment diagnostics provided follow-up information to the previous conference in this rapidly developing field.

The Conference covered the following areas:

- Additional power transformer monitoring needs, continuous fault gas monitors, load tap changer monitoring and contact wear, expert systems, research and field assessment of moisture in insulation, field experience with transformer monitoring systems, assessment of transformer insulation condition and transformer modeling.
- Retrofitting monitoring equipment to an existing circuit breaker, condition monitoring systems for high voltage current transformers, detecting SF₆ leaks, managing equipment availability, and predictive maintenance programs.
- Applications of communications, data management, and integration of monitoring and diagnostics systems for substation equipment.

In addition to the 25 technical papers, the Opening Session of the conference focused on industry trends, a marketing view of substation diagnostics, and utility industry programs in progress for substation diagnostics.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Workshop Proceedings: Advanced Diagnostics for Substation Equipment TR-102450

DETAILS: Proceedings (212 pages)

DATE: May 1993

KEYWORDS: Rellays
Test Equipment
Substations

ABSTRACT:

Utility companies require additional information on the condition and operational capability of substation electrical equipment in order to provide needed power quality while reducing maintenance and operations costs. This workshop reported ongoing work by utilities companies, manufacturers, and research entities on advanced diagnostics, and it made suggestions for additional EPRI-sponsored research.

DISCUSSION:

Substation equipment in utility plants throughout the world is being used beyond its originally designed life. As companies downsize their operational and maintenance personnel, they must concurrently continue to provide or improve the quality of electric power service to their customers. Because substations are a vital link in power supply, constant diagnosis of the condition and reliability of the installed electrical equipment is now required.

Workshop objectives were:

- To review ongoing work by utilities companies, manufacturers, and research entities in substation electrical equipment diagnostics.
- To identify the need and direction for EPRI-sponsored research to satisfy urgent utility diagnostic requirements.

EPRI-member utility engineers, technical representatives from manufacturers, consultants, and research engineers and scientists from universities and laboratories participated in a workshop held November 9-11, 1992, in Palo Alto. Three working groups focused on particular items of substation equipment and reported their conclusions and recommendations to the reconvened general body. Workshop participants discussed the recommendations and conclusions of the working groups and agreed upon final recommendations for EPRI research.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Reliability Centered Maintenance (RCM) Technical Reference for Substations

TR-106418

DETAILS: Final Report (260 pages)

DATE: Jan. 1996

KEYWORDS: Reliability Centered Maintenance
Substations
Reliability
Maintenance
Preventive Maintenance

ABSTRACT:

The overall goal of reliability centered maintenance is to improve utility industry economic posture by promoting cost-effective application of maintenance resources. EPRI's Reliability Centered Maintenance (RCM) Technical Reference for Substations provides essential technical data and guidance for conducting substation RCM studies. The technical reference is also available in a software package for use as a desktop resource.

DISCUSSION:

Preventive maintenance is the single largest controllable cost of a utility operation. Careful planning and good management are essential to achieve an optimal balance between the cost of maintenance and reliable service. Traditional maintenance programs rely on time-based actions and manufacturer recommendations to preserve equipment operation. RCM addresses the problems of traditional maintenance programs by focusing resources on the preservation of overall system function as opposed to individual equipment operation. RCM also promotes the use of more efficient monitoring tasks and recognizes that some failures can be more cost-effectively handled through corrective maintenance. This tailored collaboration project, cosponsored with seven member utility companies, focused on adapting EPRI's power plant RCM methods, tools, and resources to the needs of substation maintenance.

This RCM technical reference presents a set of resources that can be used to optimize the balance between preventive maintenance costs and service reliability. The early sections of the document provide systems evaluation references and insights, while maintenance task selection advice and guidance on implementation is included in the later chapters. Detailed discussions of technical approaches, helpful suggestions, and lessons learned are supplemented by figures and tables, where appropriate. To help the RCM evaluator obtain data and insights quickly, the reference incorporates extensive data tables and flow diagrams. Also included are frequently used terms along with an overview of technologies often applied in a substation maintenance program. Finally, each section features a convenient summary and review section.

Two software products—the RCM Technical Reference for Substations and the RCM Workstation for Substations—are available from the Electric Power Software Center. Both products require an IBM-PC compatible 486/50 system with 8 MB of RAM, an 80 MB hard

drive, and Windows 3.1. The RCM Technical Reference for Substations provides a desktop reference for conducting preventive maintenance optimization studies using RCM methods. The RCM Workstation for Substations offers an organizational and documentation tool for completing the RCM studies.

This technical reference has been developed in response to industry needs for guidance in performing substation RCM evaluations. A trial application of the RCM methods described reduced maintenance costs by 8-40%, depending on the system studied and the current state of the maintenance program. Related EPRI products currently under development include an RCM technical reference and companion software tools for transmission and distribution areas. In addition, to provide a tool for a comprehensive maintenance program and a living RCM program, EPRI is developing the Maintenance Management Workstation (MMW), an integrated system that will incorporate RCM, preventive maintenance, utility databases, analytical tools, and standard maintenance functions.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Lessons Learned From Substation Predictive Maintenance Project TC Project #7014 TR-111594

DETAILS: Final Report (118 pages)

DATE: Dec. 1998

KEYWORDS: Availability
Maintenance
Reliability
Substations
Predictive Maintenance

ABSTRACT:

A tailored collaboration (TC) conducted between 1993 and 1998 by EPRI and ten participating utility companies was aimed at optimizing substation performance through predictive maintenance. This report summarizes the lessons learned from the project; a more comprehensive report will be published after further research.

DISCUSSION:

This project developed and implemented an effective predictive maintenance strategy for substation/switchyard equipment. Existing and new technology applications were evaluated and adapted for condition monitoring of energized substation equipment. The Substation Predictive Maintenance (SPDM) process was effective in reducing O&M/capital costs, increasing equipment availability/reliability, and moving the culture of participating organizations to a more proactive approach. All participating organizations are currently using the specific survey methods, procedures, and processes developed in the project. Benefits in avoided costs for the project years are conservatively estimated at \$15 million. Other cost benefits, though not documented in the report, include savings from the reduction or elimination of PM tasks, enhanced equipment reliability, availability improvements, and a longer job-planning horizon. Several findings with industry-wide implications emerged from the project: a safe way to eliminate time based maintenance for high voltage transformer load tap changers, the identification of a novel problem with oil contamination from sample ports, and important insights into the preventive maintenance of generator step up transformers.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Performance-Based Monitoring and Control of Transformers

TR-108406

DETAILS: Final Report (220 pages)

DATE: Sept. 1997

KEYWORDS: Power System Control
Transformers
Reliability Centered Maintenance
Monitoring
Substations

ABSTRACT:

Catastrophic failures of large power transformers pose costly problems in potential repair or replacement costs, environmental hazards, and unscheduled power outages. This report documents R&D efforts to develop a transformer monitoring system capable of detecting incipient problems.

DISCUSSION:

Any catastrophic transformer failure can profoundly effect the power system, causing potentially widespread power outages. Beyond the obvious costs of unscheduled outages and those related to transformer repair or replacement, such transformer failures can present significant environmental hazards. With many transformers encased in tanks of substances deemed hazardous, failures can result in spills or fires of transformer fluids that may require costly cleanup. Through continuous monitoring, utility companies can assess transformer condition to minimize such failures and enhance transformer operations. Adaptive models that use existing monitoring data may offer additional predictive capabilities to detect transformer problems.

This report documents the development and testing of two adaptive transformer models. It describes the basic concepts behind an advanced diagnostic monitoring system, including the structure of the data analysis and methods for developing such a system. Specifically addressed are the difficulties associated with managing large amounts of data and the successful division of operational space into bins for data storage. The report also discusses sensor anomalies and operational recommendations.

In addition to model development and testing, the report provides an in-depth analysis of a failed transformer. This analysis showed that if the techniques developed had been applied, reasonable alarm levels would have been reached about eight days before failure, and severe damage to the equipment and the environment could have been averted. Finally, the report offers recommendations for further R&D efforts on transformer monitoring systems. These include development of an intelligent monitor capable of filtering “flags” that signal anomalous situations, incorporation of advanced modeling and sensor technology into the monitoring system, and additional testing of the two adaptive transformer models.

Intelligent monitoring systems capable of predicting events in transformer life cycles will enable users to identify incipient problems, thereby minimizing maintenance costs and avoiding costly failures. Such monitoring systems will also provide knowledge of actual transformer operation to permit the extra capability designed into the equipment to be used when necessary.

In related EPRI efforts, two coordinated transformer expert system projects are designed to capture the knowledge of leading power transformer authorities for use in transformer operation and maintenance. XVISOR will help diagnose problems involving specific vintage and manufacture transformers, while DESREV will assist in performing design reviews.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Acoustic Intensity Measurement of Transformers TR-100300

DETAILS: Final Report (76 pages)

DATE: Feb. 1992

KEYWORDS: Diagnostic Techniques
Transformers
Transformer noise
Acoustic intensity

ABSTRACT:

Acoustic intensity can be used to determine basic transformer noise levels in the presence of background noise and reverberation conditions. Laboratory and field measurements support use of acoustic intensity in the power distribution industry for quantifying transformer noise both on the factory floor and in the field.

DISCUSSION:

Measurement of transformer noise output normally requires that a transformer be placed in a special anechoic room. Usually such a test room is available only at the transformer factory where standard noise tests are routinely performed. Even with a special sound room, there is an additional production cost associated with noise testing of a transformer in a quiet room. Further, standard noise measurements are made while the transformer is energized but not loaded. (Load conditions are not duplicated in the factory for reasons of practicality). Thus, when operating under load in a substation, some types of transformers may have noise characteristics that are radically different from the noise characteristics experienced during the unload state in the factory. For such transformers, sound power measurements—even though performed in the factory sound room—will not reflect the true sound power of the transformer when it is finally placed into service.

Successful acoustic intensity measurements of transformer noise were made at a substation where the ambient background noise was 60.0 dBa. Under fan/air (FA) operating conditions, the measured noise level was 62.0 dBa; under oil/air (OA) operating conditions, the measured noise level was 49.0 dBa. OA denotes oil/air-convective cooling, while FA denotes forced-air cooling. Measurement of the same transformer at the factory in an ambient noise level of 73.0 dBa was also possible for the FA condition. However, the OA condition of 49.0 dBa was too low to be measured with the factory background noise of 73.0 dBa.

Two series of factory sound measurements used the acoustic intensity method to verify theoretical limitations. Results of a blind test show that acoustic intensity can accurately measure sound levels as low as 53.7 dBa in the presence of 68.7 dBa ambient noise on the factory floor. (This test used a 75-mm [3-in] microphone spacing, effectively bounding the OA transformer noise spectrum by 1.0 kHz.) The overall finding corroborates other laboratory experiments that allow a 15.0 dB reactivity index under these conditions.

Measurements of in situ sound power assist both power transformer manufacturers and users. The manufacturer benefits through reduced test costs because the transformer should not have to be removed into a special anechoic test facility. Further, the manufacturer is able to test the unit once it is installed and actually operating under a true load condition. Users benefit because a noisy or defective transformer can be identified in the field. Thus, engineers can verify the sound rating of a delivered transformer before it is fully accepted. Users can also use acoustic intensity to identify other noise sources on their systems.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Proceedings: Maintenance-Free Load Tap Changing (LTC) TR-108398

DETAILS: Proceedings (125 pages)

DATE: Jan. 1997

KEYWORDS: Transformers
Reliability
Maintenance
Life Extension
Substations

ABSTRACT:

Misoperation of Load Tap Changing (LTC) equipment is a major cause of power transformer failures and high maintenance costs. Substantial cost reductions are achievable through avoidance of very expensive winding failures and outages caused by LTC misoperation, and through improved components, intelligent monitoring, and maintenance intervals based on real need.

DISCUSSION:

Some transmission autotransformers and most step-down power transformers in the United States are equipped with LTC equipment to adjust winding voltage ratios in discrete steps while carrying load. Outside the United States, generator step-up (GSU) transformers often include on-load tap changing. Ratio changes can compensate for voltage regulation on source side and/or load side of the transformer caused by loading. Changing winding taps under load with conventional LTC equipment involves current interruption, arc by-products, and contact wear requiring routine maintenance and replacement. Vacuum switches, used in some LTC equipment, can reduce contact maintenance. Electronic switching that avoids moving parts and wear is available; however, cost restricts current usage to very special LTC applications.

Two earlier studies investigated load tap changing in the late 1980s. The first, reported in EL-6079, showed that major breakthroughs would be required before LTC equipment using solid-state devices could become economically feasible for ordinary power transformers. The second, reported in EL-6764, confirmed the need to improve reliability and reduce maintenance needs for conventional tap changers; however, lack of adequate performance specification and test procedures for reactance-switching type tap changers commonly used in the United States was a fundamental problem. Today, C57.131, Standard Requirements for Load Tap Changers, established by the IEEE Transformers Committee, fills that void for new transformers. However, ways to improve performance and reduce maintenance for the large population of existing tap changers remains an important need and the subject of EPRI-sponsored work.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Power Transformer Tank Rupture: Risk Assessment and Mitigation TR-104994

DETAILS: Final Report (137 pages)

DATE: April 1995

KEYWORDS: Substations
Transformers
Risk Assessment
Maintenance
Transformer Faults

ABSTRACT:

Catastrophic failure of oil-filled power transformer tanks can result from an internal fault, particularly a flashover electrically near the line end of the high-voltage winding. Internal pressures developed may be impossible to contain given conventional tank construction and may result in fire, danger to personnel, and extensive environmental and equipment damage. This report investigates the rupture characteristics of power transformer tanks and provides recommendations and guidelines for the mitigation of such ruptures.

DISCUSSION:

When dielectric breakdowns occur in oil-filled transformer tanks, the resulting high-temperature electrical arcs vaporize the transformer oil and decompose the vapor into gas. This forms a rapidly growing gas bubble that displaces the oil in the tank and can produce mechanical failure. Since the oil is nearly incompressible, the displacement of oil from the fault area must be accommodated by tank expansion, gas blanket compression, or flow to another compartment. In many units, tank expansion is the only means of accommodating rapidly expanding gas. Earlier U.S. studies were confined to the catastrophic failure of distribution transformers. This study expands research to include power transformer tanks.

Research revealed that:

- Tank rupture commonly occurs with arcing times not exceeding 4.5 cycles.
- The model provides a quantitative description of the tank rupture process, with results which are consistent with case history data.
- Fault energy capacity of a tank can be significantly enhanced by increasing tank flexibility. Innovative concepts include use of beams that buckle at a prescribed load, a larger number of smaller beams, and cut beams that support vacuum but not pressure. The pressure at which tanks rupture can be increased by local strengthening of weak points such as the cover-to-wall joint weld. Other structural weaknesses can be accommodated by using a gusset to distribute the local load.
- Pressure relief devices or venting into auxiliary compartments is ineffective for severe faults. Extensive tank modifications would be needed to prevent rupture of tanks subjected to high-energy faults.

Occasional explosions of oil-filled transformers have been a fact of life over the years, ranging from small distribution transformers to very large power transformers. Due to reliability, safety, and environmental concerns, users increasingly need to consider tank rupture withstand capability in specifications for some power transformer locations. However, information has been lacking as to the characteristics and parameters associated with severe internal power transformer faults, the capabilities of various tank and compartment designs to withstand such faults, and the degree of improvements attainable at reasonable cost. This project resulted in significant information in these areas along with design tools for evaluating the capacity of transformer tanks to withstand severe internal faults.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Power Transformer Oil Leak Mitigation – Technology Assessment TR-111593

DETAILS: Final Report (144 pages)

DATE: Dec. 1998

KEYWORDS: Maintenance
Substations
Transformers
Welding
Transformer Leaks

ABSTRACT:

With proper care power transformers can provide reliable service well beyond their design life, but transformer leaks become more and more likely as equipment ages and create serious and expensive technical problems. This report evaluates current and developing technologies for sealing leaking transformers including box welding and a variety of commercial sealants and specially formulated high-performance gasket materials.

DISCUSSION:

Transformer leaks present a complex technical challenge. Originating from gas relay piping, packing on valves, CT pockets, tap changers, radiators, and main tank covers, leaks have many causes. Repairing them is difficult and often costly. The sealing systems and gasketing materials used to seal such leaks have to function in the hostile environment of a working transformer where they will be subjected to vibrations, fluctuating temperature, thermal aging, and ultraviolet light. In-situ repair without drainage of dielectric fluids is desirable from a cost and time standpoint, but any repair will be under difficult conditions on oily surfaces and in tight spaces. Research and development on new materials and procedures for transformer leak repair must take these extreme conditions into account.

The project had three distinct parts: (1) Investigation of new and old welding technologies with and without removal of oil, (2) evaluation of available gasket materials, and (3) evaluation of available sealants. The project team defined a recommended process for field weld repair and made suggestions on ways in which welding techniques could be improved. The team evaluated eighteen gasket materials and nine sealants from major suppliers. All tested sealants were chosen to be removable for future repair work. The team performed simulation tests on the sealants in a transformer mock-up, subjecting them to screening tests measuring their tensile and adhesive strength on oil-coated painted surfaces. Tests were performed on both newly applied sealants and sealants aged to a life equivalent of 20-30 years. The team did not evaluate the costs of tested materials because material costs may vary widely and are generally negligible compared with the cost of outage time, labor, and future repairs.

Flux Cored Arc Welding (FCAW) in either the semi-automatic or mechanized mode is the recommended process for field weld repair. A free standing document included in this report,

Guidelines for Repair Welding Transformer Components Using the Shielded Metal Arc Welding and Flux Cored Arc Welding Processes, provides a compilation of the best welding procedures.

Tests of gasket materials identified four materials that showed superior performance by retaining their original properties, including tensile strength and flexibility, after aging in air and oil. Four sealants, two based on silicones and two based on polysulfides, displayed superior strength, flexibility, and adhesive, and aging properties. Oil compatibility tests showed that the four primary sealants had no adverse effect on transformer oil performance. Simulated testing demonstrated that three of the selected sealants could effectively seal a flange leak and that a fourth was also effective when used in conjunction with a hybrid cover coat.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

PCB Disposal Manual CS-4098

DETAILS: Final Report (404 pages)

DATE: Jan. 1985

KEYWORDS: PCB
Insulating Oil
Transformers
Waste Management
Waste Disposal
Thermal Degradations

ABSTRACT:

The technology for controlling polychlorinated biphenyls (PCBs) in utility transformers and capacitors has changed significantly in recent years, as have the regulations governing disposal methods. This revision of a 1979 PCB disposal manual updates information on disposal and treatment options and offers guidance on developing a PCB management program.

DISCUSSION:

The first edition of EPRI's PCB disposal manual (FP-1207, Volume 1) presented guidelines for evaluating alternative disposal methods for wastes containing PCBs. Since publication of that document, regulations have changed dramatically and many new disposal processes have been put on the market.

This document updates EPRI's PCB disposal manual and provides a summary of current regulations and options for PCB disposal as follows:

- **Technology.** The updated manual emphasizes technologies that have undergone rapid development since 1979. It contains examples of thermal destruction processes including liquid injection incineration, solids incineration, and molten salt destruction. It also discusses chemical destruction technologies and the need for a repository for PCB-contaminated materials.
- **Regulations.** The manual discusses current regulatory issues such as technical definitions; use and servicing restrictions; inspection, labeling, sampling, and testing requirements; transportation, storage, and disposal regulations; and record-keeping requirements.
- **Inventory.** Estimates suggest that utility transformers and capacitors account for half the PCBs used in electrical equipment since 1930. Using electricity sales data for the 10 EPA regions, the project team developed regional estimates of PCB distribution.
- **PCB management.** Reflecting the increased sophistication of PCB management, the manual presents strategies in spill response, storage, transportation and disposal.

This manual describes PCB disposal equipment and technologies in sufficient detail to be a valuable tool for users contemplating disposal alternatives. Consolidating this information into

one document was part of a wide-ranging EPRI study on the disposal of PCBs and PCB-contaminated materials. In other phases of the work, researchers have developed portable field instruments and portable field-testing kits for monitoring PCB spills. A soil decontamination system is being developed and preliminary analyses described in EPRI report CS-3807 assess the use of biotechnologies to solve PCB problems. EPRI report CS-4094 describes vault modifications as a risk reduction option.

EPRI BUSINESS GROUP: Environment Division

Case Study Evaluation of PCB Fires GS-6870

DETAILS: Final Report (124 pages)

DATE: May 1990

KEYWORDS: PCB
Dialectric Materials
Waste Management
Waste Disposal
Transformers
Fires

ABSTRACT:

Polychlorinated biphenyl (PCB) equipment fires can result in long-term closure of buildings and multimillion-dollar cleanups. This study, a documentation of two major PCB fires in the United States, can prove useful to users planning their response to similar incidents.

DISCUSSION:

Two significant PCB fires occurred in the United States; one at state offices in Binghamton, New York, and the other at a commercial building at One Market Plaza in San Francisco. Both fires began in basement transformer vaults and dispersed PCB contamination through ventilation systems, and each resulted in cleanup costs exceeding \$20 million. Yet the building in San Francisco reopened quickly, whereas the Binghamton building remained closed.

Objectives of this report were (1) to document two PCB transformer fires and the subsequent decontamination efforts and, (2) to analyze the similarities and differences between the two incidents and summarize the lessons learned.

Both city fire departments responded quickly and extinguished the fires. Local agencies assessed the extent of contamination and developed a cleanup strategy. At Binghamton, initial cleanup focused only on the immediate vicinity, and cleanup of the remainder of the building did not begin until after time-consuming sampling and analysis confirmed the presence of PCBs. Planners in San Francisco benefited from the Binghamton experience, determining the extent of contamination without delay and immediately initiating the cleanup effort. The private sector managed and funded the San Francisco operation, and an oversight committee managed the government-funded Binghamton cleanup. One Market Plaza reopened within 10 months, yet the state office building remains closed nine years after the fire.

The Binghamton and San Francisco PCB fires, although similar in magnitude and nature, differ dramatically in their final resolution. Cleanup planning after the San Francisco fire benefited greatly from the Binghamton experience. Binghamton required extensive methodology research to determine the extent and impact of contamination, but the San Francisco cleanup effort resembled a routine emergency response. Users can benefit from these experiences, anticipating planning needs and appropriate responses to future incidents.

EPRI BUSINESS GROUP: Environmental Division

**Proceedings: 1991 EPRI PCB Seminar
TR-100593**

DETAILS: Proceedings (348 pages)

DATE: May 1993

KEYWORDS: PCB
Fires
Transformers
Insulating Oils
Waste Management
Waste Disposal

ABSTRACT:

Representatives of electric and gas utilities, government agencies, research groups, and private industry from around the world met at this 1991 seminar to discuss and study numerous issues related to PCB. The seminar provided the industry with an important forum for the exchange of information concerning PCB management, disposal, replacement, and regulations.

DISCUSSION:

PCB had been used in transformers as the insulating medium because of its non-inflammability. However, several years ago it was declared toxic. Because of this, PCB management continues to be of prime concern to the utility industry, government agencies, and others. In response, EPRI has sponsored biennial international seminars to provide the industry with information on current PCB regulations, research, and management. This was the sixth in the EPRI series and the first held in cooperation with the Gas Research Institute.

The PCB seminar, held in Baltimore October 8-11, 1991, was attended by 270 representatives of the utility industry, government, research groups, and private industry from around the world. Fifty-six papers, presented in 12 sessions, addressed regulations, spills, carcass disposal, retrofill and reclassification, risk, fires, analysis, problems specific to gas utilities, health effects, decontamination of oil, PCB destruction, and substitute fluids. Papers focused on research, training, commercial projects, and case studies involving new equipment and techniques for PCB management.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Removal of PCBs From Transformer Oils of Petroleum Origin TR-100063

DETAILS: Final Report (128 pages)

DATE: Jan. 1992

KEYWORDS: PCB
Insulating Oils
Transformers
Substations
Maintenance

ABSTRACT:

Electrical insulating mineral oils in a number of transformers contain measurable amount of polychlorinated biphenyls (PCBs). An EPRI project investigated four possible approaches for removing PCBs from contaminated mineral oil. Overall, the investigation singled out one process for scale-up and demonstrated that PCBs can be removed from transformer oil by a wide range of processes, resulting in oils suitable for reuse.

DISCUSSION:

As a result of cross-contamination that occurred during an era when PCB was accepted as a transformer insulation fluid, many mineral oil transformers contain measurable amounts of PCBs. PCB content must be reduced to allow reuse of the oil, conserve resources, and simplify ultimate PCB disposal. A successful process should efficiently and reliably eliminate PCBs. In addition, the processed oil should be suitable for continued use as a dielectric fluid and should not present an unusual problem to the environment. The goal of the project reported here was to develop such a process.

Objectives of this report were (1) to evaluate processes for removal of PCBs from mineral insulating oil and, subsequently, select one process for scale-up and, (2) to test treated oil for continued use in transformers.

Following a series of laboratory trials, a suitable solvent, methyl Carbitol™, was chosen and tested in a scaled-up pilot plant. The selection and scale-up are described in this report. Results were satisfactory, and under suitable operating conditions, PCB content was reduced to below 2 ppm. Estimated costs indicated that this process was worth pursuing in a full-scale plant. Consequently, an EPRI member utility company contracted to have a full-scale 500,000 gal/yr plant built. This plant treated more than 100,000 gal of oil satisfactorily under experimental EPA permits. The design and experimental operation of this plant will be reported under EPRI project RP2028-14. The utility, however, decided to abandon the process; and no further work was conducted on this project.

The scale-up project using the liquid-liquid extraction process for PCB removal from transformer oil appeared technically and economically feasible. The process established was well researched, and the economics of the scaled-up production line were sound. However, those responsible for

equipment at the host utility were reluctant to refill transformers with recovered oil because of the possibility that it contained trace amounts of solvent and a very low level (2 ppm) of PCB. Additionally, shortly after installation of the recovery process, a local contractor offered chemical destruction of PCB in the contaminated oil at a lower cost than could be provided by the solvent extraction plant. The process was abandoned for these reasons. Work under this project was initiated during the early to mid-1980s, a time when treatment processes for PCB-contaminated oil were in their early stages. Although a continuing commercial process did not result, the project served to stimulate commercial interest and was beneficial for companies requiring removal of PCB from contaminated oil. Results of other EPRI PCB research may be found in EPRI Technical Brief #109, EPRI Published Information on PCBs (Revised), which lists the published reports.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Polychlorinated Biphenyl Substitutes in Electric Utility Equipment TR-102160

DETAILS: Interim Report (104 pages)

DATE: March 1993

KEYWORDS: PCB
Insulating Oils
Transformers
Capacitors
Substations

ABSTRACT:

As a result of use prohibitions under the Toxic Substances Control Act, dielectric fluids containing polychlorinated biphenyls are being replaced by a number of different fluids. This report presents information on the types of substitute dielectric fluids in use by electric utilities. The report includes limited compositional information from manufacturer-supplied material-safety data sheets.

DISCUSSION:

The principal source of information relating to compositional, physical, and chemical characteristics of equipment dielectric fluids is the manufacturer-supplied material-safety data sheet (MSDS). However, measurements of constituents in a dielectric fluid are limited to those with concentrations above 0.1% (1000 ppm) in the final product. The absence of data on the chemical contents below 1000 ppm leaves the electric utility industry with knowledge gaps on how to deal with spills and environmental releases of the new fluids. This survey represents the first step in developing information to fill that need.

Twenty electric utility companies supplied information for this study, with 15 describing the types of substitute dielectric fluids used. Mineral and silicone oils were mentioned most frequently as substitutes for PCB-containing dielectric fluids. Silicone oil, in particular, was used in network and building transformers where fire might be of concern. Other substitute dielectric fluids identified were R-TempR—a mixture of hydrocarbons and additives, isopropyl biphenyl, and perchloroethylene, MSDSs, obtained from several electric utilities and equipment manufacturers, provided compositional information, albeit limited, as a result of the 1000-ppm constituent reporting cutoff.

The results of this study provide specific information about the types of PCB substitute dielectric fluids in use by electric utilities. The study's outcome, however, indicates the need for additional work to more completely characterize the composition of these substitute fluids, which should not present the same environmental or health threat as posed by PCBs if accidentally released into the environment. EPRI is planning further research to characterize the composition of substitute dielectric fluids and to develop information on their transport and fate in the environment. The following related EPRI reports may be of interest to the reader. "Toxicity Profiles of PCB Substitutes" (report EA-33567), "Moses Code Version 1.0: An IBM PC Code

for Predicting the Transport and Fate of Mineral Oil Spills” (report EN-7188), “Chemical Spill Exposure Assessment Methodology (POSSM) “ (report EA-5572)”, and “Maintenance and Handling of Perchloroethylene-filled Electrical Equipment” (report EL-4407).

EPRI BUSINESS GROUP: Environment Division

Removal of PCBs From Oils by Solvent Extraction TR-101979

DETAILS: Final Report (48 pages)

DATE: May 1993

KEYWORDS: PCB
Insulating Oils
Transformers
Substations

ABSTRACT:

A commercial-size solvent extraction plant, designed and built following successful laboratory and pilot plant work, satisfactorily removed PCBs from contaminated transformer mineral oil. Due to changing needs and economic factors, however, the host utility company abandoned the plant.

DISCUSSION:

In an earlier project, solvent extraction was selected as a potentially competitive process for the removal of PCBs from contaminated transformer mineral oil (EPRI report TR-100063). The commercial process reported here followed a successful 10-gal/h pilot plant scale-up of the laboratory extraction process. At the start of the original experimental work, removal of PCBs from contaminated oil had a high profile because of the large quantities needing treatment and the unknowns in the treatment processes then in use. Subsequently, existing commercial processes developed firmer foundations; and the need for a new process became less pressing and less economically advantageous.

Following corrections of the initial design, the pilot plant for solvent extraction of PCBs from contaminated mineral oil was redesigned and successfully met the new design criteria by producing 120 gal/h of decontaminated oil with no more than 2 ppm of PCB. The redesign was necessary for two reasons: the contamination of the treated plant oil with mineral oil aging products was not anticipated in the pilot plant or the initial design of the equipment; and EPA decided on a 2-ppm PCB maximum for treated oil. Successful operating time of the redesigned plant was limited by the length of EPA temporary permits. At that point, the host utility, Georgia Power, decided not to proceed with the commercial process; and no further work was done.

The solvent extraction process was innovative and highly successful. At the start of the research, it appeared to have much promise. However, the need for accumulation and treatment of large volumes of contaminated oil at one location decreased over the relatively long period required to secure initial laboratory permits, conduct laboratory research, and design and build a pilot and operating plant. Meanwhile, other competitive commercial processes continued to develop. In the end, Georgia Power decided to go with one of the existing commercial processes and abandoned the solvent extraction plant after successful startup and temporary operation. Since no other opportunities arose to treat contaminated oil in the large volumes necessary for the

economic operation of the solvent extraction process, EPRI conducted no additional work on the process.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Ex Situ Bioremediation of Mineral Oil in Soils: Aerated Pile Treatment TR-108562

DETAILS: Final Report (88 pages)

DATE: April 1998

KEYWORDS: Mineral Oil
Insulating Oils
Transformer Insulation
Contamination
Decontamination

ABSTRACT:

Mineral oil dielectric fluid (MODF) has replaced PCB oil as the insulating medium in electrical transformers. Although eliminating PCBs has reduced the environmental impact resulting from transformer leaks, soil contaminated with mineral oil still often requires remediation. This study evaluated the feasibility of ex situ biotreatment by aerated pile treatment for Southern Company Services/Georgia Power. Results indicate that aerated piles can reduce mineral oil concentrations by 23-67% in one month. Simple aeration to stimulate biodegradation was the most effective method evaluated.

DISCUSSION:

Because the environmental impact of MODF spills into soil is not well understood, states regulate this fluid similarly to petroleum fuel oil for cleanup purposes. This has led to costly remedial efforts, with excavating contaminated media and disposing it in landfills. However, landfills are becoming increasingly regulated, and their use leaves future liability issues unresolved. Southern Company Services/Georgia Power and EPRI sought to explore the effectiveness of ex situ treatment technologies involving aerated piles to decontaminate soil for on-site reuse. This report is a companion to EPRI's TR-108561 describing treatment of MDOF using ex situ treatment technologies of land farming and composting.

The aerated soil pile demonstration revealed the following:

- Total mineral oil concentration declined by statistically significant levels in four of six treatments. Most degradation occurred within the first month, with very little degradation occurring in the succeeding three months of the study. Only pH-treated soils continued to show declining trends by the end of the experiment.
- The aromatic fraction of the mineral oil was more susceptible to biodegradation than the aliphatic fraction. In fact, the biodegradation process preferentially attacked lower molecular weight mineral oil constituents likely to be the most hazardous, most soluble, and most mobile in the environment.
- Mineral oil biodegradation is possible, but limits exist regarding the ultimate level of remediation that can realistically be achieved.

The issue of whether the decline in mineral oil levels experienced in this study could have been associated with dilution, rather than biodegradation, remains unclear. Field-scale demonstrations were not pursued because of the likelihood that regulatory levels would not have been met over reasonable time frames. However, this effort suggested other avenues of research that resulted in a major project in the Pacific Northwest, documented in EPRI's Insulating Oil Characteristics report TR-106898, Vols. 1-2) which describes the characteristics and environmental performance of mineral oils. Further, EPRI research addresses In Situ Treatability of Mineral Oil in Soils (TR-108560) and Ex Situ Bioremediation of Mineral Oil in Soils: Land Treatment and Composting (TR-108561). Taken together, these studies provide convincing justification for risk-based decision making for cleanup of mineral-oil-contaminated soil.

Treatment standards should be determined based on the risk of exposure or toxicity to humans, animals, and plants. Thus, the standard for acceptable treatment may vary depending on the location of a spill event. The results from this study demonstrate that even several thousand mg/kg of mineral oil in soils is not toxic to sensitive indicator organisms. If mineral oil remediation is regulated based on risk reduction and lack of environmental impact, bioremediation can be an extremely effective and efficient treatment technology. As a result of the collective body of research now available, several state regulatory agencies are considering order of magnitude increases in regulatory levels for amounts of spilled mineral oil permissible in soils.

EPRI BUSINESS GROUP: Environment Division

In Situ Treatability of Mineral Oil in Soils

TR-108560

DETAILS: Final Report (250 pages)

DATE: June 1998

KEYWORDS: Mineral Oils
Transformer Insulation
Contamination
Biodegradation

ABSTRACT:

Mineral oil dielectric fluid (MODF) has replaced PCB oil as the insulating medium in electrical transformers. Although eliminating PCBs has reduced the environmental impact resulting from transformer leaks, soil contaminated with mineral oil still often requires remediation. This project presents the results of laboratory application of seven biological treatment regimes to soil contaminated with mineral oil. The results demonstrate the expected extent of mineral oil biodegradation, change in chemical composition of the mineral oil, rate of biodegradation, and key engineering requirements associated with the process.

DISCUSSION:

Because the environmental impact of MODF spills into soil is not well understood, states regulate this fluid similarly to petroleum fuel for cleanup purposes. Such regulation has led to costly remedial efforts, with utilities excavating contaminated media and disposing it in landfills. However, with landfills becoming increasingly regulated and possible liability issues unresolved, the New England Electric System (NEES) and EPRI sought to explore the effectiveness of in situ treatment technologies.

MODF total petroleum hydrocarbon (TPH) levels dropped by more than 50%, from 8000 mg/kg (ppm) to about 4000 mg/kg during six months of incubation, ending at 3400 mg/kg after eight months. The most effective treatments included biostimulation (addition of nutrients) or AOP chemical co-treatment followed by treatment with indigenous bacteria. Achieving TPH reductions in soil to target levels of 500 mg/kg may only be possible, if at all, after prolonged treatment periods. This is due to MODF sorption on soil particles and solubility, limited bioavailability to microorganisms for degradation, and chemical constituent recalcitrance. As a result, NEES and EPRI investigated alternative cleanup criteria based on health risk assessments. Risk calculations using the Massachusetts Department of Environmental Protection equations showed that a target level of 4800 mg/kg would be protective of human health and the environment.

The issue of whether the decline in mineral oil levels experienced in these studies could have been associated with dilution, rather than biodegradation, remains unclear. However, this project was one of the earliest to successfully argue for the application of risk-based standards for decisions on remediation of MDOF. Related EPRI research in this area includes the Insulating Oil Characteristics report (TR-06898, Vols. 1-2), Ex Situ Bioremediation of Mineral Oil in Soils:

Aerated Pile Treatment (TR-108562), and Ex Situ Bioremediation of Mineral Oil in Soils: Land Treatment and Composting (TR-108561). Taken together, these studies provide convincing justification for risk-based decision making for cleanup of mineral-oil-contaminated soil.

Treatment standards should be determined based on the risk of exposure or toxicity to humans, animals, and plants. Thus, the standard for acceptable treatment may vary depending on the location of a spill event. Results from this study demonstrate that even several thousand mg/kg of mineral oil in soil is not toxic to sensitive indicator organisms. If mineral oil remediation is regulated based on risk reduction and lack of environmental impact, bioremediation can be an extremely effective and efficient treatment technology. As a result of the collective body of research now available, several state regulatory agencies are considering order of magnitude increases in regulatory levels for amounts of spilled mineral oil permissible in soils.

EPRI BUSINESS GROUP: Environment Division

WEMOS Gas-in-Oil Monitor TR-102005

DETAILS: Final Report (232 pages)

DATE: April 1995

KEYWORDS: Transformer Insulation
Transformer Oils
Transformers
Gas Analysis
Insulating Oils

ABSTRACT:

Initial work on Taguchi-type metal oxide semiconductor (MOS) sensors indicated that they were sensitive to several of the gases produced by the overheated cellulosic insulation and mineral oil found in transformers, and that their output drifted in time. Modifications of the sensors with postmanufacturing surface active treatments achieved improved but not completely satisfactory stability.

DISCUSSION:

Analysis of dissolved gases in a transformer's insulating oil signals incipient problems resulting from local or generalized overheating. Traditionally, scientists have analyzed samples of insulating oil containing gas off-line in a laboratory using a gas chromatograph—a time- and labor-intensive process. The aggregate of combustible gases (predominately hydrogen) has been measured on-line, using a commercial instrument, which partially alleviated the problem. The need remained, however, to also independently measure at least hydrogen and carbon monoxide on-line and, if possible, other gases such as ethylene and acetylene.

Once the MOS sensors were developed and tested at participating field evaluation units, two problems became apparent: (1) the sensors were not selective enough between hydrogen and carbon monoxide, and (2) a more serious problem developed resulting in rapid loss of calibration because the sensors were not sufficiently stable and their response drifted with time. IITRI, through the use of surface active treatments, met with some success in improving the stability of the Taguchi-type sensor.

Although the follow-up work at IITRI resulted in some improvement in the stability characteristics of MOS sensors, it was not sufficient to warrant further field trials at this time. Instead, the decision was made to halt research on the MOS sensor, at least temporarily, and to seek other technology (see ongoing project RP2115-29/RP2445-03). The work reported here does detail the application of the WEMOS permeability cell, and it also provides a starting point if it is decided to continue work on the Taguchi MOS sensor.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Improved Lightning Arrester Protection Results, Final Results TR-109670-R1

DETAILS: Final Report: (152 pages)

DATE: Dec. 1998

KEYWORDS: Lightning
Substations
Power Transmission Systems
Power Distribution Systems

ABSTRACT:

Research is needed to better understand how lightning enters and propagates through the electrical system and to improve methods for protecting both the distribution and transmission system and customer facilities.

DISCUSSION:

This study was stimulated by the IEC Subcommittee 37A and IEC Advisory Joint Working Group 64. Of concern is energy that would be impressed on low-voltage surge protective devices located at the entrance to and inside a structure. Tests were done to understand how lightning current distributes in the electrical circuit of a lightning protected building. EPRI cosponsored this study with Duquesne Light Company.

The purpose of this report was to study responses of electrical systems when they are exposed to real world lightning conditions with a goal to improve lightning protection.

- The project presented the first simultaneously recorded arrester discharge current and voltage waveforms during very close, direct lightning strikes to a power distribution system. Energy absorbed by arresters as a function of time was estimated for short- and long-duration records. For short-duration records, maximum estimated energy absorption was about 6 kJ in 200 microseconds. For long-duration records, maximum estimated energy absorption was about 31 kJ in 6 microseconds, about 75 percent of the arrester's maximum energy absorption capability (4.0 kJ/kV of voltage rating, 10 kV).
- The division of lightning current injected into the neutral of the distribution line among multiple pole grounds was analyzed. The observed difference in waveshapes of currents in different grounds suggested that grounding impedance's were frequency dependent, non-linear, or both. Current waveforms to ground have quite different durations, suggesting that the lower-frequency components in the total lightning current were distributed differently. More than 75 percent of the total lightning current at 100 microseconds flowed to ground at the pole with the lowest dc ground resistance.
- The study analyzed the division of lightning current injected into the simulated house earthing system. Effects of the presence or absence of surge protection devices (SPD) and variation of the dc grounding resistance of the simulated house earthing system also were examined. The grounding rods appeared to filter out the higher-frequency components of the

lightning current, allowing the lower frequency components to enter the service entrance. Grounding rods in Florida sandy soil exhibited capacitive as opposed to resistive behavior. This effect was observed for dc resistance of grounding rods ranging from many hundreds of ohms to some tens of thousands of ohms. Results of the simulated house testing did not appear to support the current division hypothesized by IEC Technical Committee 81, in that more than one-third of the total current was observed to flow along the service entrance neutral toward the transformer, instead of flowing to ground at simulated house or being fed into the SPDs of the simulated house.

- DC ground resistance of a 2.4-m zinc-plated steel grounding rod decreased 32 percent, from 530 ohms to 360 ohms, in heavy rain. Lesser amounts of rainfall caused resistance decreases of the order of 10 ohms with a recovery time of a few days.
- The ratio of primary transformer to secondary transformer voltages due to lightning strikes on the primary circuit varied from 5 to 40.

Lightning continues to be a major cause of outages and damage in lightning-prone areas in the United States. It has been estimated that lightning-related utility outage loss and utility and customer facility and equipment damage cost about one billion dollars annually. Also, utility customers are more sensitive to power line disturbances and have stricter power quality and reliability needs due to increasing use of power sensitive equipment. Underground systems are no immune from lightning-caused overvoltage effects. This study showed that lightning can find its way into underground systems and into customer facilities and underground cables can be damaged from nearby lightning strikes.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Circuit Breaker Maintenance: Volume 2 – Medium Voltage Circuit Breakers; Part 3 – Westinghouse Types DH and DHP NP-7410-V2P3

DETAILS: Final Report (212 pages)

DATE: April 1994

KEYWORDS: Control Equipment
Switchgear
Predictive Maintenance
Preventive Maintenance

ABSTRACT:

This comprehensive guide will help enhance and optimize maintenance of Westinghouse DH and DHP circuit breakers. It consolidates utility industry guidelines, applicable standards, original equipment manufacturer recommendations, and hands-on experience relative to these breakers. Optimized maintenance will increase reliability and reduce costs associated with corrective maintenance and equipment downtime.

DISCUSSION:

Increased awareness of breaker performance trends, reliability, and failure effects has prompted an in-depth review of breaker maintenance practices and standardized technical guidance. Circuit breaker failures are costly, both in plant downtime and in potential damage to plant equipment and personnel.

EPRI developed this guide to establish a working level understanding of medium-voltage circuit breaker performance trends, reliability, and failure modes from which maintenance practices can be enhanced.

This maintenance guide focuses on Westinghouse DH and DHP medium voltage circuit breakers installed at nuclear power and other utility industry plants. It addresses breaker operation, reliability and failure data, degradation/failure mechanisms, maintenance recommendations, detailed inspection and test guidance, and replacement parts data.

In its consolidation of industry guidelines, standards, and recommendations, this guide presents practical information not previously available for the maintenance technician, planner, or engineer. The guide is one of a series of guides (NP-7410) on low and medium voltage circuit breakers. This guide is divided into three volumes, which are further divided into parts that correspond to a specific class, manufacturer, and model. Volume 1, with four parts, covers low voltage circuit breakers. Volume 2, in three parts, covers medium voltage circuit breakers. Volume 3, a stand alone document, covers molded case circuit breakers.

Circuit breaker maintenance is an ongoing responsibility for electric power plants. Improper maintenance practices can decrease electrical system reliability and availability. Because downtime resulting from poor maintenance is costly, improving just a few maintenance activities

can result in significant cost savings. This guide provides prudent test and inspection methods, which, in turn, result in more effective use of maintenance resources. Power plant personnel using this guide will be better equipped to establish an effective time- and condition-based program.

EPRI BUSINESS GROUP: Energy Conversion Division

Guidance on Routine Preventive Maintenance for Magne-Blast Circuit Breakers: Supplement to NP-7410-V2P2 TR-109641

DETAILS: Final Report (Vol. 2-92 pages)

DATE: Oct. 1998

KEYWORDS: Circuit Breakers
Preventive Maintenance
Substations

ABSTRACT:

The information contained herein represents a consensus among utility personnel on maintenance of Magne-Blast circuit breakers, taking into consideration the manufacturer's recommendations and the unique application of these circuit breakers within our industry. This document identifies routine preventive maintenance tasks for Magne-Blast circuit breakers and, where appropriate, provides the task's associated purpose, justification, and description.

DISCUSSION:

Maintenance guidance provided by the manufacturer on Magne-Blast circuit breakers has not been updated for many years. This effort is an attempt by nuclear utilities to consolidate and update guidance provided by the manufacturer and members of the Users Group. It also should be noted that guidance provided by GE is neither specific nor unique to the nuclear industry. Guidance provided here is specifically directed toward Magne-Blast circuit breakers within nuclear power plants.

Objectives of this report were:

- To provide guidance on routine preventive maintenance for General Electric Magne-Blast (AM and AMH) medium voltage (4-16 kv) circuit breakers.
- To establish a platform from which the entire utility industry can justify and improve maintenance programs for these circuit breakers.
- To develop a technical basis for proper maintenance so that users can enhance and justify their site-specific procedures.

This guidance is applicable to both vertical lift and horizontal (AM and AMH) Magne-Blast circuit breakers with ML-13 operating mechanisms, nominal voltage: 4.16-38 kv, nominal MVA class: 150-1000 MVA, and continuous current: 1200-3000 amps. Although not a procedure and not intended to be used as a procedure, this guidance is intended to assist plants in determining what maintenance tasks may be considered for their maintenance program.

Individual routine preventive maintenance tasks for Magne-Blast circuit breakers are identified here. Each task attempts to provide the task name, the purpose of the task, the justification (or

basis) for each task, and the task description. Guidance on preventive maintenance intervals is also furnished.

EPRI BUSINESS GROUP: Energy Conversion Division

Circuit Breaker Timing and Travel Analysis TR-112783

DETAILS: Final Report (56 pages)

DATE: May 1999

KEYWORDS: Circuit Breakers
Control Equipment
Maintenance
Switchgear
Predictive Maintenance
Preventive Maintenance
Substations

ABSTRACT:

This guideline provides some basic information and insight into the use, benefits, and limitations of circuit breaker timing and travel analysis, as applied to low and medium voltage circuit breakers.

DISCUSSION:

User groups, under the sponsorship of EPRI, are involved in the development of circuit breaker maintenance guidance documents for industry use. In the course of this development, it was apparent that it would be beneficial for the groups to collectively address timing and travel analysis. By collectively addressing this type of testing, the industry could establish a position on the use, benefits, and limitations of time and travel analysis. This effort was designed to develop a technical basis for the use of timing and travel testing in proper maintenance, such that utility companies could enhance and justify their specific site procedures. By providing guidance that contains the collective experience of the user groups, utility companies have established a platform from which the entire industry can justify and improve maintenance programs for low and medium voltage circuit breakers.

This guidance defines timing and travel tests, discusses test equipment and set-up, and test variables to consider, denotes typical test criteria, discusses the information gleaned from testing, and provides specific user group and manufacturer recommendations. In most cases, specific manufacturer recommendations have never before been documented. Based on comments from utility industry personnel, the most valuable result to come from development of this guidance is that this information has been collected and placed into a single, easily accessible documented source. The general consensus within the industry is that circuit breaker timing and travel analysis (tests) provides some indication of the condition of specific circuit breaker subcomponents, but does not provide a comprehensive assessment of the overall condition of a circuit breaker. Trending of timing test data is not recommended by any of the three major circuit breaker manufacturers (ABB, GE or Westinghouse) and is not generally performed. Timing tests are usually considered a pass or fail (go/no-go) test.

This effort is a collaborative industry effort with numerous utility industry and non-utility personnel providing their experience and knowledge. This document was written and designed to be used in conjunction with the circuit breaker maintenance guide series (EPRI NP-7410).

This is considered to be a living document. The circuit breaker user groups, along with EPRI, are tasked with providing an annual forum or mechanism to incorporate additions or changes to this guidance. It is expected that plant personnel and the circuit breaker user groups will continually review the contents.

EPRI BUSINESS GROUP: Energy Conversion Division

Reduced Control Voltage Testing of Low and Medium Voltage Circuit Breakers

TR-112814

DETAILS: Final Report (36 pages)

DATE: July 1999

KEYWORDS: Circuit Breakers
Switchgear
Maintenance
Testing
Substations
Power Distribution

ABSTRACT:

This report provides some basic information and insight into the use, benefits, and limitations of reduced control voltage testing of low and medium circuit breakers.

DISCUSSION:

Circuit breaker users groups, under the sponsorship of EPRI, are involved in the development of circuit breaker maintenance guidance documents for industry use. Over the course of developing guidance, it was apparent that it would be beneficial for the groups to collectively address reduced control voltage testing. By collectively addressing this test, the industry could attempt to establish a position on the use, benefits, and limitations of reduced control voltage testing. This effort was designed to develop a technical basis for the use of reduced control voltage testing in proper maintenance, such that users could enhance and justify their specific site procedures.

By providing guidance on reduced control voltage testing of low and medium voltage circuit breakers, users can establish a platform from which the entire industry can justify and improve maintenance programs for these circuit breakers.

This document was developed by a utility industry working group under the management of EPRI. The utility working group (1) reviewed utility industry procedures and vendor manuals, and (2) obtained input from utility personnel, manufacturers, and other organizations. After initial development, the draft was provided to a larger working group and to manufacturers for review and comment. GE, ABB, and Westinghouse NSD representatives reviewed the document and were offered opportunities to make comments. Laboratory testing of circuit breakers was not performed, as this was not deemed necessary to accomplish the objectives of this effort. This guidance is applicable to both low (480/600 volt) and medium voltage (4160/15,000 volt) circuit breakers.

This guidance defines reduced control voltage testing, presents the information obtained from this type of testing, provides a utility industry consensus with respect to the regulator, presents factors that should be taken into consideration when calculating minimum control voltage, and provides the industry's current position on trending and predictive maintenance.

The general consensus within the industry is that testing with reduced control voltage is a good engineering practice. Trending of data is not generally performed and is not recommended. Reduced control voltage testing is generally considered a pass or fail (go/no-go) test.

This effort is a collaborative industry effort with numerous utility industry personnel providing their experience and knowledge. By documenting a consensus opinion of the industry, EPRI-NMAC hopes to elevate the collective knowledge of the industry with respect to circuit breaker maintenance programs, while simultaneously providing guidance on prudent and cost-effective maintenance practices.

This is considered to be a living document. The circuit breaker user groups, along with EPRI, are tasked with providing an annual forum or mechanism to incorporate additions or changes to this guidance. It is expected that plant personnel and the circuit breaker user groups will continually review the contents. This document was designed to complement the circuit breaker maintenance guide series (EPRI NP-7410).

EPRI BUSINESS GROUP: Energy Conversion Division

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POWER CABLE & TRANSMISSION LINES

TIM 2.4: Transmission Inspection and Maintenance System (FIELD)

Win 95/NT

AP-108090-R2DK

DETAILS: Final Report

DATE: August 1999

KEYWORDS: Computers
Databases
Inspections
Maintenance
Transmission Line Condition

ABSTRACT:

The transmission Inspection & Maintenance (TIM) System acquires, stores, and retrieves transmission line inspection data. Its unique design increases data reliability while reducing the time to perform inspections and determine maintenance required. Version 2.4 SQL adds many new features to the previous version.

DISCUSSION:

TIM advances the state-of-the-art in overhead transmission line inspection and assessment methods. Begun in 1993, the project involved research to quantify the cost-effectiveness and reliability of commonly used inspection procedures. Researchers also sought to identify limitations and gaps in existing capabilities as well as potential enhancements. They conducted experiments in which different crews inspected two different transmission lines while independent observers noted the procedures used by these crews. The research focused on why some inspection crews achieved better results than others and what procedures or instruments would improve inspection capability. From this analysis, researchers then identified specific gaps in measurement and inspection technology and suggested enhancements and modifications. TIM V2.4 SQL is the latest product release in the series.

This system has two principal objectives:

- To provide line condition information capable of predicting remaining line life.
- To easily identifying critical repairs and changes in lines.

The TIM system uses a paperless, graphics-based approach to acquire data. The system includes a pen-based, hand-held field computer; digital photographic camera; and office-based server/client PCs. The main module in TIM is the Office Module, which users can install on server or network clients to manage inspection information. Using the module, they can set up a master set of all lines and segments and then create subsets of information for inspectors to use in the field. The inspector's module in TIM is the Field Module, which is installed on hand-held computers for field use. It records and temporarily stores inspection data until it is transferred to the Office Module for long-term management.

TIM is a breakthrough in overhead transmission line inspection and maintenance management. Designed to integrate easily with existing maintenance management systems, the tool also can serve as the foundation for a fully integrated maintenance management database. TIM V2.4 SQL includes some exciting new features:

- A completely new work management interface that allows personnel to create work requests and maintain repair status information.
- A new global positioning and geographical information management interface (GIS/GPS) that displays interactive maps.
- A new quick-build feature that helps staff quickly set up lines by copying or moving multiple structures at a time.
- A new archiving feature that records historical data for trend analysis and auditing.
- Online user guides for quickly finding information, whether from a desktop computer or a mobile field computer.
- New segment and structure priority ratings and revised line priority ratings.

EPRI BUSINESS GROUP: Energy Delivery Utility Division

Thermal Models for Real-Time Monitoring of Transmission Circuits TR-105421

DETAILS: Final Report (350 pages)

DATE: Dec. 1995

KEYWORDS: Transmission Lines
Monitoring

ABSTRACT:

This report describes the development and testing of the Dynamic Thermal Circuit Rating (DTCR) software package. This package integrates existing and newly developed thermal models for all common types of transmission power equipment and allows the user to calculate circuit ratings in real time with a maximum of flexibility and a minimum of equipment data, instrumentation, and cost.

DISCUSSION:

EPRI began this study as a result of earlier research on dynamic thermal circuit rating (DTCR) sponsored by the Empire State Electric Energy Research Company. This work, completed in 1988, showed that DTRC methods utilizing readily available weather and load data were economic and useful. EPRI determined that development of a PC-based DTCR software package was a reasonable extension of this study and could make use of previous EPRI research on power transformers (PTLOAD), overhead lines (DYNAMP), and underground cable (ACE) ratings.

The DTCR software package allows a user to estimate real-time equipment temperatures and ratings for a wide range of power equipment, including power transformers, overhead lines, underground cables, and substation switching gear. Real-time weather, load, and temperature data is provided to multiple PC serial ports from one or more digital data loggers. Equipment temperatures and ratings are displayed and stored in standard ASCII files. Thermal rating algorithms allow up to four different thermal ratings calculations. Circuit thermal ratings are reported equal to the minimum rating of any series element of the circuit. Multiple circuits consisting of multiple elements can be rated simultaneously. The DTCR software package is thoroughly documented, flexible in setup and use, and easily transportable to other operating systems.

The report describes the analytical bases for the various power equipment rating algorithms incorporated in the package, including the bases for new thermal models for switches, line traps, and buses developed for this project. The report gives the results of field tests of the complete package at Georgia Power and provides documentation for the software package.

Comparing loading to thermal rating limits and finding critical power equipment temperatures in real time are essential to maximizing the utilization of equipment and minimizing the probability of equipment damage from thermal overload. This software package allows utility industry personnel to perform such real-time monitoring.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

**Testing of XLPE Transmission Cable Terminations at Three Utilities:
Southern California Edison, Public Service Company of Colorado, and
PECO Energy Company
TR-108073**

DETAILS: Final Report (47 pages)

DATE: May 1997

KEYWORDS: Transmission Cables
Underground Transmission
Diagnostic Techniques
Dielectric Properties

ABSTRACT:

Detection of discharges at an early stage will increase the reliability of high-voltage cable systems. EPRI has sponsored partial discharge testing of 14 cross-linked polyethylene (XLPE) cable terminations at Southern California Edison, Public Service Company of Colorado, and PECO Energy Company. Three of the 14 terminations showed evidence of partial discharge activity. This report describes the testing procedures and results obtained from performing very high frequency partial discharge measurements.

DISCUSSION:

A new high frequency measuring technique will enable engineers to detect partial discharges in polymer-insulated cables and accessories. The very high frequency partial discharge (VHF PD) technique can be used for systems with a concentric neutral earth screen of individual copper wires as well as for systems with a solid metallic sheath. When the VHF PD technique is combined with a new phase-angle measurement system, the phase relationship between discharge pulses and the operating voltage can be determined. The system also makes it possible to perform on-site partial discharge measurements without connecting the test equipment to high-voltage parts of the system.

VHF PD testing of 14 cable terminations at Southern California Edison, Public Service Company of Colorado, and PECO Energy Company revealed partial discharge activity in three terminations. A summary of key results at each utility follows:

- **Southern California Edison's Tamarisk-Thornhill 115-kV Circuit**—Diagnostic testing revealed very low noise levels at the Eisenhower and Thornhill substations. No measurable partial discharges were detected at the Eisenhower substation terminations. Some random noise signals at the Thornhill substation were not related to partial discharges.
- **Public Service Company of Colorado's Cherokee 115-kV Switchyard**—The testing revealed small overall noise levels with some large intermittent signals of 700 pC, which is relatively high. At the switchyard side, the measurements revealed no signals other than the large intermittent disturbances.

- **PECO Energy Company's North Philadelphia 69-kV Transformer Tie**—Because of operating conditions, no measurements were performed with the circuit de-energized. Measurements with the circuit energized revealed partial discharges at the transformer side, while no partial discharges were detected at the distribution side. These results are similar to ones obtained previously in 1994.

Statistics show that most failures in solid dielectric transmission cable systems occur in accessories. Partial discharge testing of installed accessories will prevent possible breakdowns. EPRI is sponsoring work to investigate diagnostic tests for extruded transmission cable systems. Results of this project will be available in early 1998.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Advanced Cable Fault Locator: Volumes 1 and 2 EL-7451-LV2

DETAILS: Final Report (Vol.1-212 pages: Vol. 2-228 pages)

DATE: Oct. 1991

KEYWORDS: Cable Faults
Electrical Fault Detection
Electrical Fault Locations
Underground Cables

ABSTRACT:

EPRI has developed a new concept for fault location in underground residential distribution (URD) circuits. This concept uses fault-generated waves to perform both real-time and after-the-fact fault location on URD circuits up to 1 mile long.

DISCUSSION:

To minimize the length of time a customer experiences service interruption, a utility company must quickly find the source of a fault and repair the problem. On an underground system, fault location is time consuming because the distribution system is not visible. Though methods used today to locate a fault are reasonably accurate, they require a skilled operator to obtain the best results. In addition, some fault location methods may be detrimental to the remaining life of the cable. EPRI, therefore, investigated new concepts for fault location in URD cables.

Fault-generated current and voltage transients can indeed be used to locate faults with high accuracy on underground cable systems. In concept, a fault locator installed on a looped URD primary circuit could automatically identify the fault location. The concept was proved on a model distribution system and on an actual distribution system, with location accuracy of 2% or less of the total cable length. As envisioned, the device to implement this concept would consist of a voltage or current sensor, a processing unit, and a readout indicating the distance to the fault. All fault data acquisition and signal processing to determine the distance to the fault would be performed automatically by the unit. Volume 1 of this report provides an overview of concepts for development of the fault locator, and Volume 2 presents a detailed proprietary concept description.

The fault locator envisioned replaces fault indicators used by utility companies to identify defective cable. This device can be used in two ways: as a permanently installed on-line monitor on a loop of cable with transformers or as a portable tool to help troublemen locate faults. If the locator is on-line, the troublemen interrogate it to determine the distance to the fault, then call the dispatcher who identifies the transformers on either side. If the troublemen bring the locator with them, they need to re-energize the circuit by re-fusing or using a single thumper pulse to locate the fault. The device would then indicate the distance to the fault, and the troublemen would call the dispatcher to determine the location in terms of adjacent transformers. In both cases, other methods would need to be employed to pinpoint the exact fault location.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

CORRIDOR – TLWorkstation™: (Transmission Line Workstation)
Version 3.0
AP-107048-CD
AP-107048-DK

DETAILS: Computer Code (PC-Windows)

DATE: Oct. 1997

KEYWORDS: Transmission Lines
Workstation
Computer Code

ABSTRACT:

The CORRIDOR module of TLWorkstation™ allows utility engineers with a minimum background in electromagnetic analysis to solve complex rights-of-way problems with railroad and pipelines. The program calculates the steady-state or fault-induced voltage and current caused by adjacent electric power transmission lines, at locations of interest along pipelines, railroads, communications wires, shielded cables, or other conductors.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

NOTE:

Software (SW-40080) and software (SW-40076) associated with this workstation are available separately.

**RNOISE – Radio Noise Profiles Version 3.0: Orderable as Part of AP-107048
or Alone
SW-40076**

DETAILS: Computer Code (PC-Windows)

DATE: Oct. 1996

KEYWORDS: Transmission Lines
Radio Transmission
Electromagnetic Interference
Electrical Conductors

ABSTRACT:

RNOISE – TLWorkstation™ Module. Corona on a transmission line conductor injects impulsive currents into the conductor. The currents produce electromagnetic fields over a wide band of frequencies which interfere with receivers near the transmission lines. This is called electromagnetic interference or radio noise. RNOISE is used to calculate the electromagnetic interference or radio noise from high voltage transmission lines in fair and foul weather.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

**CORRIDOR Version 3.0: Orderable as Part of AP-107048 or Alone
SW-40080**

DETAILS: Computer Code (PC-Windows)

DATE: Oct. 1996

KEYWORDS: Transmission Lines
Electromagnetic Interference
Electromagnetic Analysis

ABSTRACT:

CORRIDOR – This module of TLWorkstation™ allows utility engineers with a minimum background in electromagnetic analysis to solve complex rights-of-way problems with railroad and pipelines. The program calculates the steady-state or fault-induced voltage and current caused by adjacent electric power transmission lines, at locations of interest along pipelines, railroads, communications wires, shielded cables, or other conductors.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

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PUMPS, VALVES & PIPING SYSTEMS

Valve Application, Maintenance, and Repair Guide TR-105852-V1

DETAILS: Final Report (Vol. 1-534 pages)

DATE: Feb. 1999

KEYWORDS: Maintenance
Valves
Power Plant Reliability

ABSTRACT:

The Valve Application, Maintenance, and Repair Guide is a two-volume series that provides a generic overview of valve application, selection, maintenance, and repair. Volume 1 of the series is a comprehensive reference on the application and use of valves that provides guidance on the selection of specific types of valves on the basis of functional and system requirements. This document is based on an earlier EPRI document (NP-6516, Guide for the Application and Use of Valves in Power Plant Systems). Extensive illustrations and sample calculations make the guide useful to a wide range of personnel. This volume has been expanded to include general maintenance requirements and diagnostics for different valve types.

Information on valves and valve operators, where other comprehensive NMAC documents are available (such as Air Operated Valves, Solenoid Valves, check Valves, Safety and Relief Valves, and the Technical Repair Guide series on Limitorque operators), have been referenced without duplicating the contents in this volume.

DISCUSSION:

The improper application, incorrect use, and ineffective maintenance of valves in power plant systems cause significant losses in plant availability. Over the last several years, EPRI, the U.S. NRC, and the electric utilities have conducted many valve and actuator research projects to improve plant safety and availability by reducing valve and actuator problems. These projects resulted in many proprietary and non-proprietary documents that deal with the various specialized areas of valve/actuator sizing, performance characteristics, maintenance, repair, testing, and diagnostic techniques. However, information to aid plant personnel in resolving these problems is difficult to glean from scattered sources, and access may be restricted by proprietary considerations.

Although the information contained in the guide focuses on the application and maintenance of valves in power plant systems, it is also directly applicable to comparable system applications in the chemical, petroleum, marine, and similar industries. The intended audience of the guide includes system designers; engineers who establish specification requirements for valves; personnel who install, operate, maintain, and repair valves; plant training instructors; and others for whom a more in-depth knowledge of valves could lead to improved valve performance. The guide will be helpful in evaluating valve/actuator applications in existing systems, selecting new and replacement valves/actuators, and developing/updating valve maintenance programs and procedures.

EPRI BUSINESS GROUP: Energy Conversion Division

**Valve Application, Maintenance, and Repair Guide: In Situ State-of-the-Art
Valve Welding Repair (Gate, Globe, & Check Valves), Volume 2
TR-105852-V2**

DETAILS: Final Report (Vol. 2-392 pages)

DATE: Dec. 1996

KEYWORDS: Valves
Welding
Maintenance
Power Plant Reliability

ABSTRACT:

The Valve Application, Maintenance and Repair Guide is a three volume series that provides a generic overview of valve application selection, maintenance, and repair. Volume 2 of this series is a comprehensive guide for in situ weld repair of gate, globe, and check valve components such as bodies, bonnets, discs, and seats. The information in this guide, though directed toward nuclear plant personnel, will assist all power plant engineers, planners, and maintenance personnel responsible for valve maintenance and repair. Volume 1 of this report will contain information on valve design, application, and sizing; while Volume 3 will provide information on welding repair of butterfly, ball and plug-type valves.

DISCUSSION:

Several EPRI-sponsored studies and surveys have concluded that valve failures are the single largest contributor to unscheduled shutdowns and lost plant availability. While a majority of these failures are maintenance related and can be addressed in short order, the more time consuming problems are typically related to cracks or wear of the valve body or critical internal components. Replacing a valve or part, especially those which are large or safety related, can take in excess of 26 weeks to obtain, if it is available at all. Today, with the major emphasis on shorter outages and downtime, utilities companies are opting for innovative repair techniques which keep the valve either on-line or at the plant site. This guide has been developed to prove the information necessary to identify and evaluate the problem, select the appropriate repair option, establish the repair and procedures, and carry out a successful repair.

This guide provides general design and operating criteria for gate, globe, and check valves. It presents wear and degradation problems that are unacceptable for plant performance and/or safety and provides repair options. It also provides the most current and effective welding repair techniques and technology to successfully repair valve components in accordance with the requirements of the governing code body.

This guide presents the background information necessary to understand why a valve is not meeting either internal or external leak requirements, and provides detailed repair options and procedures to address the problem with sound engineering practices meeting the requirements of the ASME Boiler and Pressure Vessel Code. The Guide is written in such a manner to allow the responsible engineer to understand each step in the repair process, to write repair procedures and

specifications, and to follow the work as it is performed by in-house or contractor personnel. Experienced valve repair personnel looking for specific information should refer to specific topical sections or appendices for detailed information.

EPRI BUSINESS GROUP: Energy Conversion Division

Air-Operated Valve Maintenance Guide NP-7412-R1

DETAILS: Final Report (290 pages)

DATE: Nov. 1996

KEYWORDS: Valves
Control Equipment
Maintenance
Predictive Maintenance
Preventive Maintenance

ABSTRACT:

Air-operated valve (AOVs) are used extensively in the power generation industry for process-control and system-isolation functions. This guide provides methods for establishing predictive and preventive maintenance programs for AOVs. It suggests techniques for reducing failure rates and discusses proven repair methods that can help reduce downtime and unplanned outages.

DISCUSSION:

An increased awareness of AOV importance at nuclear power plants has led to progressively more sophisticated maintenance practices within the nuclear industry. Non-nuclear plants are also heavily dependent on reliable AOV operation. The dynamic method used by fossil power plants to satisfy transient electrical demands places additional stress on plant components, including AOVs. Therefore, there is a growing need for standardized technical guidance related to AOVs.

This guide discusses air-operated valves (AOVs) and common accessories. Diagrams indicating the application and operation of various types of actuators are presented as an aid for thorough investigation of malfunctioning equipment. Recent developments in diagnostic equipment for AOVs are covered, and valve traces on valves with maintenance-related problems are used to demonstrate how the diagnostic equipment can quickly solve complex valve problems.

This guide includes a troubleshooting section with tables that provide easily accessible information to minimize troubleshooting costs. A detailed discussion diaphragms that provides guidance for selecting, installing, and maintaining AOV diaphragms is furnished. Appendixes augment the guide by providing a glossary of terms and various engineering schedules, including useful engineering parameters for the proper maintenance of AOVs and accessories.

Power plants rely on AOVs for the proper operation of many plant systems. AOVs are used extensively on both large- and small-bore piping systems and heating, ventilating and air-conditioning (HVAC) ducting to provide isolation and flow control functions. Process applications include water, steam, N₂, H₂, and air. Predictive and preventive maintenance is one of the key ways to enhance AOV performance and subsequently reduce AOV failure rates. Through the proper implementation of key AOV maintenance activities, plants can realize

significant savings. This guide will help power plant professionals take the most effective and appropriate maintenance actions. Related EPRI research includes reports NP-7079, “Instrument Air Guide,” and NP-7414, “Solenoid Valve Maintenance and Application Guide.”

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

This guide is equally applicable to fossil fuel and other industrial power plants such as the pulp and paper industry.

Main Feedwater Isolation Valve Maintenance Guide NP-7212

DETAILS: Final Report (1064 pages)

DATE: May 1991

KEYWORDS: Valves
Training
Maintenance
Feedwater
Isolation Valves
Hydraulic Equipment

ABSTRACT:

This guide provides operational and maintenance information—including new color-coded drawings—for the main feedwater isolation valves (MFIVs) supplied by the Anchor/Darling Valve Co. Such information can provide a better understanding of the equipment and should increase reliability and reduce MFIV maintenance and downtime.

DISCUSSION:

Although the utility industry has gradually been increasing its knowledge of MFIVs, this equipment has continued to be the subject of much discussion. In fact, MFIVs were listed in the top ten maintenance issues on the prioritized list of the Nuclear Maintenance Applications Center. Because of the critical application of MFIVs in the containment isolation portion of nuclear power generation plants, proper maintenance and operation of this equipment is crucial to efficient plant operation and public safety. This guide is designed to provide the latest and most complete information on MFIVs.

The MFVI guide presents complete operational and maintenance data for the valve and actuator. It also includes information on valve and actuator components, troubleshooting, and past experiences. This guide offers a comprehensive, integrated view of MFIVs for the novice maintenance technician or engineer, as well as a compendium of information that allows quick access to specific data for the more experienced maintenance technician or engineer.

Individual plants can use this maintenance guide for training personnel, increasing understanding of MFIVs, and developing detailed maintenance and troubleshooting practices. The guide also facilitates communication between managers and technicians concerning the complexity of MFIV equipment maintenance. A companion maintenance guide is also available for main steam isolation valves (MSIVs) supplied by Anchor/Darling (EPRI report NP-7211).

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

This guide is equally applicable to fossil fuel and other industrial power plants such as the pulp and paper industry.

Check Valve Maintenance Guide TR-100857

DETAILS: Final Report (302 pages)

DATE: Aug. 1995

KEYWORDS: Valves
Training
Predictive Maintenance
Preventive Maintenance
Check Valves
Power Plant Availability

ABSTRACT:

This guide provides comprehensive technical information on various types of check valves. It can help maintenance engineers determine the condition of valves and develop proper maintenance procedures, and it can serve as an aid in developing check valve training materials. This guide is a companion to Application Guide for Check Valves, NP-5479, in the nuclear power industry.

DISCUSSION:

This document provides technical guidance and recommendations for proper and cost-effective maintenance of check valves and comprehensive information for developing predictive/preventive maintenance procedures and training materials.

This guide complements previously published information. It will assist utility personnel in preparing plant-specific programs and procedures for check valve maintenance. It includes design and application information and the advantages and disadvantages of each type of check valve. It gives information on valve types, sizes, vendors, failure modes, and effects and summarizes the applicable ASME codes, industry standards, and regulatory requirements. Also included is information on the elements of preventive and predictive maintenance programs, methods of inspecting and determining valve condition, nonintrusive monitoring techniques, disassembly and reconditioning, and postmaintenance testing. Appendices provide supporting information.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

This guide is equally applicable to fossil-fuel and other industrial power plants such as the pulp and paper industry.

Solenoid Valve Maintenance and Application Guide NP-7414

DETAILS: Final Report (244 pages)

DATE: April 1992

KEYWORDS: Valves
Training
Maintenance
Solenoid Valves

ABSTRACT:

Solenoid Operated Valves (SOVs) are widely used in both nuclear and fossil-fuel power plants and sometimes provide critical safety functions. The Solenoid Valve Maintenance and Application Guide provides information about SOV operation, limitations, and design variations. This guide can be used to train plant maintenance personnel and to improve maintenance programs.

DISCUSSION:

The guide addresses concerns raised in nuclear plant reports and describes SOV operation in detail. It covers topics important to proper maintenance and operation of SOVs, describes variations of major valve components and operational peculiarities of different designs, and discusses major diagnostic techniques that are commercially available.

Degradation of internals caused by process-borne debris and coil degradation due to temperature and humidity appear to be the significant factors leading to SOV failures. Condition monitoring techniques are of limited use due to the absence of SOV performance history in individual plants. The guide recommends periodic valve cycling for all SOVs. Pick-up drop-out voltage tests are recommended after valve disassembly and repair.

The guide can assist in planning SOV maintenance programs. It provides information on SOV design characteristics for consideration in selecting or specifying SOVs for application. Power plants can adapt the guide for training plant maintenance personnel. Related research includes EPRI report NP-7079.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

While this report addresses problems specifically related to the nuclear power industry, the guidance is completely applicable to fossil-fuel and other industrial power plants such as the pulp and paper industry.

Advanced Technology Training System (ATTS) for Motor-Operated Valve Maintenance

TR-103368

DETAILS: Final Report (52 pages)

DATE: July 1994

KEYWORDS: Valves
Motor-Operated Valves
Maintenance
Training

ABSTRACT:

The ATTS courseware package contains instructional materials on mechanical, electrical, and troubleshooting aspects of Limitorque SMB-000 actuators used in conjunction with gate and globe valves. The package—intended as a supplement for current Limitorque training in motor-operated valve maintenance—consists of courseware on a disk, a student manual, and an instructor manual.

DISCUSSION:

The ATTS courseware for motor-operated valve (MOV) maintenance was developed as part of a joint research program, cosponsored by EPRI and the Central Research Institute of Electric Power Industry (CRIEPI) in Japan, to investigate ways to reduce human errors in nuclear power plant maintenance activities. MOV maintenance is particularly susceptible to human error due to the overall complexity of troubleshooting, detecting, diagnosing, and correcting faults. In addition, electricians and mechanics work separately during the MOV overhaul and may not have a total system perspective. This report demonstrates the effectiveness of advanced technology training in the mechanical, electrical, and troubleshooting aspects of MOV maintenance.

On the basis of training analysis, four MOV training modules were developed and evaluated for the ATTS courseware. The first module introduces MOVs, providing a fundamental knowledge of their operation and overhaul. The second and third modules address mechanical and electrical aspects of MOVs to help students understand the operational theory behind MOV actuators. The fourth module features a troubleshooting simulation that allows students to diagnose failures and solve problems. In all, the simulations contain 17 troubleshooting scenarios, including graphical representation of system components, test equipment, and control panels. Evaluations at two plants showed that students readily accepted this type of training, and more importantly, the training significantly reduced the number of premature and incorrect diagnoses during troubleshooting tasks. The ATTS courseware requires an IBM-compatible 80386 or 80486 computer with 4 MB of RAM and 5 MB of available hard drive space as well a 256-color SVGA monitor and a mouse.

The ATTS courseware is the result of a comprehensive research program investigating ways to reduce human errors and increase productivity in nuclear power plant maintenance activities.

The training simulation materials will prove particularly useful to inexperienced mechanical maintenance personnel, electricians requiring additional exposure to the mechanical and electrical operation of MOVs, and maintenance personnel who have not actively worked with MOV actuators for some time. Overall, the ATTS simulation courseware will provide meaningful hands-on experience to enhance the performance of MOV maintenance tasks.

EPRI BUSINESS GROUP: Energy Conversion Division

Valve Body-to-Bonnet Seal Welding Development TR-108140

DETAILS: Final Report (64 pages)

DATE: Jan. 1997

KEYWORDS: Valves
Welding
Maintenance
Seal Welding
Repair

ABSTRACT:

Body-to-bonnet process leakage of non-isolate valves during plant operation can lead to unscheduled shutdown and loss of revenue to power plant owners. On-line repair methods have been developed to provide permanent repairs without taking the system off-line or isolating the valve. This report provides well-documented and demonstrated welding methods and procedures to repair leaking lip seals, canopy seals, and seal weld joints on-line and under pressure.

DISCUSSION:

Conventional repair methods for the repair of leaking valve body-to-bonnet joints with lip seal or canopy seal provisions require isolating or shutting down the system, disassembling the valve, reassembling the valve, and then applying a seal weld if the responsible engineer elects to utilize that provision. In many cases, the financial impact of this effort can be several hundred thousand dollars per day if the plant must be taken off-line. Plant maintenance personnel have attempted on-line repairs utilizing welding methods and on-line injection methods [Furmanite(r)] and have received mixed results. As an alternative, the EPRI Repair and Replacement Applications Center has and have received mixed results. As an alternative, the EPRI Repair and Replacement Applications Center has developed a practical repair approach that incorporates a code-quality seal weld with the system under pressure.

The program established sound repair practices and welding procedures guidelines to perform on-line body-to-bonnet repairs. Detailed mockup fabrication drawings, test results, repair procedures, and welding parameters are provided in this report to guide utility personnel or their contractor through a successful training effort and field application.

The on-line valve body-to-bonnet seal welding method offers an effective permanent repair method or alternative to the temporary under pressure leak sealing, when a utility company is faced with shutting down a unit due to a leaking valve body-to-bonnet joint. This cost-effective approach can be implemented quickly with no requirement for special tools or equipment. From an ASME Code perspective, the valve was designed to accommodate such a weld, therefore, a component design change is not typically required. Welding is performed in accordance with the requirements of AMSE Section IX.

EPRI BUSINESS GROUP: Energy Conversion Division

NOREM Applications Guidelines: Procedures for Gas Tungsten Arc and Plasma Transferred Arc Welding of NOREM Cobalt-Free Hardfacing Alloys TR-105816

DETAILS: Final Report (152 pages)

DATE: Nov. 1995

KEYWORDS: Valves
Welding
Maintenance
Repair

ABSTRACT:

Wire products have been successfully fabricated and new procedures developed for machine and manual gas tungsten arc welding (GTAW) of the iron-base NOREM hardfacing alloys. These developments enhance the attractiveness of NOREM alloys both in replacement valves and in field repairs of installed valves. This report describes the GTAW procedures and summarizes plasma transferred arc welding (PTAW) parameters for shop applications of NOREM alloys.

DISCUSSION:

An earlier EPRI report (TR-101094) described the results of the first attempts to develop GTAW procedures for NOREM hardfacing alloys. However, utility personnel reported some difficulty in independently qualifying these procedures. Additional studies were therefore undertaken to see if more flexible welding procedures could be identified for NOREM wire products. The work described here provides a wider range of acceptable welding conditions than these described in TR-101094.

Objectives of this report were to develop machine and manual GTAW procedures that minimize preheating requirements for depositing NOREM weld wire; to help utility companies and valve repair organizations independently qualify GTAW welding procedures; to compile information developed by other groups using PTAW techniques to deposit NOREM powder.

Researchers successfully used GTAW processes to deposit sound weld overlays on SA-516 carbon steel and Type 304 stainless steel piping without any preheating. Metal-core wire using prealloyed gas-atomized powder as filler material and featuring a lower nitrogen content than earlier investigated consistently provided sound welds and great flexibility to the welder and could be used to perform a local weld repair. Powder with the higher nitrogen content was successfully deposited by two other organizations using PTAW with a modest preheat of 200 degrees Fahrenheit. Such a moderate preheat will remove residual moisture and help maintain consistent cooling rates. Preheat should be considered anytime hardfacing is applied to carbon steel substrates. Wear measurements showed that changes in alloy composition of the wire did not adversely affect the galling wear resistance of the NOREM alloys.

Loop tests under simulated nuclear reactor operating conditions and laboratory evaluations of small valves hardfaced with NOREM show that its performance matches or exceeds that of the long-established cobalt-base Stellites™. Because valves with NOREM hardfacing have been

purchased or installed by some 25 nuclear utilities, a NOREM product form and welding procedures suitable for field applications were needed. This study resulted in a NOREM chemistry that can be deposited more easily and more consistently using the GTAW process than the previously identified composition (report TR-101094). In addition to its “welder friendly” status, the NOREM alloy also exhibits wear resistance equivalent to that of cobalt-base hardfacing alloys. NOREM alloys should be considered for further applications in both nuclear and fossil plant valves.

EPRI BUSINESS GROUP: Energy Conversion Division

Performance of NOREM Hardfacing in Plant Valves: In Situ Application and Leak Rate Testing of Feedwater Check Valves TR-107987

DETAILS: Final Report (100 pages)

DATE: Sept. 1997

KEYWORDS: Valves
Welding
Check Valves
Maintenance
Repair
Hard Facing

ABSTRACT:

The NOREM cobalt-free hardfacing alloy provides outstanding resistance to adhesive (galling) wear. This report describes the first in situ repair of nuclear plant valves using NOREM. In this case, two large 24-in. check valves at the Entergy Grand Gulf Nuclear Plant were refurbished during two recent refueling outages. Local leak rate tests made after the valves were refurbished and after one was in service for an 18-month fuel cycle showed outstanding performance.

DISCUSSION:

Iron-base NOREM hardfacing alloys have been used in more than 400 replacement valves in nuclear power plants. Entergy's Grand Gulf Nuclear Plant took the lead in refurbishing installed feedwater check valves with NOREM and used local leak rate testing to monitor performance. These valves were selected because they were a significant source of released cobalt and had a history of performing poorly in mandated local leak rate tests (LLRTs). This project applied EPRI-sponsored research which developed welding consumables and procedures for NOREM use in field repairs of installed valves (report TR-107231).

Objectives of this report were:

- To qualify welding procedures for NOREM hardfacing alloys and apply these procedures in refurbishing two 24-in. feedwater check valves.
- To perform LLRTs on the valves following refurbishment and after service.
- To provide "lessons learned" that would facilitate further in situ applications of NOREM and other hardfacing alloys.

During refueling outage 7 (RF07), NOREM hardfacing was successfully applied on plugs, in-body seats, and three of the four valve guide ribs (specifically, the three ribs that contact the plug during operation) of feedwater check valve F010B. Time constraints forced completion of the refurbishment on F010A to take place during refueling outage 8 (RF08). This report identifies the factors responsible for the delay and provides detailed recommendations to facilitate subsequent in situ repair or refurbishment using NOREM hardfacing. The RF07 LLRT

results were 0.6 gallons per minute (gpm) for the F010B valve and 6 gpm for the F010A valve after partial refurbishing. The F010A valve seat was not lapped to the same extent as the F010B seat, which may have contributed to its higher leak rate. After 18 months of service, the RF08 LLRT result for the F010B valve was 6 gpm. Following completion of work on F010A during RF08, the measured LLRT was 0 gpm. The maximum acceptable LLRT value for these valves is 7 gpm. Overall, the low measured LLRT values obtained with NOREM hardfacing marked a significant improvement over those measured when the valve was hardfaced with cobalt-base alloys or subsequently modified with a resilient elastomer (“soft seat”). Conducting LLRTs in water rather than air also contributed to the improved performance.

EPRI BUSINESS GROUP: Energy Conversion Division

Valve/Steam Trap Leakage Quantification User Guide TR-103198-P4

DETAILS: Interim Report (50 pages)

DATE: Dec. 1997

KEYWORDS: Steam Traps
Valves
Maintenance
Leak Detectors

ABSTRACT:

This report describes the CHECWORKS™ software tool, which quantifies steam leakage through secondary plant components such as valves or steam traps, and its user guide. This information can be used to improve plant efficiency by identifying the source and magnitude of steam losses, which relate directly to lost electrical output.

DISCUSSION:

In 1996, Union Electric used the network flow analysis (NFA) capability of the CHECWORKS Flow-Accelerated Corrosion application in a manual fashion to estimate the amount of steam leaking from a supposedly closed valve. Temperatures downstream of normally closed valves are monitored to indicate leakage. By comparing the analytically predicted temperature downstream of the valve with the measured temperature, Union Electric was able to quantify the leakage and the economic value of the loss. The utility used this information to make maintenance decisions. CHECWORKS Valve/Steam Trap Leakage Quantification application evolved from this experience.

The CHECWORKS Valve/Steam Trap Leakage Quantification application automates the process of analyzing valves and traps for potential steam leaks. The standard capabilities of CHECWORKS NFA are provided with the additional capability to model steam traps. The user defines the system to analyze, then identifies the failed component and the location to survey downstream temperature.

The CHECWORKS Valve/Steam Trap Leakage Quantification software tool assists in identifying steam leak losses. Components may be examined over the complete failure range (0-100%). The module executes the required number of cases and provides summary tables and plots of pressure and temperature versus leak rate.

The CHECWORKS Valve/Steam Trap Leakage Quantification application is a tool, giving a quick and easy method to identify leakage that may affect secondary plant efficiency. This information can be in a turbine heat balance program to accurately estimate electrical power lost. The information also improves staff ability to select the most important components for corrective maintenance.

EPRI BUSINESS GROUP: Energy Conversion Division

CHECWORKS™ Flow-Accelerated Corrosion: User Guide TR-103198-P1

DETAILS: Final Report (500 pages)

DATE: Dec. 1997

KEYWORDS: Corrosion
Corrosion Monitoring
Predictive Maintenance
Flow-Accelerated Corrosion
Water Flow

ABSTRACT:

The CHECWORKS™ Flow-Accelerated Corrosion (FAC) application is a software program that evaluates the severity of FAC in nuclear and fossil power plants. This summary describes the CHECWORKS FAC application (version 1.0F) and its user guide.

DISCUSSION:

Flow-accelerated corrosion (FAC) causes wall thinning of piping, vessels, and components. Wall thinning results from dissolution of the normally protective oxide layer (magnetite or hematite) that forms on the surface of carbon and low alloy steel when exposed to moving water or wet steam. The oxide layer reforms, and the process continues. The problem is widespread in all types of nuclear and fossil power plants including boiling water reactors (BWRs), pressurized water reactors (PWRs), heavy water reactors (HWRs), and graphite-moderated reactors. Wall thinning rates as high as 3 mm/year have been observed. If thinning is not detected in time, either leaks or instantaneous complete ruptures can and do occur.

Installed on the EPRI CHECWORKS™ software platform, EPRI's approach uses an empirical model to predict FAC rate on a component-by-component basis. Most susceptible locations are identified, and extensive inspections are not necessary. The basic model has been in use since 1987 and found to accurately predict plant behavior. FAC predictions include the following related evaluations:

- Water Chemistry Analysis – determines oxygen level and operating pH of typical nuclear and fossil-fueled power plants around the steam cycle.
- Network Flow Analysis – determines unknown local operating conditions (flow rate, temperature, pressure, or steam quality) that are needed for FAC predictions.
- Wear Rate Analysis – predicts rate of wall thinning, total amount of thinning, and remaining service life of piping components degraded by FAC.
- UT Data Analysis – allows users to import, manage, display, store, and evaluate data from ultrasonic inspection of piping components.
- FACTRAK – helps plan and manage activities associated with FAC inspections.

Benefits of using the CHECWORKS FAC application to predict FAC in nuclear and fossil plants include:

- Identifying problem areas long before a leak or rupture might occur;
- Using far fewer inspection locations than would be required with other less accurate methodologies;
- Establishing a remaining service life for non-inspected as well as inspected components;
- Optimizing water chemistry and evaluating other options to select the most cost-effective way of controlling FAC on a line-by-line basis;
- Reducing the hours needed to manage, evaluate, and store piping inspection data;
- Providing a useful tool to help manage FAC inspection activities.

The CHECWORKS FAC application user guide describes how to use FAC and provides guidelines on interpreting program results.

A number of utility companies worldwide use FAC to help predict flow-accelerated corrosion in their piping systems and assist in managing its control. Users include all U.S. nuclear utilities, many U.S. fossil plants, and utilities in Canada, the Czech Republic, Japan, Korea, Slovenia, and the Republic of China.

EPRI BUSINESS GROUP: Energy Conversion Division

CHECWORKS Cooling Water Corrosion Users Manual TR-103198-P2

DETAILS: Final Report

DATE: Sept. 1998

KEYWORDS: Cooling Water
Corrosion
Pitting
Predictive Maintenance

ABSTRACT:

Degradation of cooling water and fire protection systems in all types of power plants is a significant problem. While typically not a safety issue, they contribute to high operations and maintenance (O&M) costs and to reduced plant availability. To help plant owners reduce these costs and increase system reliability, predictive models have been developed for 14 forms of degradation that commonly affect their performance.

DISCUSSION:

A variety of mechanisms are degrading cooling water and fire protection systems of operating nuclear and fossil plants. These mechanisms include microbiologically influenced corrosion (MIC), pitting, cavitation, and galvanic corrosion. In addition, piping and heat exchangers are subject to sedimentation and fouling from several sources. Many factors make the problem difficult for even the most experienced engineer: diversity of corrosion attacks, system complexity, seasonal and operational variations, need to meet industry requirements (such as Generic Letter 89-13), federal and state water quality restrictions on effluents, and the Maintenance Rule. Work necessary to keep the system operable include inspections, cleaning, repairs and replacements of piping and equipment, coating application and maintenance, performance trending, selection and application of water treatment, and associated engineering support. Related O&M costs can be quite high. A 1990 EPRI survey found average utility company costs to be \$1.8 million per year per unit for service water system maintenance and \$280 thousand per year per unit for service water treatment costs (in 1990 dollars). O&M costs for other cooling water and fire protection systems also are high.

Analysts developed 14 degradation models to create a new application of CHECWORKS™, a software that can evaluate plant systems on a component-by-component basis. Data that users can enter into the CHECWORKS Cooling Water Corrosion (CWC) module include system geometry, materials, connection type (for example, butt weld or flanged joint), equipment types, flows, temperatures, pressures, water attributes, and water treatment. The user interface is built around an interactive re-creation of the system piping and instrumentation diagram (P&ID).

The benefits of using CHECWORKS™ CWC include the ability to:

- Focus inspections at the most vulnerable locations
- Identify system susceptibilities to avoid surprises

- Optimize inspection and cleaning schedules of heat exchangers
- Quantitatively evaluate mitigation options
- Develop a long-term replacement and repair strategy
- Store related design, operation, and inspection information on a component basis in an open database that can be filtered and sorted by user prompts
- Generate system isometrics by highlighting a portion of the P&ID.

The CWC application provides a number of benefits to nuclear and fossil plant owners. Using CWC, they can better understand susceptibilities of their cooling water and fire protection systems to a wide variety of perils, select inspection locations, evaluate mitigation options, and develop long-term repair and replacement strategies.

EPRI BUSINESS GROUP: Energy Conversion Division

CHECWORKS™ Applications Manager: User Guide TR-103198-P3

DETAILS: Final Report (62 pages)

DATE: Dec. 1997

KEYWORDS: Corrosion
Corrosion Monitoring
Predictive Maintenance
Software Tools
Maintenance
Flow-Accelerated Corrosion

ABSTRACT:

The CHECWORKS™ Application Manager is the software program that allows users to install and run corrosion-related applications and share data among them. This summary describes the individual CHECWORKS Application Manager (version 1.0D) User Guide.

DISCUSSION:

Corrosion in nuclear and fossil power plants is a significant problem, with nuclear plant availability losses related to corrosion averaging close to 5% the past decade. In addition, corrosion creates plant and personnel safety concerns. To help resolve this problem, EPRI has developed CHECWORKS (Chexal • Horowitz • Engineering • Corrosion • workstation), a software platform that includes specific software applications to address plant corrosion mechanisms. For ease of use—including a consistent “look and feel”—and greater efficiency, individual EPRI corrosion software programs are being integrated within CHECWORKS. The Application Manager software provides this integration and is the vehicle for launching individual CHECWORKS applications.

The objectives of this report is to integrate the capabilities of EPRI’s existing family of corrosion computer codes and make corrosion damage predictions easier and less costly to perform.

The Applications Manager integrates various applications using a common database and shared software libraries. It is responsible for installation and configuration of CHECWORKS software on the user’s system. It also provides security levels for all users, updates and reconfigures the user’s system when new software is issued, and performs simple diagnostic tests to ensure integrity of installed software.

The Application Manager manages and launches all CHECWORKS applications and facilitates common features, including:

- Microsoft Windows compatibility
- Installation and removal of applications
- Security access

- Printing
- Graphic image management
- Support for PC networking
- Built-in libraries of material properties, including common water additives and pipe sizes
- User-modifiable libraries

The Application Manager User Guide describes these features so that users can best use them.

Utility companies worldwide are using CHECWORKS software, including the Application Manager, to help predict corrosion in their piping systems and assist in managing its control. Users include all U.S. nuclear utilities, many U.S. fossil plants, and utilities in Canada, the Czech Republic, Japan, Korea, Slovenia, and the Republic of China.

EPRI BUSINESS GROUP: Energy Conversion Division

CHECWORKS™ Navigator User Guide TR-103198-P6

DETAILS: Final Report (34 pages)

DATE: Oct. 1998

KEYWORDS: Corrosion
Flow-Accelerated Corrosion
Computer Programs
Maintenance
Power Plant Availability

ABSTRACT:

The CHECWORKS™ Navigator is a software program that allows users to install and run corrosion-related applications. This report describes the CHECWORKS Navigator, version 1.0 and provides a user guide for the software.

DISCUSSION:

Corrosion in nuclear and fossil power plants is a significant problem. Nuclear plant availability losses related to corrosion have averaged close to 5 percent during the past decade. In addition, corrosion creates plant and personnel safety concerns. As a result, EPRI continues to invest considerable resources in corrosion-related research. Results of the research are yielding engineering models that can predict much of the corrosion behavior of operating plant equipment. Among EPRI's contributions in this area was the CHEC™ family of codes for controlling flow-accelerated corrosion (FAC). Researchers are now extending this approach to cover many other types of corrosion.

This report provides a single source of information about CHECWORKS applications and allows users to install and run CHECWORKS applications consistently.

The CHECWORKS Navigator is a browser-type program that allows users to explore all CHECWORKS applications. Its user interface provides an application selector and information window. The application selector window provides a list of CHECWORKS applications that are installed or can be obtained from EPRI. The information window displays information about the selected application and whether or not it is installed. The information window also provides help information when it is requested. The CHECWORKS Navigator allows users to:

- Install CHECWORKS applications
- Run CHECWORKS applications
- Remove CHECWORKS applications if necessary
- View information about any CHECWORKS application

The CHECWORKS Navigator user guide describes these features in detail.

The CHECWORKS Navigator represents the latest generation of CHECWORKS software. CHECWORKS software is currently being used by all U.S. nuclear utilities, many U.S. fossil plants, and utilities in Canada, the Czech Republic, Japan, Korea, Slovenia, and Taiwan to help predict damage to piping systems, and assist in managing an overall program to control such damage. EPRI expects that the CHECWORKS Navigator user guide will be used in conjunction with the CHECWORKS Navigator to help plant engineers use CHECWORKS software efficiently.

EPRI BUSINESS GROUP: Energy Conversion Division

Job Cards for Pump and Valve Maintenance: Volume 1: Development and Evaluation Joint EPRI-CRIEPI Human Factors Studies TR-103951-V1

DETAILS: Final Report (Vol.1-56 pages)

DATE: Dec. 1994

KEYWORDS: Maintenance
Pumps
Valves
Human Performance
Human Factors Engineering

ABSTRACT:

Volume 1 of this report describes the content requirements, format specifications, development procedures, and evaluation data for a set of ruggedized job cards to aid personnel in performing pump and valve maintenance. Volume 2 describes the results of a survey concerning implementation of the job cards on an industrywide basis.

DISCUSSION:

A previous EPRI-CRIEPI project identified ruggedized, hand-held information aids—job cards—as having significant potential for reducing the frequency and severity of errors associated with overhauling the main feedwater pump and other types of centrifugal pumps. Front-end analyses revealed a number of functional areas where significant errors had occurred, including improper torquing, faulty rigging, inadequate inspection, incorrect readings, and failure to meet technical standards. Maintenance workers will benefit from having ready access to concise, graphics-based information aids that supplement the governing work documents. The aim of the job cards is to provide mechanics with easily accessible, readable, and comprehensive materials to aid memory, provide general information, guide troubleshooting, supplement training, and orient workers unfamiliar with current plant practices.

The job cards were packaged in sets of 55-73 laminated, 5- by 7-inch colorized cards. The cards were organized into nine functional categories, including general maintenance, pumps, valves, rigging, troubleshooting, alignment, V-belts and sheaves, documents, and system information. Surveys of end users showed that the job cards were well accepted by most users and received high marks for usability and usefulness. Although job card content was customized for the two trial-use plants, specific feedback showed that over half of the job cards could be implemented as-is in a number of plants, whereas another one-third would require only minor changes to be used at other plants.

This project is part of a larger joint EPRI-CRIEPI research program to reduce human errors and improve productivity in U.S. and Japanese nuclear power plants. On the basis of the initial studies conducted for this joint program, interventions were identified that have significant potential for reducing errors and improving productivity. Six of these interventions were evaluated as having potentially high payoff and were selected for further investigation. Among

those selected for development were maintenance aids in the form of job cards. This report describes the development, testing, and evaluation of these cards.

EPRI BUSINESS GROUP: Energy Conversion Division

Job Cards for Pump and Valve Maintenance: Volume 2: Feasibility of Industrywide Implementation Joint EPRI-CRIEPI Human Factors Studies TR-103951-V2

DETAILS: Final Report (Vol. 2-112 pages)

DATE: Dec. 1994

KEYWORDS: Maintenance
Pumps
Valves
Human Performance
Human Factors Engineering

ABSTRACT:

Volume 2 of this report describes the results of a utility industry survey to determine the feasibility of implementing, on an industrywide basis, a set of ruggedized job cards to aid personnel in performing pump and valve maintenance. Volume 1 describes the content requirements, format specifications, development procedures, and evaluation data for the job cards.

DISCUSSION:

Job cards are durable, handheld, task-specific information aids that can be used by mechanics and other maintenance personnel while on the job. The aim of the job cards is to provide mechanics with easily accessible, readable, and comprehensive materials to aid memory, provide general information, guide troubleshooting, supplement training, and orient workers unfamiliar with current plant practices. Previously, a development project was conducted to determine the format, content, form factor, and packaging of the job cards. This work culminated in the evaluation of job card usability and usefulness at two test sites. Because the concept was well received by users at both sites, job cards represent a sufficiently mature technology to be transferred to the nuclear power industry. Volume 2 of this report documents the methods, results, and recommendations for industrywide implementation of job cards.

At the time of the survey, the job cards were packaged as 73 cards, organized into nine categories: general maintenance, pumps, valves, rigging, troubleshooting, alignment, V-belts and sheaves, documents, and system information. The survey asked respondents to answer a series of questions covering their overall assessment of the job card package (applicability to their plant), their assessment of individual cards (content and format) and card categories, and the requirements for new cards and modifications to existing cards. Responses to the survey were recorded in a booklet and subjected to statistical data processing.

The overall results of the survey were positive, with most respondents rating the job cards “positive” or better. Almost two-thirds of the job cards were deemed acceptable for use at multiple plants with no further modification, providing the basis for mass-producing generic cards. In addition, the survey identified another 8-10 cards that would be useful at other plants with some degree of customization. On the basis of the survey results, other recommendations

included (a) dropping the documents category from the set altogether; (b) exploring the identification of new job card topics in the equipment categories of snubbers; air compressors; diesel generators; as well as heating, ventilation, and air conditioning; and (c) applying the job card to two other maintenance crafts, electrical and instrumentation and control.

EPRI BUSINESS GROUP: Energy Conversion Division

Main Feedwater Pump Maintenance Guide TR-105933

DETAILS: Final Report (297 pages)

DATE: Dec. 1995

KEYWORDS: Maintenance
Pumps
Reliability Centered Maintenance
Feedwater Pumps
Power Plant Reliability

ABSTRACT:

Loss of a main feedwater pump can have severe economic impact on a nuclear or fossil-fuel power plant. The majority of forced outages or power reductions is believed to be attributed to non-design issues. Case leaks, excessive vibration, seal leaks, and lubrication system problems are shown to significantly impact feedwater pump availability. Improved maintenance practices and increased attention to these issues is critical for realizing longevity of main feedwater pumps.

DISCUSSION:

Main feedwater pumps provide the required flow and pressure to nuclear and fossil fuel feedwater systems. For over two decades, EPRI research has been undertaken to increase the reliability and operation of feedwater pumps. Plant power outages and power reductions have resulted in significant loss in plant capacity due to main feedwater pump availability. A single year's lost capacity has resulted in as high as 0.44% plant capacity factor loss in the utility industry.

This document provides a summary of main feedwater pump problems and their associated failure modes and analysis. Programs of preventive and predictive maintenance are recommended. Maintenance practices to improve pump reliability are presented.

This guide can assist in the proper maintenance and troubleshooting of main feedwater pumps. It can aid the user in establishing a maintenance program that should provide a high level of feed pump reliability while minimizing maintenance costs. The material covered in this guide can also be used for training operators and maintenance personnel in feed pump maintenance. Related EPRI research includes over two dozen publications related to this subject matter.

EPRI BUSINESS GROUP: Energy Conversion Division

A Method to Predict Cavitation and the Extent of Damage in Power Plant Piping

TR-103198-T1

TR-103109-T2

DETAILS: Final Report (Vol. T1-126 pages; Vol. T2-126 pages)

DATE: Dec. 1993

KEYWORDS: Piping Systems
Cavitation
Erosion Corrosion
Maintenance
Predictive Maintenance
Power Plant Reliability

ABSTRACT:

Cavitation erosion has been encountered in most nuclear and fossil power plants. EPRI developed a comprehensive program to understand its causes and the influence of governing parameters. This report provides a method for predicting the likelihood that cavitation will occur in piping components and its expected severity. This method can be used to evaluate candidate corrective actions.

DISCUSSION:

Cavitation erosion damage in power plant piping systems is a serious concern because it is often difficult to detect and can lead to unscheduled repairs and costly outages. With the formation and collapse of vapor bubbles, cavitation creates noise and vibration, leaving a sharp sandpaper finish that can quickly erode through the component wall.

A literature review was performed to develop a clear description of the cavitation phenomenon. Four severity levels of cavitation erosion were defined: incipient cavitation, critical cavitation, incipient damage, and choking cavitation. The predictive method selected is based on a variety of data, including flow characteristics, sound and vibration levels, and pitting rates of material specimens exposed to cavitation. These data indicate that the intensity of cavitation for each level may be represented by a third-order polynomial equation. Cavitation coefficients were developed using orifice and valve data for a baseline pressure and size. Scaling factors are provided to facilitate extrapolation to other pressures and sizes.

The method described in this report can be used to predict the onset of cavitation erosion and estimate the extent of cavitation damage in specific plant piping systems. The predictive method currently includes orifices; butterfly, globe, cone, ball, and gate valves; and bends and elbows. Other components are excluded due to the paucity of data. Because the accuracy of the method depends to a large extent on the amount of available test data, components are categorized according to three classes of reliability, with orifices having the highest rating of the components considered. Ongoing data collection will further improve the reliability of the predictive method. Tier 1 of this report discusses the cavitation phenomenon as well as EPRI's method for

predicting its onset and extent of damage. Tier 2 contains the cavitation coefficients, which will be revised and updated as new data become available.

EPRI BUSINESS GROUP: Energy Conversion Division

Water Hammer Handbook for Nuclear Plant Engineers and Operators TR-106438

DETAIL: Final Report (368 pages)

DATE: May 1996

KEYWORDS: Water Hammer
Piping System
Maintenance
Preventive Maintenance

ABSTRACT:

Water hammer events continue to be responsible for costly equipment damage and plant outages. This Water Hammer Handbook is designed to help engineers prevent, mitigate, and accommodate water hammer events. The handbook provides assessment techniques, design approaches, and operating procedures. Also included are a root cause summary and an extensive overview of nuclear plant water hammer experience on a system-by-system basis.

DISCUSSION:

Although water hammer events in nuclear power plants do not constitute a significant safety risk, their occurrence can result in equipment damage that may adversely affect plant operation. EPRI established a research project to help significantly reduce, if not eliminate, the impact of such events.

Researchers reviewed and analyzed data on 283 water hammer events that had been reported over a 20-year period in publicly available government and industry sources. Following this review, they identified seven mechanisms or operating scenarios that can lead to water hammer. They next developed a methodology, based on evidence collected from field inspections, for determining water hammer event scenarios and probable root causes. Finally, they compiled and analyzed the design and procedural changes adopted by utility companies to prevent water hammer events from recurring. This handbook was developed to provide utility personnel with a one-volume summary of the extensive material developed during the water hammer project.

This “Water Hammer Handbook” identifies actions that can be taken to prevent or decrease the likelihood of water hammer, including design approaches and operating procedures. The handbook provides guidelines for diagnosing the root causes and assessing the consequences of water hammer events on a system-by-system basis. These guidelines offer a systematic approach for conducting a water hammer investigation, describing in detail how to interpret the observed damage.

The results of this project are detailed in EPRI report NP-6766, which contains a compilation of reported events (Volume 1), a description of root causes of reported events (Volume 2), a discussion of experimental data on water hammer (Volume 3), a description and evaluation of analytical models and computer codes applicable to water hammer assessment (Volume 4), guidelines for water hammer prevention, diagnosis, and assessment (Volume 5), and a

description of plant configurations and operation procedures for systems susceptible to water hammer (Volume 6). **This handbook summarizes these results in one easy-to-use volume.** Extensive references are provided to the full six-volume set should more detailed information be required.

EPRI BUSINESS GROUP: Energy Conversion Division

NOTE:

This handbook was specifically developed for nuclear power plants and provides an extensive overview of water hammer problems experienced in these plants. These problems, however, are not different from any other power plant facility and the information in this handbook is also applicable to fossil-fuel and other industrial power plants.

**Water Hammer Prevention, Mitigation, and Accommodation: Volume 1:
Plant Water Hammer Experience
NP-6766-V1**

DETAILS: Final Report (Vol. 1-92 pages)

DATE: July 1992

KEYWORDS: Water Hammer
Piping Systems
Preventive Maintenance

ABSTRACT:

Water hammer events continue to be responsible for costly equipment damage and plant outages. This report compiles and classifies nuclear plant water hammer experience in a database format.

DISCUSSION:

Although water hammer events in power plants do not constitute a significant safety risk, their occurrence can result in equipment damage, which can adversely affect plant operation. EPRI established this research project to help significantly reduce the impact of such events, if not eliminate.

This report compiles and documents water hammer events, and classifies these events by types of plants, systems, and root causes. A database now exists that will allow a utility engineer to compare the documented problem systems with the engineer's own systems of interest and to evaluate the water hammer phenomena on a system-by-system basis.

Water hammer events still occasionally occur in power plants, sometimes causing damage to both plant components and piping systems. These events can affect plant operation and availability through forced plant outages, especially in nuclear plants. The results of completing other tasks in this project—including the determination of root causes of reported events (volume 2); the compilation of experimental data on water hammer (volume 3); the description and assessment of analytic models and computer codes applicable to water hammer assessment (volume 4); and the development of guidelines for water hammer prevention, diagnosis, and assessment (volume 5)—are reported in subsequent volumes of this report.

EPRI BUSINESS GROUP: Energy Conversion Division

Water Hammer Prevention, Mitigation, and Accommodation: Volume 2: Root Cause Analysis for Plant Water Hammer Experience NP-6766-V2

DETAILS: Final Report (Vol. 2-296 pages)

DATE: July 1992

KEYWORDS: Water Hammer
Piping System
Maintenance
Preventive Maintenance

ABSTRACT:

Water hammer events continue to be responsible for costly equipment damage and plant outages. This report describes analyses of previously reported events to determine the root causes and mechanisms of water hammer. It identifies portions of systems that are vulnerable to water hammer along with remedial actions that have been taken.

DISCUSSIONS:

Although water hammer events in power plants do not constitute a significant safety risk, their occurrence can result in equipment damage, which can adversely affect plant operation. EPRI established this research project to help significantly reduce the impact of such events, if not eliminate them.

This report examines the root causes of previously reported water hammer events, and evaluates the remedial actions that were taken.

The researchers reviewed data on 283 events that had been reported over a 20-year period in publicly available government and industry sources. The events were analyzed to determine the specific water hammer mechanism and root cause. Seven mechanisms or operating scenarios that can lead to severe water hammer were identified. The root causes were categorized as being due to errors in design, incorrect operator actions or procedures, or malfunctions in components or control systems.

An event description for each publicly reported water hammer has been produced. These events are classified by plant systems, damage severity level, physical mechanism, and remedial actions taken. On the basis of this information, areas of systems that are susceptible to water hammer have been identified.

The results of other tasks in this project are reported in the other volumes of this report. These include a compilation of reported events (volume 1); a description of experimental data on water hammer (volume 3); a description and assessment of analytic models and computer codes applicable to water hammer assessment (volume 4); guidelines for water hammer prevention, diagnosis, and assessment (volume 5); and a description of plant system configurations and operating procedures that are susceptible to water hammer (volume 6).

EPRI BUSINESS GROUP: Energy Conversion Division

Water Hammer Prevention, Mitigation, and Accommodation: Volume 3: Experimental and Engineering Data NP-6766-V3

DETAILS: Final Report (Vol. 3-304 pages)

DATE: July 1992

KEYWORDS: Water Hammer
Piping Systems
Maintenance
Diagnostics

ABSTRACT:

Water hammer events continue to be responsible for costly equipment damage and plant outages. This report describes the experimental and engineering database used to develop water hammer prevention, diagnosis, and assessment guidelines.

DISCUSSION:

Although water hammer events in power plants do not constitute a significant safety risk, their occurrence can result in equipment damage, which can adversely affect plant operation. EPRI established this research project to help significantly reduce the impact of such events, if not eliminate them.

This report compiled available experimental data suitable for the development of water hammer prevention, diagnosis, and assessment guidelines; and identifies specific areas of water hammer where experimental data are currently unavailable or insufficient.

A compilation of available experimental data, categorized by the previously identified mechanisms, has been produced. Engineering application techniques and summaries of analytic procedures are also presented.

The results of other tasks in this project are reported in the other volumes of this report. These include a compilation of reported events (volume 1); a determination of root causes of reported events (volume 2); a description of assessment of analytic models and computer codes applicable to water hammer assessment (volume 4); guidelines for water hammer prevention, diagnosis, and assessment (volume 5); and a description of plant system configurations and operating procedures that are susceptible to water hammer (volume 6). This report provides the background information necessary for the development of the guidelines that are presented in volume 5 of this report.

EPRI BUSINESS GROUP: Energy Conversion Division

**Water Hammer Prevention, Mitigation, and Accommodation: Volume 4:
Review of Analytic Models and Computer Codes Part 1: Sample Problems
and Comparisons
NP-6766-V4P1**

DETAILS: Final Report (Vol. 4-368 pages)

DATE: July 1992

KEYWORDS: Water Hammer
Piping Systems
Diagnostics
Computer Codes

ABSTRACT:

Water hammer events continue to be responsible for costly equipment damage and plant outages. This report describes a comparative study of available computer programs for transient thermofluid analysis.

DISCUSSION:

Although water hammer events in power plants do not constitute a significant safety risk, their occurrence can result in equipment damage, which can adversely affect plant operation. EPRI established this research project to help significantly reduce the impact of such events, if not eliminate them.

This report evaluates the effectiveness of several computer codes that can be used for water hammer analysis by comparing the calculated results of several benchmark problems.

Six organizations provided solutions to the benchmark problems. The codes that were used are reviewed in detail, including discussions on the adequacy of documentation, theoretical bases, and validation. The results of the benchmark calculations are also presented. All the participants analyzed the single-phase flow systems, and for these cases most codes performed well. For situations involving two-phase flow, different versions of the RELAP5 code were used with reasonable success.

The second part of this volume is a compendium of analytic models commonly used to simulate single- and two-phase transients. The results of other tasks in this project are reported in other volumes of this report. These include a compilation of reported events (volume 1); the determination of the root causes of reported events (volume 2); a description of experimental data on water hammer (volume 3); guidelines for water hammer prevention, diagnosis, and assessment (volume 5); and a description of plant system configurations and operating procedures that are susceptible to water hammer (volume 6).

EPRI BUSINESS GROUP: Energy Conversion Division

Water Hammer Prevention, Mitigation, and Accommodations: Volume 4: Review of Analytic Models and Computer Codes Part 2: Theoretical Bases NP-6766-V4P2

DETAILS: Final Report (Vol. 4-212 pages)

DATE: July 1992

KEYWORDS: Water Hammer
Piping Systems
Diagnostics
Computer Codes

ABSTRACT:

Water hammer events continue to be responsible for costly equipment damage and plant outages. This report provides an extensive review of analytic models for both single- and two-phase transient thermofluid calculations as well as structural analysis applicable to water hammer.

DISCUSSION:

Although water hammer events in power plants do not constitute a significant safety risk, their occurrence can result in equipment damage, which can adversely affect plant operation. EPRI established this research project to help significantly reduce the impact of such events, if not eliminate them.

This report compiles and reviews the thermal-hydraulic and structural models that are used for water hammer analysis.

A compendium of the theory of water hammer analysis has been produced. This will be useful to anyone wanting more background information than described in the other volumes of this report. Valve and pump data that are useful for transient flow analysis are also included.

Part 1 of this volume is a comparative study of available computer programs for transient thermofluid analysis. The results of other tasks in this project are reported in the other volumes of this report. These include a compilation of reported events (Volume 1); the determination of the root causes of reported events (Volume 2); a description of experimental data on water hammer (Volume 3); guidelines for water hammer prevention, diagnosis, and assessment (Volume 5); and a description of plant system configurations and operating procedures that are susceptible to water hammer (Volume 6).

EPRI BUSINESS GROUP: Energy Conversion Division

Water Hammer Prevention, Mitigation, and Accommodation: Volume 5
Part 1: Water Hammer Assessment Guidelines
NP-6766-V5P1

DETAILS: Final Report (Vol. 5-288 pages)

DATE: July 1992

KEYWORDS: Water Hammer
Piping Systems
Assessments
Preventive Maintenance

ABSTRACT:

Water hammer events continue to be responsible for costly equipment damage and plant outages. This report provides guidelines for assessing the consequences of these events.

DISCUSSION:

Although water hammer events in power plants do not constitute a significant safety risk, their occurrence can result in equipment damage, which can adversely affect plant operation. EPRI established this research project to help significantly reduce the impact of such events, if not eliminate them.

A set of guidelines has been developed that can be used to assess the consequences of water hammer events.

The development of guidelines for water hammer diagnosis and prevention are discussed in parts 2 and 3 of this volume. The results of other tasks in this project are reported in the other volumes of this report. These include a compilation of reported events (Volume 1); a determination of root causes of reported events (Volume 2); a description of experimental data on water hammer (Volume 3); a description and assessment of analytic models and computer codes applicable to water hammer assessment (Volume 4); and a description of plant system configurations and operating procedures that are susceptible to water hammer (Volume 6).

EPRI BUSINESS GROUP: Energy Conversion Division

Water Hammer Prevention, Mitigation, and Accommodation: Volume 5 Part 2: Water Hammer Prevention Guidelines NP-6766-V5P2

DETAILS: Final Report (Vol. 5-176 pages)

DATE: July 1992

KEYWORDS: Water Hammer
Piping Systems
Preventive Maintenance
Guidelines

ABSTRACT:

Water hammer events continue to be responsible for costly equipment damage and plant outages. This report provides guidelines for the prevention or mitigation of these events.

DISCUSSION:

Although water hammer events in power plants do not constitute a significant safety risk, their occurrence can result in equipment damage, which can adversely affect plant operation. EPRI established this research project to help significantly reduce the impact of such events, if not eliminate them.

The report presents a set of guidelines for actions that can prevent or decrease the likelihood of water hammer. The remedial actions that have previously been adopted by utility companies are grouped together for each of the seven mechanisms identified for severe water hammer and are cross-referenced to the most important systems associated with the nuclear power plant.

The development of guidelines for water hammer assessment and diagnosis are discussed in parts 1 and 3 of this volume. The results of other tasks in this project are reported in the other volumes of this report. These include a compilation of reported events (Volume 1); a determination of root causes of reported events (Volume 2); a description of experimental data on water hammer (Volume 3); a description and assessment of analytic models and computer codes applicable to water hammer assessment (Volume 4); and a description of plant system configurations and operating procedures that are susceptible to water hammer (Volume 6).

EPRI BUSINESS GROUP: Energy Conversion Division

Water Hammer Prevention, Mitigation, and Accommodation: Volume 5
Part 3: Water Hammer Diagnostic Guidelines
NP-6766-V5P3

DETAILS: Final Report (Vol. 5-84 pages)

DATE: July 1992

KEYWORDS: Water Hammer
Piping Systems
Preventive Maintenance
Diagnostics
Guidelines

ABSTRACT:

Water hammer events continue to be responsible for costly equipment and damage and plant outages. This report provides guidelines for diagnosis of the root causes of these events.

DISCUSSION:

Although water hammer events in power plants do not constitute a significant safety risk, their occurrence can result in equipment damage, which can adversely affect plant operation. EPRI established this research project to help significantly reduce the impact of such events, if not eliminate them.

A set of guidelines for diagnosis of the root causes of water hammer events has been developed. These provide a systematic, step-by-step approach for conducting a diagnostic investigation, and the guidelines show how to interpret damage observed on piping, pipe supports, and components. Once the root cause has been determined, it should be possible to eliminate the recurrence of the event through either procedural or design modifications.

The development of guidelines for water hammer assessment and prevention are discussed in parts 1 and 2 of this volume. The results of other tasks in this project are reported in other volumes. These include a compilation of reported events (Volume 1); a determination of root causes of reported events (Volume 2); a description of experimental data on water hammer (Volume 3); a description and assessment of analytic models and computer codes applicable to water hammer assessment (Volume 4); and a description of plant system configurations and operating procedures that are susceptible to water hammer (Volume 6).

EPRI BUSINESS GROUP: Energy Conversion Division

Water Hammer Prevention, Mitigation, and Accommodation NP-6766-V6

DETAILS: Final Report (Vol. 6-312 pages)

DATE: July 1992

KEYWORDS: Water Hammer
Piping Systems
Preventive Maintenance

ABSTRACT:

Water hammer events continue to be responsible for costly equipment damage and plant outages. This report identifies plant system configurations and operating procedures that are susceptible to water hammer.

DISCUSSION:

Although water hammer events in power plants do not constitute a significant safety risk, their occurrence can result in equipment damage, which can adversely affect plant operation. EPRI established this research project to help significantly reduce the impact of such events, if not eliminate them.

Areas susceptible to water hammer have been identified on a system-by-system basis. The report includes a description of the phenomena initiating water hammer and how existing procedures and designs affect the possibility of water hammer.

The results of other tasks in this project are reported in the other volumes of this report. These include a compilation of reported events (Volume 1); a determination of root causes of reported events (Volume 2); a description of experimental data on water hammer (Volume 3); a description and assessment of analytic models and computer codes applicable to water hammer assessment (Volume 4); and guidelines for water hammer prevention, diagnosis, and assessment (Volume 5).

EPRI BUSINESS GROUP: Energy Conversion Division

Recommended Cleaning Practices for Service Water Systems TR-108923

DETAILS: Final Report (130 pages)

DATE: Dec. 1997

KEYWORDS: Service Water Systems
Heat Exchangers
Piping
Chemical Cleaning
Maintenance

ABSTRACT:

This report provides recommended practices for cleaning of service water systems that can be applied to any power piping system. It is essential to know and understand the corrosion mechanism, operating history, and/or aquatic growth behavior of the system prior to selecting cleaning strategies.

DISCUSSION:

In order to optimize plant performance and availability, it is important to maintain the cleanliness of service water systems. A fouled service water system can be cleaned by chemical or mechanical means. Waste disposal must also be addressed during service water system cleaning. Utility companies must consider the myriad of Federal, State, and Local laws and regulations, permits, and record keeping governing the transport, treatment, and ultimate disposal of hazardous waste. Prior to service water system cleaning, it is imperative to know how the system is used and what its history entails.

The objective of this report is:

- To provide a compendium of recommended practices for cleaning service water systems
- To enhance a service water cleaning program by providing method selection considerations and implementation assistance
- To minimize the difficulties associated with implementing a service water cleaning program by applying the practices for process method selection and implementation

Service water cleaning practices were reviewed and used to compile a database that provides for:

- Hydrolasing
- Mechanical cleaning pipe with pigging and rotary processes
- Mechanical cleaning heat exchangers with scrapers and brushes
- Abrasive blast cleaning
- Chemical cleaning

These can be used to streamline the cleaning process. It is necessary to consider the potential cleaning methods due to the enormous costs associated with cleaning and removal of waste.

EPRI BUSINESS GROUP: Energy Conversion Division

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MISCELLANEOUS

Power Plant Electrical Reference Series, Volumes 1-16 EL-5036-V1 thru V16

Volume 1: Electric Generators; Volume 2: Power Transformers; Volume 3: Auxiliary System Planning; Volume 4: Wire and Cable; Volume 5: Grounding and Lightning Protection; Volume 6: Motors; Volume 7: Auxiliary Electrical Equipment; Volume 8: Station Protection; Volume 9: DC Distribution System; Volume 10: Electrical Control and Instrumentation; Volume 11: Cathodic Protection; Volume 12: Electric Freeze Protection and Process Heating; Volume 13: Communications; Volume 14: Electrical Noise Reduction; Volume 15: Plant Improvements and Modifications; Volume 16: Handbook to Assess the Insulation Condition of Large Rotating Machines

DETAILS: Reference Series (Vol. 1-111 pages; Vol. 2-67 pages; Vol. 3-50 pages; Vol. 4-104 pages; Vol. 5-54 pages; Vol. 6-176 pages; Vol. 7-52 pages; Vol. 8-177 pages; Vol. 9-40 pages; Vol. 10-79 pages; Vol. 11-42 pages; Vol. 12-61 pages; Vol. 13-111 pages; Vol. 14-55 pages; Vol. 15-65 pages; Vol. 16-198 pages)

DATE: Sept. 1987

KEYWORDS: Electric Power Generation
Power Plant Control
Power System Engineering
Power System Planning
Power Plant Equipment

ABSTRACT:

This comprehensive and practical guide to electric power apparatus and electrical phenomena provides an up-to-date source book for power plant managers, engineers, and operating personnel. Aiding in the recognition and prevention of potential problems, the 16-volume guide can help save staff time and reduce operating costs.

DISCUSSION:

Topical reference guides prepared by electrical manufacturers have helped handle power plant emergencies and make decisions about plant design, system planning, and preventive

maintenance. Because of budget constraints, however, manufacturers today seldom publish or update such guides.

This report provides a practical, up-to-date reference manual covering the electric power apparatus and electrical phenomena commonly encountered in U.S. power plants.

Fifteen hardcover volumes illustrated with photographs and diagrams provide guides to the selection, specification, installation, operation, testing, and maintenance of power plant equipment and systems. Focusing on a specific topic, each volume includes thorough descriptions for laymen, formulas and detailed calculations for engineers, and troubleshooting procedures for plant operators. Volume 1, *Electric Generators*, covers machine ratings, insulation and cooling, as well as requirements for auxiliary equipment. Volume 2, *Power Transformers*, describes the function and application of liquid-immersed, dry-type, and vapor-cooled equipment ranging in size from 500 kVA to 1000 MVA. Power connections between the generator and the transmission system, as well as the power supply for plant operation, are discussed in Volume 3, *Auxiliary System Planning*, and Volume 4, *Wire and Cable*, summarizes all aspects of cable-size selection to meet industry standards. Volume 5, *Grounding and Lightning Protection*, presents the relative advantages of different grounding designs and discusses the formation and characteristics of lightning strokes. Volume 6, *Motors*, highlights the importance of matching the right motor to its driven equipment and to its environment. Load-switching and fault-interrupting equipment are described in Volume 7, *Auxiliary Electrical Equipment*, which presents component benefits, drawbacks, and applications. Volume 8, *Station Protection*, is a guide to the relaying that removes equipment from the system during abnormal conditions while ensuring its availability during normal operation. Volume 9, *DC Distribution System*, discusses battery-powered systems. *Electrical Control and Instrumentation*, Volume 10, provides detailed circuit designs as well as discussions of abnormal conditions and environmental and safety considerations. In Volume 11, *Cathodic Protection*, the power plant engineer will find practical information for mitigating or eliminating corrosion. *Electric Freeze Protection and Process Heating*, Volume 12, discusses the use of heating systems to prevent the freezing of fluids and solids and to provide process temperature control for other fluids and gases. In-plant staff and signal processing are described in *Communications*, Volume 13. To cope with interference from electrical noise, which can disrupt such critical plant systems as communications, instrumentation, and protective relays. *Electrical Noise Reduction*, Volume 14, presents predictive methods and a troubleshooting guide. Volume 15, *Plant Improvements and Modifications*, includes design analysis techniques and systematic procedures for improving reliability and efficiency and for extending plant life and Volume 16, is a handbook to assess rotating machine insulation condition. A book of abstracts and topics, which serves as a guide to the entire series, is also available.

EPRI BUSINESS GROUP: Energy Conversion Division

Instrument Power Supply Tech Note TR-107044

DETAILS: Final Report (82 pages)

DATE: Dec. 1996

KEYWORDS: Instrumentation
Control Equipment
Power Supply
Predictive Maintenance
Preventive Maintenance

ABSTRACT:

Power supplies are used throughout the instrument systems of power plants. This Technical Note provides design, aging, failure, and maintenance information for these power supplies.

DISCUSSION:

Instrument power supplies are generally considered reliable and often have a long operating life. However, just like other equipment, they do age in service and might eventually fail. Plants have taken different approaches to instrument power supply maintenance, including periodic monitoring and component replacement.

This Technical Note provides an in-depth review of instrument power supply, design, aging, failure, maintenance, and troubleshooting. Different approaches to maintenance are described in sufficient detail so that the user can understand the pros and cons of each method. Electrolytic capacitors are discussed in detail because of their potential effect on power supply performance.

Instrument power supplies age in service and may ultimately wear out. Different approaches to power supply maintenance can be equally effective. The best strategy for any given case depends on the importance of the power supply, the cost of maintenance versus the benefits gained, and the consequences of power supply failure. This Technical Note provides information that will help users choose a maintenance strategy that best fits their needs.

EPRI BUSINESS GROUP: Energy Conversion Division

Battery Monitoring System (BMS): Phase 4 – Field Evaluation TR-11092

DETAILS: Final Report (84 pages)

DATE: Nov. 1998

KEYWORDS: Batteries
Energy Storage
Monitoring
Substations
Maintenance

ABSTRACT:

The need for low cost maintenance of substation battery-backed emergency power systems has motivated electric utility interest in the development of a battery monitoring system (BMS) that can automatically discover, trend, and signal degradation of all cells within a battery bank and all banks throughout a system. This report describes the final phase of development and field testing of an EPRI-sponsored BMS that tracks key cell and bank parameters and reports them on a PC workstation running under Windows™ 95/98/NT.

DISCUSSION:

Earlier research led to the invention of a number of sensors and sensing methods suited to the noninvasive corroborative sensing of vital cell condition parameters for lead-acid wet-cell batteries. This proof-of-principle work led to the development of a complete battery monitoring system and its testing at sites at three utility companies. On the basis of this experience, the BMS has been redesigned, subjected to additional field testing, and is now commercially available.

The report describes the background of the BMS development project and provides a description of the system, its capabilities, and the current specifications of its sensors. It details the changes made to reduce the cost of the system and the design specification that was used to define and guide the design of the new Windows-based user interface. A table compares the features and capabilities of the original MS-DOS version with those of the new Windows version. The report lists the locations and sizes of the field-trial banks where the new BMS is operational and discusses the results of field trials at these sites. It describes the commercialization status of the BMS for flooded, lead-acid batteries and identifies near-term markets for this product. The BMS monitors voltage, temperature, current-path integrity, bypass current, fluid level, specific gravity, and state-of-charge at the cell level. It monitors voltage, DC and AC current, and temperature at the bank level.

Transmission and generation substations require emergency power backup for monitoring and control of operations during power outages, and for timely restoration of service following the outage. In a period of increasing business pressures to maintain and/or increase customer satisfaction, reliable substation backup power is essential. At the same time, the need to trim maintenance budgets for cost competitiveness puts increasing pressure on limited maintenance personnel resources. Normal maintenance of auxiliary systems such as backup battery power

supplies may be degraded in this new environment, leading to unanticipated failures of the battery subsystem at the time it is most needed. Foreseeing the need for fully automated battery monitoring equipment which would reduce maintenance labor costs and extend battery life, EPRI and its advisors have sponsored a substantial research and development effort to provide the utility industry with a low-cost, yet effective battery monitoring system. After several years of development and prototype testing, the BMS system has been fully commercialized and is available from the developer, MCM Enterprises, Ltd., under license from EPRI. The present report documents the most recent development and field testing activities, denoted as Phase IV, which culminated in the commercial introduction of the BMS in mid-1998.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Manual of Bearing Failures and Repair in Power Plant Rotating Equipment GS-7352

DETAILS: Final Report (388 pages)

DATE: July 1991

KEYWORDS: Bearings
Rotating Machinery
Lubrication
Maintenance
Preventive Maintenance
Failure Analysis

ABSTRACT:

Bearing failures are a leading cause of unavailability for power plant rotating machinery, often resulting in prolonged forced outages and costly repairs. This manual, which assists in identifying bearing failure modes and selecting remedial actions to prevent future failures, provides guidelines for repair techniques.

DISCUSSION:

Bearing system failures, costing the utility industry an estimated \$150 million annually, are a major problem for all power plant rotating machinery. Bearing failure can cause very serious damage not only to the bearing but also to the rotor, stator, and nearby equipment. Identifying the mode of failure and possible causes is an essential element in preventing future failures.

This report identifies system-diagnosis links established for 16 different failure modes, using:

- Hundreds of photographs characterizing each failure mode
- Microscopic slides at low and high magnification
- Physical and chemical laboratory techniques for identifying the nature of the damage
- Supplementary descriptions of relevant information, such as degree of oil contamination, origin of destructive electric currents, and the presence of fatigue-inducing forces

For each failure-inducing root cause, the report specifies remedies in terms of repair of existing bearing design; bearing redesign to avoid repetition of the destructive process; and system alternatives, such as modified housings, oil delivery, and choice of lubricant. Further, the report details proper techniques for bearing refurbishment, including puddling; rebabbiting; measurement of clearances, tolerances, and alignments; and proper installation of monitoring instruments.

The visually detailed and systematic format of this manual is designed to assist engineering and maintenance personnel in diagnosing the mode of bearing failures and responding appropriately. Identifying the mode and cause of a bearing failure and often remedying the problem on site will contribute to reduced maintenance costs.

EPRI BUSINESS GROUP: Energy Conversion Division

Capacitor Application and Maintenance Guide TR-112175

DETAILS: Final Report (128 pages)

DATE: Aug. 1999

KEYWORDS: Capacitors
Predictive Maintenance
Preventive Maintenance

ABSTRACT:

Capacitors are energy storage devices that are widely used in many electronic and electrical applications. They provide filtering (blocking, isolation, and other functions) in both electronic and power circuits. Capacitor use in electronic circuit applications is second only to resistors.

DISCUSSION:

Capacitors can remain in storage for a considerable time before use. Plant personnel must have some assurances that the devices in storage will be usable or have guidance on when to remove unusable devices from inventory. Also, equipment that depends upon capacitors for proper operation can be affected by some of the same consideration used to determine capacitor capability.

Objectives of this report are:

- To review plant practices related to capacitors and equipment that relies on capacitors
- To understand what conditions affect capacitors in storage and, therefore, affect capacitor shelf life
- To understand conditions that affect capacitor performance
- To provide procurement and storage recommendations for capacitor users
- To provide maintenance recommendations related to testing and condition monitoring of capacitors in operation and in storage

This guide discusses the various types of capacitors and their general design. The stressors that affect capacitors during storage and operation are described here. There has been limited industry and regulatory guidance provided for operating and maintaining capacitors. Research and vendor recommendations appear to be geared toward predicting capacitor operating life under design conditions. Maintenance recommendations in this document are geared toward providing optimal life for capacitors in storage and reasonable availability of equipment that relies on capacitors. Aluminum electrolytic capacitors were the most widely used in the applications that concern plant personnel.

The work that has been presented by vendors and others provides a fairly conservative approach to dealing with capacitors in storage. There is extensive information related to operating life

estimation for capacitors in service. There is a missing link in that there is very little guidance provided for condition monitoring and what can be measured by plant personnel to detect impending capacitor failure. This missing link warrants investigation. A study to take both naturally aged and artificially aged capacitors, compare parameters, test capacitors until failure, and take measurements to determine if failure can be anticipated would provide the industry with valuable data. The results of a program of this nature would provide a predictive maintenance tool for capacitor users.

EPRI BUSINESS GROUP: Energy Conversion Division

Protecting Electrical Equipment From Red Imported Fire Ants TR-109987

DETAILS: Final Report (62 pages)

DATE: Jan. 1998

KEYWORDS: Insects
Fire Ants
Substations
Transformers

ABSTRACT:

A behavioral characteristic of fire ants may lead to a means to control their inhabitation of electrical equipment. Initial tests suggest that the method can prevent or reduce fire ant infestation in pad-mounted transformer cabinets.

DISCUSSION:

Fire ants have been a problem in electrical equipment since their introduction into the United States in the 1940s. By invading electrical equipment, fire ants cause short circuits and also introduce damage-causing food, soil, and debris. When their nest is in a pad-mounted transformer, the lineman opening the enclosure must deal with the ants before working on the original problem. This can lead to greatly extended outage duration. To solve the problem, EPRI, TU Electric, and Houston Lighting & Power (HL&P) have cosponsored this project.

The study found a characteristic of fire ant behavior to exploit that either reduced their vitality or encouraged the ant colony to move its nest away from the device. In initial laboratory experiments, the device successfully attracted and killed a substantial number of fire ants. Many of those that were not killed outright by the device became deranged and started attacking other ants in the colony. The device also caused ants to gaster-flag, releasing a chemical scent into the air as an alarm response. The scents increase the general level of activity in the colony, reducing the colony's long-term vitality.

In a field trial on the HL&P distribution system, results were not as conclusive as in the laboratory. In one case, ants were able to overcome the device by burying it. These field results, however, did show the device will either cause the colony to move out of the pad-mounted transformer enclosure or reduce the remaining colony's vitality.

It appears that a new method has been discovered to control fire ants. The method has been found to reduce the ants infestation of pad-mounted transformer enclosures. More tests are necessary, however, before the method is consistently proven. Tests are continuing.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Proceedings: EPRI Corrosion-Resistant Coatings Technology Workshop TR-108017

DETAILS: Proceedings (234 pages)

DATE: May 1997

KEYWORDS: Corrosion
Protective Coatings
Transformers
Electrical Equipment
Maintenance
Life Extension

ABSTRACT:

This workshop focused on corrosion problems encountered by electric utilities. The forum brought together utility company representatives, suppliers to utilities, and coating manufacturers to share information on problems encountered and to gain the perspectives of those who supply equipment and coating systems.

DISCUSSION:

Corrosion of metallic components is a major concern for electric utilities. Components include transformer tanks and other electrical equipment. In some cases, transformer tank coatings may corrode to a point where they require replacement, yet the transformer core and coil assembly remain functional. Corrosion of electrical equipment leads to increased operation and maintenance costs. Maximizing life and decreasing maintenance costs for such equipment is a paramount concern for the utility industry.

Attendees of the meeting developed recommendations for future EPRI action:

- EPRI should perform a survey of utility companies, equipment manufacturers, and coating manufacturers to establish which coatings, cathodic protection systems, and other corrosion control methods have been installed. Predicted lifetimes and other pertinent information should be sought.
- EPRI should prepare a guidelines document summarizing the state-of-the-art in tank protection methods, based on the results of this survey and a literature review. The document should include a life-cycle cost/benefit analysis for different possible scenarios and be accompanied by Windows-based software that allows the user to input his own scenario.
- Design improvements that will reduce the risk of corrosion on transformer tanks should be recommended.
- Training seminars at several USA locations.
- Methods of recording the aggressiveness of the environment at the transformer location should be developed.

- Diagnostic/predictive tools for estimating coating lifetime and for on-line monitoring of the current conditions of the coating should be developed.
- Testing of new coating systems at independent testing laboratories should be coordinated.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Error Correction Methods for Measuring Harmonics in Power Systems TR-105215

DETAILS: Final Report (188 pages)

DATE: Oct. 1995

KEYWORDS: Harmonics
Diagnostics
Over-Voltage
Voltage Control
High Voltage
Wave Form

ABSTRACT:

Using non-ideal instrumentation to measure high-voltage power waveforms results in measurement errors, which contribute to errors in waveform analysis and ultimately to unnecessary emergency actions by the protection system. The error correction algorithms described in this report account for errors arising from non-ideal instrument transformer characteristics and digitization. These algorithms can be implemented quite inexpensively on personal computers and are sufficiently generic to run on any measurement system for which there is an available software model.

DISCUSSION:

Voltage and current waveforms in a power system are subject to harmonic distortion as well as transient disturbances. The negative effects attributed to harmonics in a power network include device heating, solid-state equipment malfunction, and communication interference. Transients contribute to several negative effects in a power system, including overvoltage, heating, deterioration of insulation, low power quality, and computer relay malfunction. Because waveform distortion increases as power system complexity increases, it is very important to develop accurate measurement methods for quantifying and qualifying distortion in the power system. The work described here represents the first step toward developing methods for mitigating distortion.

For non-ideal instrument transformer errors, the correction algorithm is derived from the transformer measurements and programmed into a digital signal processor. The output of the algorithm can be configured as a reconstruction of the input waveform or as a set of Fourier coefficients for the harmonics. Testing has demonstrated that this method, which involves control theory concepts or computing the inverse of the system, significantly decreases errors in the harmonic coefficients.

For digitization error correction, digitized measurements for a time interval must first be obtained. Next, a curve-fitting algorithm is used to fit the measured data to splines or a Fourier series. This technique is then applied to the next window of data. The windows overlap by several data points so there is a continuity of the reconstructed signal, allowing error correction to be performed almost completely in real-time mode. Testing demonstrated that this method,

which involved a least squares estimate, reduced errors in a 12-bit quantizer by a factor of four. The two developed methods can be used together by first implementing the digitization error correction to reconstruct the exact waveform measurements. Next, the reconstructed measurement signal is applied to the non-ideal transformer algorithm. Testing showed that if the output tracking method is used in connection with the non-ideal transformer, then the transformer becomes insensitive to measurement noise (including digitization-generated noise). In such a case, digitization error correction is not necessary.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Power System Voltage Stability TR-103861

DETAILS: Reference Book (38 pages)

DATE: March 1994

KEYWORDS: Voltage Control
Power System Stability
Electrical Blackouts

ABSTRACT:

Voltage stability is a challenge that will predictably increase in importance because more and more utility companies are facing voltage stability-imposed limits. Several major system failures such as the Tokyo blackout in July 1987 was caused by voltage instability and collapse. Utility engineers, consultants, and university researchers have intensely studied voltage stability over the last ten to fifteen years, and hundreds of technical papers, conferences, symposiums and seminars have resulted. Furthermore, practical analysis techniques have been developed by some utilities and they are now planning and operating power systems to prevent voltage instability for credible disturbances. This book provides a comprehensive and practical explanation of voltage stability to help in planning and operation of electric power systems. It covers both transient and longer-term phenomena, presents solutions to common instability problems, and features planning and operating guidelines as well as computer methods for power flow and dynamic simulation. The book also describes actual voltage instability incidents. The nine chapters included in this book present the general aspects of electric power systems, the definition of voltage stability, transmission system reactive power compensation and control, power system loads, generation characteristics, simulation of equivalent systems, voltage stability of a large system, voltage stability with HVDC links, and power system planning and operating guidelines. It also includes appendices on notes on the per unit system, voltage stability and the power flow problem, power flow simulation methodology, dynamic analysis methods for longer-term voltage stability, equivalent system 2 data, voltage instability incidents, and an index.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

PQTB – Voltage Sag Analysis Module Version 1.0
AP-109127
CD-109127

DETAILS: Computer Code (Windows)

DATE: Dec. 1997

KEYWORDS: Power Quality
Computer Programs
Software Tools
Predictive Maintenance
Voltage Control

ABSTRACT:

The Power Quality Toolbox (PQTB) offers power quality engineers a set of specialized tools for various aspects of power quality investigations. Featuring a modular structure, the Power Quality Toolbox offers ease of use coupled with powerful analysis and calculation capabilities.

The Voltage Sag Analysis Tool allows utility companies to predict power quality performance for their customers. It greatly simplifies the engineering task of preparing these performance predictions, reducing the engineering effort from days down to minutes. It is a tool that can be used to educate their customers on power quality because performance predictions allow customers to understand:

- The expected power quality performance of the power delivery system;
- The importance of equipment immunity to power quality disturbances;
- The difficult task the utility companies face in preventing faults on hundreds of miles of exposed distribution lines;
- The need for power conditioning equipment, and information for developing economic justification for this equipment.

The Voltage Sag Analysis Tool combines existing utility industry short circuit models with line performance data to develop these predictions.

EPRI BUSINESS GROUP: Energy Delivery & Utility Division

Repair, Upgrade, and Closure of Underground Storage Tanks GS-6830

DETAILS: Final Report (92 pages)

DATE: May 1990

KEYWORDS: Storage Tanks
Waste Management
Petroleum Products
Pollution Control
Maintenance
Repair

ABSTRACT:

This report is designed to help better understand and meet federal regulations controlling the repair, upgrade, and closure of underground storage tanks. It provides a careful analysis of the new regulations and presents descriptions and cost estimates of possible methods of compliance.

DISCUSSION:

Requirements and timetables for the repair, upgrade, or closure of existing underground storage tanks are specified in federal regulations mandated by Subtitle I of the Resource Conservation and Recovery Act. Final federal regulations for the management of underground storage tanks became effective in December 1988. Tank owners are now required to equip existing tanks with overflow prevention equipment, release detection systems, and corrosion protection. Most tanks currently in operation will require retrofit to comply with these standards, and leaking tanks must either be brought up to standard or closed. This report reviews the regulations and explores options concerning the repair, upgrade, and closure of underground storage tanks that utility companies may undertake to comply with the new standards. Part one discusses repair and retrofit; part two discusses closure.

Federal regulations indicate that storage tanks must be leakproof and equipped with overflow prevention equipment, release detection systems, and corrosion protection. Repair options are limited to correcting perforations or installing internal linings—surface coating would cost 46,000-\$8000, and linings would cost \$10,000-\$12,000. Because of the new regulations, most existing storage tanks must be upgraded. Spill and overfills must be implemented; release detection systems must be provided; and adequate corrosion protection must be guaranteed for all metal components. Upgrading an existing storage tank will cost several thousand dollars or more. Options for permanent closure include removal, scrapping or disposal, and abandonment in place. Risk management decisions, which will determine costs, must be based on the tank's age, size, material of construction, and contents.

Careful planning of strategies for compliance with the regulations will minimize costs and out-of-service time for individual tanks. Information provided in this report will help design compliance strategies that optimize response to the regulations. Related EPRI research on underground storage tanks includes report CS-5261, which analyzes options for remediation of

leaking underground storage tanks, and report CS-5780, which examines monitoring devices for underground storage tanks. TANKS and QUICKTANKS, decision models consider the management of risks at underground tank sites.

EPRI BUSINESS GROUP: Environment Division

Release Detection for Underground Storage Tank Piping Systems GS-6906

DETAILS: Final Report (60 pages)

DATE: July 1990

KEYWORDS: Storage Tanks
Waste Management
Petroleum Products
Pollution Control
Leak Detection
Piping Systems

ABSTRACT:

Federal regulations require leak-detection systems on piping for underground storage tanks. This report describes the technical requirements, timetables for installation, and three types of systems that comply with the regulations.

DISCUSSION:

EPA estimates that more than half of all releases from underground storage tanks result from piping failure. Federal regulations on piping associated with underground storage tanks specify three options for leak detection: line leak detectors, line tightness testing, or external release detection. Utility companies can use the information provided on leak-detection systems to explore site-specific compliance options.

This report is a reference manual on available leak-detection systems and on federal requirements for leak detection on piping associated with underground storage tanks. Line leak detectors monitor continuously for leaks. Line tightness testing, comparatively, is not a monitoring method but confirms that a leak has occurred. It is conducted after a tank tightness test indicates a possible piping leak. Groundwater, vapor, and interstitial monitoring are external leak-detection methods used monthly to detect releases. Underground storage tank systems must comply with the release detection requirements for both pressurized and suction piping. Pressurized piping must have an automatic line leak detector that restricts or shuts off the flow of product or triggers an alarm in response to a release. Pressurized piping must also have an annual line tightness test or monthly monitoring. American-type suction piping must have a line tightness test once every three years or monthly monitoring. European-type suction piping, less commonly found in the United States, is exempt from leak-detection requirements.

Adequate leak detection will minimize risks associated with operation of underground storage tanks. The choice of appropriate techniques depends on the type of tank and piping, site-specific factors such as depth to groundwater, and cost. In report CS-5780, EPRI presented options for leak-detection systems for underground storage tanks. Information in this report will help understand the options available for leak detection on tank piping. Related EPRI research on underground storage tanks includes reports CS-5261 and GS-6830. The TANKS and

QUICKTANKS MODELS, are decision models that consider the management of risks at underground sites.

EPRI BUSINESS GROUP: Environment Division

Testing, Monitoring, and Maintenance of Aboveground Storage Tanks GS-7086

DETAILS: Final Report (120 pages)

DATE: Dec. 1990

KEYWORDS: Storage Tanks
Waste Management
Waste Disposal
Monitoring
Petroleum Products
Maintenance

ABSTRACT:

The electric utility industry uses aboveground storage tanks (ASTs) to store and transfer fuel oil, motor fuel, and other liquids. This report describes currently available methods for testing, monitoring, and maintaining ASTs.

DISCUSSION:

Although a broad federal program guides the installation, operation, and maintenance of underground storage tanks (USTs), regulations concerning ASTs are less comprehensive. New, more inclusive regulations for ASTs are being discussed by federal regulators. This report provides information to help evaluate and upgrade AST operations.

Existing federal regulatory requirements differ depending on the material being stored. If an AST containing petroleum products is located adjacent to a navigable waterway, a Spill Prevention, Control, and Countermeasures Plan may be required. Coast Guard regulations may also be applicable. Tank storage of hazardous wastes is regulated under Subtitle C of the Resource Conservation and Recovery Act. There are no directly applicable federal regulations for AST storage of hazardous materials. AST management has typically been guided by national standards-setting organizations such as the American Petroleum Institute, the American Society for Testing and Materials, Underwriters' Laboratories, and the National Fire Protection Association. Testing of ASTs assess the integrity of the tank and the likelihood of future releases. Available techniques include hammering and penetrant dye, vacuum box, ultrasonic, radiographic, acoustic emission, magnetic flux exclusion, and magnetic particle testing. Tank monitoring identifies loss of product caused by leaking. Common methods of monitoring include inventory control and tank level, sump, interstitial, vadose zone, and groundwater monitoring. Inspection and maintenance of ASTs are intended to prevent leaks. Visual inspection, preventive maintenance, and routine repairs are the principal components of an inspection and maintenance program.

Adequate testing, monitoring, and maintenance of ASTs will minimize risks associated with their operation. Choice of appropriate techniques depends on the type of tank, the material stored, site-specific factors such as depth of groundwater, and cost. Information in this report will help to understand the options available for operation of ASTs. EPRI report CS-5780 presents options

for leak-detection systems for USTs. Report GS-6906 presents options for release detection from tank piping. Related research on USTs includes Report CS-5261, which analyzes options for remediation of UST petroleum spills; Report GS-6830, which describes repair, upgrade, and closure of underground tanks; and Report GS-6700, which identifies options for cleanup of manufactured-gas plant sites. The TANKS and QUICKTANKS models are decision models that facilitate risk management at underground tank sites.

EPRI BUSINESS GROUP: Environment Division

Target:

Pulp, Paper and Forest Products

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