Fossil Materials and Repair - Program 87

Program Overview

Program Description
Today's fossil power plants increasingly are adopting market-driven operating strategies such as cycling, pushing for maximum output during peak price periods, and frequent fuel switching to take advantage of spot market opportunities. These practices can accelerate material damage in major power block components. The ability to accurately predict the remaining life of components allows for optimized maintenance and replacement strategies, increased availability, and greater profitability.

The Electric Power Research Institute’s (EPRI’s) Fossil Materials and Repair program (Program 87) provides the integrated materials selection guidance, corrosion mitigation methods, and repair and welding technologies needed to improve equipment performance, reliability, and profitability.

Research Value
Safety and availability loss due to failures are two key issues driving R&D on major fossil power plant components, especially in older plants. EPRI’s Major Component Reliability programs provide data on critical material degradation mechanisms, conduct materials and chemistry-related R&D for advanced generation technologies, and quantify the benefits of chemistry improvements. The programs help utilities balance the risks and costs of the largest, most costly equipment, and focus on using proven technologies to create solutions.

Members of the Fossil Materials and Repair program can use the R&D to:

- Increase availability through better understanding of plant materials
- Eliminate repeat failures, minimize equipment damage, and reduce outage frequency and duration by utilizing improved knowledge of damage mechanisms and life assessment methods
- Reduce failures from high- and low-temperature corrosion
- Obtain in-depth knowledge of advanced ferritic and austenitic alloys and processes used to fabricate and join these alloys
- Utilize new and advanced repair technologies
- Maximize component life by improved materials selection guidance and procurement specifications

Approach
Through a continuum of materials and repair guidelines, handbooks, technical projects, and conferences/workshops, the program helps manage and reduce the operating risks associated with material degradation and failure. Projects develop resources to estimate remaining life, assess and conduct state-of-the-art repairs, decide on replacement materials, and address costly corrosion and erosion problems faced in real-world business settings.

- Research into availability increases through improved materials performance focuses on all aspects of materials used in power production, including degradation, failure analysis, selection, component life assessment, and advancements in materials technologies. Key areas of research include materials guidelines, failure analysis guidelines, materials selection and advancements, new tools for evaluating in-service degradation of materials, and life prediction.
- Developments and repair solutions in fossil repair applications are provided to members via demonstrations, procedures, reports, conferences, and workshops. Deliverables are targeted to provide applications technologies to extend component life, reduce repair costs, improve materials performance, and reduce downtime for repair activities.
R&D of reliability of materials in corrosive, abrasive, and high-temperature operation is aimed at reducing corrosion in power plant piping, heat exchangers, boiler tubing, and other components — which costs power companies millions of dollars each year — through improved understanding of corrosion mechanisms, innovative coatings assessments, and the development of models to predict and control corrosion phenomena.

Accomplishments

EPRI’s Fossil Materials and Repair program is a proactive industry leader in all aspects of plant materials performance, repair and welding technology development, and corrosion mitigation.

- Industry leadership in addressing fabrication, installation, welding, and degradation of creep-strength-enhanced ferritic steels and advanced austenitic stainless steels
- Development of a comprehensive International Boiler Metallurgical Guideline
- Guidance on behavior and remaining life of austenitic stainless steel materials used for superheater and reheater tubing applications
- Comprehensive Steam Turbine Metallurgical Guidelines
- Welding guidelines for boiler applications and advanced ferritic and austenitic alloys
- Series of metallurgical handbooks (Grade 11, Grade 22, X20, carbon steels, and stainless steels)
- New models for assessing oxide growth and exfoliation
- New automated welding technologies for superheater and reheater repair
- Innovative solutions and new welding consumables for dissimilar metal weld damage repair

Current Year Activities

The program R&D for 2011 will focus on key member issues dealing with the application of small specimen testing, stainless tubing materials, creep-fatigue damage, improving failure analysis, dissimilar metal weld damage and repair, high-temperature weld selection, oxidation of superheaters/reheaters, and erosion/corrosion issues in steam turbine components. Specific efforts will include:

- Material database for small specimen remaining life assessments
- Effect of aging on creep-fatigue
- New handbooks
- Weld metal selection for high-temperature service
- New filler metals for creep strength enhanced ferritic steels
- Nanocoatings
- Steamside exfoliation model deployment

Estimated 2011 Program Funding

$3.0M

Program Manager

John Shingledecker, 704-595-2619, jshingledecker@epri.com
Summary of Projects

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<th>Project Number</th>
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<th>Description</th>
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<tr>
<td>P87.001</td>
<td>Availability Increases Through Improved Materials Performance</td>
<td>This project performs research on all aspects of plant material performance, including damage mechanisms, metallurgical phenomenon, failure analysis, material selection, and component life assessment.</td>
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<td>P87.002</td>
<td>Fossil Repair Applications and Welding Technology</td>
<td>Fossil Repair Applications and Welding Technology provides members with new repair technologies that are critical to owners for maintaining the plant, addressing emergency failures, reducing outage times, and reducing the risk of future damage. Research is conducted to address these needs through new innovative repair tools, new welding consumables, fabrication and installation guidance, productivity improvements in welding, and the performance of welded structures.</td>
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<tr>
<td>P87.003</td>
<td>Reliability of Materials In Corrosive, Abrasive, and High-Temperature Operation</td>
<td>This project performs research to understand the often complex corrosion and erosion issues related to plant materials. Solutions in the form of guidelines, technical reports, and coating technology are provided to program members.</td>
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**P87.001 Availability Increases Through Improved Materials Performance (058205)**

**Key Research Question**

Today's fossil power plants increasingly adopt market-driven operating strategies, such as cycling, pushing for maximum output during peak price periods, and frequent fuel switching to take advantage of spot market opportunities. These new operating modes can accelerate material damage in virtually all major power plant components, including pressure parts and rotating components. Proper selection of materials and the right operating strategy can eliminate damage while increasing plant availability and reducing repair costs. To accomplish this goal, improved understanding of damage mechanisms and material degradation is needed. The construction of new plants, mainly supercritical, is utilizing new materials where specification guidance and data on performance are required.

**Approach**

This project focuses on all aspects of materials used in power production, including materials degradation, failure analysis, material selection, component life assessment, and advances in materials technologies. Developments in this area will be integrated with repair applications developed in Project 87.002 and corrosion and oxidation damage mechanisms evaluation in Project 87.003. Key areas of research will include materials guidelines, improved understanding of failure mechanisms, failure analysis guidelines, materials selection and advancements, and material specific life prediction methodologies and data. Joint activities with Programs 63 and 65 are included to improve component life.

**Impact**

- Apply comprehensive metallurgical guidelines for both metallurgical property information and the tools to predict component life.
- Help members evaluate advanced materials entering the market and the components fabricated from them and to select optimum materials for long-term operation.
- Provide industry with tools and databases for small specimen testing to improve life assessment and understanding of in-plant material degradation.
- Work with industry leaders in addressing creep-strength-enhanced ferritic steels (Grades 91, 92, 122, 23, and 24) and advanced austenitic alloys (347HFG, Super 304H, HR3C, etc.).
- Participate in the international development of guidelines and improved methodologies for assessing creep-fatigue damage in components, the result of unit cycling and deployment of a host of new alloys.

### How to Apply Results

Members can use the research information in this project to select optimum materials for a variety of components, ranging from piping, tubing, and headers to steam turbines and discs; gain the technical basis for improving internal material procurement specifications to ensure long-term material reliability; consistently apply improved remaining-life techniques to assess component life; address advanced ferritic and austenitic alloy issues; and better understand the factors that can influence component damage and remaining life.

### 2011 Products

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<tr>
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<tr>
<td><strong>Material Database for Small-Specimen Remaining Life Assessments of Power Plant Piping:</strong> Long-term operation of power plant piping has resulted in the potential for base metal failures during continued operation. Material variability often is the key unknown in assessing the remaining life of these components. Small-specimen extraction techniques exist to remove material from serviced pipe without the need for repair. However, to apply small-specimen testing techniques, such as small punch testing (SPT) to life assessment, users need correlation databases. This project will continue the work started in 2010 to build an SPT database for chromium-molybdenum (CrMo) steels, including serviced material for improved life assessment by small specimen testing.</td>
<td>12/31/11</td>
<td>Technical Report</td>
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<td><strong>Effect of Material Aging on Creep-Fatigue - Testing and Data Evaluation:</strong> EPRI has led an international effort to standardize creep-fatigue testing and analysis, and Program 87 has assembled a database of creep-fatigue data as part of this effort. Most of the data used in creep-fatigue models is based on new materials. As baseloaded plants begin to cycle more frequently, some components that have seen significant service exposure (aging) may be subject to creep-fatigue interactions. Data and analysis of creep-fatigue in aged material is needed to understand the damage process and accurately model it. For this project, data will be obtained on serviced Grade 22 and 91 materials for the purpose of understanding the micromechanisms of damage and for modeling.</td>
<td>12/31/11</td>
<td>Technical Update</td>
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<td><strong>Failure Analysis Guide Update: Standard Practices for Investigations:</strong> A two-volume extensive failure analysis guideline for fossil power-plant components was completed by Program 87 in 2009. In 2010, work was initiated with a utility advisor team to improve this guide by producing a shorter third volume on how to conduct a failure analysis and to include a few case studies to examine how the process works. In 2011, with feedback from members, this third volume will be completed.</td>
<td>09/30/11</td>
<td>Technical Report</td>
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<td><strong>Advanced Stainless Steel Pocket Handbook:</strong> This metallurgical handbook will focus on three alloys that are now being routinely installed in superheaters and reheaters in retrofit applications and new supercritical boilers: TP347HFG, Super304H, and HR3C (TP310HCbN). This handbook will follow in the series of &quot;pocket&quot; handbooks that include carbon steel, Grade 11 and 12, and austenitic stainless steels, etc., and will be developed using EPRI's state-of-knowledge review of advanced austenitics.</td>
<td>12/31/11</td>
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**Fossil Materials and Repair - Program 87**

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<td><strong>Strain-Induced PrecipitationHardening of Stainless Steel:</strong> Precipitation of fine carbides in cold- and warm-formed stainless steels during high-temperature service has caused failures in tube bends, swages, and welded attachments. In 2009, EPRI P87 reviewed the service experience and fundamental mechanism of strain-induced precipitation hardening (SIPH), and in 2010, addressed field heat-treatment. For 2011, work will continue to understand the effect that alloy chemistry plays in SIPH and examine the relationship between laboratory data and field experience.</td>
<td>12/31/11</td>
<td>Technical Report</td>
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<td><strong>Material Guideline on Generator Rotor Forgings:</strong> Materials information on rotor forgings is scattered throughout EPRI guidelines or is not available. In this work, a singular metallurgical reference guideline will be assembled for generator forgings, including alloys, specifications, processing, and properties. Similarities and differences with low-pressure (LP) turbine forgings will be highlighted.</td>
<td>12/31/11</td>
<td>Technical Update</td>
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<td><strong>Material database for Small-Specimen Testing of Drum Materials:</strong> A project to assess the toughness and fracture toughness properties of serviced drums was completed by P87 in 2010. To develop additional tools for remaining life assessment of drums, small punch testing (SPT) will be conducted on these same materials for assessment of fracture properties.</td>
<td>12/31/11</td>
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**Future Year Products**

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<tr>
<td><strong>Application Guideline for Small Punch Data to CrMo Piping Life Assessment</strong></td>
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<td>Technical Update</td>
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<tr>
<td><strong>Effect of Material Aging on Creep-Fatigue - Micromechanism of Damage</strong></td>
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**P87.002 Fossil Repair Applications and Welding Technology (058206)**

**Key Research Question**

Reliable repair technologies are a key part of any organization’s run-repair-replacement decisions and are invaluable to power plant owners in maintaining the plant and addressing emergency failures. Repair of damage mechanisms investigated in 87.001 and corrosion evaluations from 87.003 will be key to this project. It incorporates two key topics: fossil plant repair applications (immediate repair needs) and advanced repair and welding technologies (focused on development of longer-reaching repair technologies, including improved welding consumables and improved understanding of weld performance).

**Approach**

Developments and repair solutions will be provided to members via demonstrations, procedures, reports, conferences, new products, and workshops. Deliverables include applications technologies to extend component life, reduce repair costs, improve materials performance, and reduce downtime for repair activities. Participants in this project gain direct access to EPRI’s welding, materials, and power plant repair experts, as well as the collaborative expertise of fellow program participants.
Impact

- Improve practices, equipment, and methodologies to reduce the cost and time involved in repairing and replacing superheat and reheat tubing
- Provide solutions for dissimilar metal weld (DMW) repair
- Ensure quality new plant performance by using fabrication and installation guidance when working with OEMs, vendors, and architectural engineering firms
- Apply guidelines for selecting welds and processes at high temperature
- Quantify and standardize highproductivity welding processes

How to Apply Results

Members will have access to research results on advanced repair technology through guidelines and reports, such as the Fabrication & Installation Guidelines, which can be used to specify and follow fabrication practices used by vendors and OEMs. Members are encouraged to attend the conferences on welding and repair to ensure effective technology transfer. These conferences are supplemented by workshops and technical support services as required. Members will be able to use the adaptation of existing repair technology in new applications and development of repair technologies. Newly available consumable products, such as P87 filler metal, will be made available to improve welded component performance.

2011 Products

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<td><strong>Weld Metal &amp; Process Selection Guidelines for Joints at High-Temperature Service:</strong> Selecting the proper welding consumable and welding process for joints that will operate at high temperature (in the time-dependent regime) requires considerable engineering judgment. Meeting an ASME Section IX qualification for a given joint will not guarantee adequate lifetime of plant components and in some cases may accelerate damage. This guide will illuminate these issues and provide a framework and recommendations for weld metal selection, joint design, and welding process for welds that will operate at high temperature.</td>
<td>12/31/11</td>
<td>Technical Update</td>
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<td><strong>Tempering Parameters for Grade 92:</strong> P/T92 use is increasing in plant construction, yet few data are available on properties and performance of welded joints subject to varying heat-treatments. Building on knowledge gained with P91, a heat-treatment study will be conducted on P92 base metal and welds to develop a tempering parameter correlation that can be used to ensure proper field heat-treatment of components.</td>
<td>12/31/11</td>
<td>Technical Update</td>
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<tr>
<td><strong>Creep Strength-Enhanced Ferritic Steel Weld Metal for Tempering at Low Temperatures:</strong> Post-weld heat-treatment (PWHT) is required for creep-strength-enhanced ferritic (CSEF) steels such as P/T91 and 92. Current weld consumables for these alloys require high PWHT to achieve adequate tempering. With the variability and control in field PWHT, the current PWHT temperatures are close to the lower critical transformation temperature of base metals. In 2010, Program 87 began exploring alternate filler metal compositions, which could temper at lower temperatures to reduce the risk of failures due to improper field PWHT. In 2011, selected compositions will be subjected to long-term mechanical property evaluation and demonstration tests.</td>
<td>12/31/11</td>
<td>Technical Report</td>
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<td><strong>Review of Temperbead Welding Procedures &amp; Code Rules:</strong> New temperbead welding rules in ASME Section IX may be overly conservative. In this project, the extensive history of temperbead repair in which EPRI has been involved will be reviewed and summarized. Recommendations for improved temperbead rules will be addressed.</td>
<td>12/31/11</td>
<td>Technical Update</td>
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Repair without PWHT for Thin-Section CSEF Steels: The repair of creep-strength-enhanced ferritic (CSEF) steels requires post-weld heat-treatment (PWHT), which can be difficult, costly, and time consuming. A short-term repair that did not require PWHT for CSEF steels would assist utilities in reducing the cost of unplanned outages in HRSG tubing and boiler tubing. This project will investigate the applicability of temperbead repair with gas-tungsten arc welding (GTAW) on T91, including process and filler metal selection and variables.

P87.003 Reliability of Materials In Corrosive, Abrasive, and High-Temperature Operation (058207)

Key Research Question

Corrosion in power plant piping, heat exchangers, boiler tubing, and other components costs power companies millions of dollars each year. At high temperatures, oxides growing in steam circuits control many of the failure and damage mechanisms around the plant, including remaining life, solid particle erosion, and short-term overheating. Hot corrosion attack and wastage due to erosion reduce tube life and require coatings, weld overlay, or alternate materials. Additionally, fossil power plants experience a multitude of low-temperature corrosion problems in a variety of plant systems, including raw water and pretreatment systems, cooling water, service water and fire protection systems, condensers, cooling towers, auxiliary heat exchangers, low-pressure feedwater heaters and piping, deaerators, steam turbines, electric generators, air heaters and ducts, flue gas desulfurization systems, and flue gas ducts and stack. Corrosion problems with high cost impact on the fossil power industry will receive highest priority.

Approach

This project addresses corrosion and abrasive damage at both low and high temperatures through the development of a fundamental understanding of these damage mechanisms affecting power plant materials and components. Various coatings, including nanostructured coatings, will be investigated for mitigation of both corrosion and erosion in various components. Modeling of the corrosion process and methodologies to control key industry issues such as exfoliation of stainless steel tubing will be undertaken.

Impact

- Temperature effects, as a result of an oxide scale buildup, can have an adverse affect on remaining life, and how the oxide exfoliates can determine if tube pluggage and resulting short-term overheat or turbine solid particle erosion (SPE) damage is a concern. This project will investigate new materials as they are developed and installed in power plants to understand the oxidation rate, oxide morphology, and eventual exfoliation of the oxide.
- Develop improved understanding of high-temperature erosion and corrosion in hard-facing alloys.
- Improve many aspects of power plant equipment condition, including oxidation, corrosion, and erosion resistance, with developments in nanostructured coatings.
- Minimize damage and address all metallurgical aspects of low-temperature corrosion.
How to Apply Results

Results delivered through guidelines, reports, and workshops give members a fundamental understanding of damage mechanisms affecting power plant components. Knowing how oxides exfoliate can assist in determining if tube plugging is likely and in understanding solid particle erosion of turbine blade diaphragms. The guidelines can be integrated into members’ processes and procedures to improve operations and reduce damage caused by high-temperature operations.

2011 Products

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<tr>
<td><strong>Nanostructured Coatings for Improved Oxidation and Erosion Resistance of Valve Materials:</strong> Damage in steam turbine valve stems is attributed to erosion from spalled oxides. In 2010, Program 87 initiated a project to extend the life of valve stems by developing a process to apply nanocoatings to valve stem materials, verifying the coating integrity and erosion performance, and trial-coating a valve stem. In 2011, this technology will be applied in a field trial, and performance will be monitored/evaluated.</td>
<td>12/31/11</td>
<td>Technical Report</td>
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<td><strong>Oxidation of High-Chromium Ferritic Steels:</strong> Studies have shown the thickness of steam-grown oxides, often used to evaluate metal temperature, is highly dependent on chromium (Cr) levels between 8 and 12%Cr. Sulfur, nickel, and other elements also affect the oxidation rates and scale thickness. Current oxide thickness-to-temperature calculations are generalized for all 9%Cr materials (which often contain only 8%Cr), but improved accuracy of these calculations may be obtained by adding in compositional weighting factors. This project will assess the use of composition to improve temperature prediction (and possibly exfoliation) models for 9%Cr materials by oxide thickness measurements.</td>
<td>12/31/11</td>
<td>Technical Update</td>
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<td><strong>Carburization in Superheater Tubes:</strong> A number of failures of superheater tubes (specifically stainless steels) after the installation of low-NOx burners have been attributed to carburization. In this project, the basic understanding of carburization will be reviewed, examples of field failures will be obtained with particular emphasis on low-NOx conditions, and suggestions for material solutions (where possible) will be presented.</td>
<td>12/31/11</td>
<td>Technical Update</td>
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<td><strong>Application of a Model to Predict and Control Steam-Side Exfoliation:</strong> Program 87 has developed a model to predict steam-side oxidation and exfoliation in superheater and reheater tubes dependent on material, surface modifications, and operating conditions. In 2009, this project focused on evaluating two case studies in detail. Using this knowledge, the model will be refined further, with an emphasis on an interface that meets the needs of plant engineers.</td>
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