

## **87 Fossil Materials and Repair**

### **Program Overview**

#### **Program Description**

This program provides the integrated materials selection guidance, corrosion mitigation methods, and repair techniques needed to improve equipment performance, reliability, and profitability. Through a continuum of materials and repair guidelines, handbooks, and 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.

#### **Industry Needs and Issues Addressed**

- Metallurgical guidelines and handbooks for advanced ferritic and austenitic alloys
- Procurement guidelines for supercritical applications
- Advanced repair technologies to address superheat and reheat tubing including dissimilar metal welds
- Creep-fatigue in aging and advanced plants
- Life-management tools and property data for advanced ferritic and austenitic alloys
- Corrosion in plant piping, heat exchangers, boiler tubing, and other components, which cost power companies millions of dollars each year
- Improved understanding of exfoliation and oxide growth in advanced alloys
- Coating technologies, such as nanocoatings, which can substantially reduce plant corrosion and erosion issues

#### **Impact**

- Eliminate repeat failures, minimize equipment damage, and reduce outage frequency and duration, improving plant availability
- 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
- Maximize component life

#### **Key Accomplishments**

- Industry leadership in addressing creep-strength-enhanced ferritic steels, fabrication, installation, and welding issues
- Development of comprehensive International Boiler Metallurgical Guideline
- Guidance on 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

#### **Current Year Objectives**

- Improved component assessment methods for creep-fatigue damage interaction and creep-fatigue data for Grade 91/92 alloys
- Turbine valve materials guideline
- Sampling and small specimen testing guideline for in situ properties and life assessment
- Installation of advanced nanocoatings on blades in a steam or gas turbine for service assessment

- Improved understanding of low-temperature creep crack growth in carbon steels and austenitic stainless steels.
- Update of the mechanical properties volume of the Steam Turbine Metallurgical Guideline to include more international materials

#### Industry Involvement

- Estimated 2009 funding: \$3.1M

#### Program Technical Lead

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### Summary of Projects

Project Number	Project Title	Value
P87.001	Availability Increases Through Improved Materials Performance	This project will focus on all aspects of materials used in power production including degradation, failure analysis, selection, component life assessment, and advancements in materials technologies. Four key areas of research will include materials guidelines, failure analysis guidelines, materials selection and advancements, and component life prediction.
P87.002	Fossil Repair Applications	Developments and repair solutions will be 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.
P87.003	Reliability of Materials In Corrosive, Abrasive, and High Temperature Operation	Corrosion in power plant piping, heat exchangers, boiler tubing, and other components costs power companies millions of dollars each year. Deliverables are aimed at reducing corrosion costs through improved understanding of corrosion mechanisms, innovative coatings assessments, and the development of guidelines.

### Project Descriptions

#### P87.001 Availability Increases Through Improved Materials Performance (058205)

##### Issue

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. A whole fleet of new plants, mainly supercritical, are coming on-line with a series of new materials issues.

##### Description

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, failure analysis guidelines, materials selection and advancements, and component life prediction. Many of the projects are joint activities with Programs 63 and 65.

**Value**

- Apply comprehensive metallurgical guidelines for both metallurgical property information and the tools to predict component life.
- Select optimum materials for long-term operation using materials specifications. Many advanced materials are entering the market, and utilities face decisions concerning long-term operation of components fabricated with them.
- Work with the industry leader in addressing creep-strength-enhanced ferritic steels (Grades 91, 92, 122), fabrication, installation, and welding issues.
- 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; consistently apply improved remaining-life techniques to assess component life; address P91 and advanced ferritic and austenitic alloy issues; and better understand the factors that can influence component damage and remaining life.

**2009 Products**

Product Title & Description	Planned Completion Date	Product Type
<p><b>International Steam Turbine Metallurgical Guideline—Chemistry, Manufacturing, Service Degradation, Life Assessment, and Repair--Volume 1:</b>                      A comprehensive metallurgical guideline to provide up-to-date materials information for steam turbine rotors and discs was assembled in 2004. It concentrated primarily on Westinghouse and GE equipment. In 2009, the guideline will be updated to incorporate materials information for European, Japanese, and Korean equipment. Note -- this is Volume 1 of a two-volume guideline.</p>	7/30/2009	Technical Report
<p><b>International Steam Turbine Metallurgical Guideline—Materials Property Database for HP-IP and LP Rotors, Volume 2:</b> In 2004, P87 delivered a comprehensive materials property database focused primarily on Westinghouse and GE rotors/discs. It provided property data including tensile, Charpy, fracture toughness, fatigue, creep, and crack growth data. Additional property data from Europe, Japan, and the United States will be added for 2009, to expand the database to supply utilities with properties paramount for assessing component life.</p>	12/31/2009	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<p><b>Metallurgical Handbook for Precipitation Hardened Stainless Steels:</b> This metallurgical handbook will focus specifically on precipitation hardened stainless steel alloys and will continue the series of earlier handbooks, which included the Grade 11, Grade 22, carbon steel, austenitic stainless steel, and X-20 handbooks. These volumes cover applications, standards, cross-references to other standards around the world, chemistry, physical properties, microstructure, and mechanical properties. These are produced in a handy 5-by-7 pocket size.</p>	12/31/2009	Technical Update
<p><b>Low-Temperature Crack Growth in Piping Due to Creep Brittleness:</b> One of the factors that promotes creep brittleness in steels is the presence of active elements such as As, Sn, Sb, and P at the grain boundaries. The levels of these elements is strongly influenced by the steel-making process and the scrap used during the melting process. The increased use of scrap warrants improved compositional controls over what conventionally is found in the codes governing steel chemistries. This project will identify and develop the basis for improving compositional controls and then work with the American Society for Testing and Materials (ASTM) and the American Society of Mechanical Engineers (ASME) to implement them.</p>	12/31/2009	Technical Update
<p><b>Strain-Induced Precipitation Hardening of Stainless Steels:</b> Precipitation of columbium or titanium carbides at dislocations within the metal matrix substantially increases the strain and strength of grains in stainless steel alloys at elevated temperatures. Simultaneously, grain boundaries in these alloys are weakened by the presence of tramp elements. Austenitic stainless steels that form temper-resistant precipitates (e.g., TP347) are particularly prone to this damaging affect. This project will work to define both the alloys and their relative resistance to this damage. EPRI will work with ASTM and ASME to tighten the limits on tramp elements that exacerbate this problem.</p>	12/31/2009	Technical Update
<p><b>Metallurgical Guidelines for Steam Turbine Casings, Nozzle Block Materials, Valves, Valve Stems, and Blades:</b> This project began to assemble data for assessment of aging stationary steam turbine and valve components in 2008. A metallurgical guide will be developed to assist in addressing all aspects of damage and properties for these components, to allow engineers to more easily assess component life. This project is performed in conjunction with P65.</p>	12/31/2009	Technical Report
<p><b>Improved Component Assessment Methods for Creep-Fatigue Interaction:</b> Over the last three years, EPRI has led an international program on Creep-Fatigue Interaction (TI funded). One of the goals of the program is a comprehensive guideline that walks utilities (or others) through the individual steps required to assess a component using both creep and fatigue inputs. This guideline will be used around the world as the authoritative guideline for creep-fatigue interaction issues.</p>	6/30/2010	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<b>Creep-Fatigue Properties for Grade 92 Base Metal and Weldments:</b> Little creep-fatigue property data has been developed for Grade 92 alloys, even though the alloy has been used widely throughout the world. Plant cycling and load following practices require improved knowledge of both creep and fatigue interactions. This project will begin developing supporting creep fatigue data properties for Grade 92, which will be used to better predict component life and to improve current design practices.	12/31/2009	Technical Update
<b>Procurement Guideline for Supercritical Boiler Components--Materials:</b> Many utilities are looking to build or already are building new supercritical power plants. EPRI has provided guidance on how to design and specify these plants, and as new materials enter the market, utilities need more specific materials procurement information and guidance. This project will provide a succinct guide on materials used for supercritical designs (including both boiler and steam turbine).	12/31/2009	Technical Report

#### Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<b>International Steam Turbine Metallurgical Guideline—Materials Property Database for HP-IP and LP Rotors, Volume 2</b>		Technical Report
<b>Low-Temperature Crack Growth in Piping Due to Creep Brittleness</b>		Technical Report
<b>Strain-Induced Precipitation Hardening of Stainless Steels</b>		Technical Report
<b>Creep-Fatigue Properties for Grade 92 Base Metal and Weldments</b>		Technical Report

### P87.002 Fossil Repair Applications (058206)

#### Issue

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. This project incorporates two key topics: fossil plant repair applications (immediate repair needs) and advanced repair technologies (focused on development of longer-reaching repair technologies).

#### Description

Developments and repair solutions will be provided to members via demonstrations, procedures, reports, conferences, 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.

**Value**

- Improve practices, equipment, and methodologies to reduce the cost and time involved in repairing and replacing superheat and reheat tubing.
- Ensure quality new plant performance by using fabrication and installation guidance when working with OEMs, vendors, and architectural engineering firms.
- Apply guidelines for advanced ferritic and austenitic alloys that are required for scrubber applications now and will be needed for ultrasupercritical power plants in the near future.

**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.

**2009 Products**

Product Title & Description	Planned Completion Date	Product Type
<p><b>Automated Repair of Superheat &amp; Reheat Tubing (joint with P63):</b> Work began in 2007 on a methodology to address superheat and reheat tubing repair and replacement without spreading of the tube using an “arms reach” repair method. The welding method is being developed based on an extended “arms reach” approach employed for CANada Deuterium Uranium (CANDU) reactors. In 2009, development will be completed and the equipment will be demonstrated on a superheat/reheat (SH/RH) tube removal/replacement.</p>	12/31/2009	Technical Update
<p><b>Repair Methods for Rework/Replacement of Dissimilar Metal Welds:</b> The automated equipment for repair/replacement of superheat and reheat tubing will provide an excellent platform for removal and replacement of existing dissimilar metal welds (DMW) damage. The SH/RH project has focused primarily on removal and replacement of a tube section. This project will focus on development of the machining capability to remove the DMW around 360 degrees of a tube (to within 3/16-inch of the ID surface) deep within a bundle. The “arms reach” welding technology developed in the SH/RH project will be employed to demonstrate restoration of the DMW using the new P87 filler wire.</p>	12/31/2009	Technical Update
<p><b>Fabrication &amp; Installation Guideline:</b> In 2007, a fabrication and installation guideline was initiated to provide a resource to specify and follow fabrication practices used by vendors and OEMs. It is being written from a component perspective to supply relevant data and background for both fabrication and installation practices surrounding that component.</p>	12/31/2009	Technical Report

Product Title & Description	Planned Completion Date	Product Type
<p><b>Metallurgical Sampling and Small Specimen Testing for Improved Life Assessment of Components:</b> Improved component life prediction can be readily established through small specimen testing. Methods for extracting small specimens will be demonstrated, and small specimen capabilities will be established. An assessment will be made of testing methods including subsize tensiles and Charpy impact methods, small punch for toughness, and creep impression methods. Testing methodologies will feed directly into current project activities such as drum characterization and creep-strength-enhanced ferritic steels assessment.</p>	6/30/2009	Technical Report
<p><b>Brazing Repair Technologies for Drums:</b> Brazing technology development initiated under the TI program will be transferred to P87 and demonstrated. Specifically, brazing practices have been explored for repairing drums in service. Work has included both cleaning of cracks and subsequent brazing of the crack, which eliminates the need for post-weld heat treatment of the damaged region. P87 will work with utility members to perform a field demonstration of this repair technology. A concise repair guideline will be developed to identify important issues surrounding this technology.</p>	6/30/2009	Technical Update
<p><b>Exothermic Welding Methods for Boiler Tubes:</b> Exothermic welding techniques were explored under a TI project for joining boiler tubes in 2007/08. The technology is based on exothermic welding, which has been used for decades to join railroad ties. P87 will look to extrapolate this technology for joining of boiler tubes. Key issues include exothermic welding compounds, equipment, and potential radial upset. The technology identified under the TI initiative will be transferred to the P87 program, and multiple tube joints will be completed and tested for field trials.</p>	12/31/2009	Technical Report
<p><b>Recommended Practice for Dissimilar Metal Weld Joints Involving Grade 92 and 122:</b> This project will investigate various approaches for joining dissimilar metal welds between alloys Grade 92 and 122 and advanced austenitic stainless steels. It will include identification of proper welding fillers, practices, weld joints, weld qualifications, and heat treatment issues. A concise guideline will be developed from this information.</p>	12/31/2009	Technical Update
<b>Future Year Products</b>		
Product Title & Description	Planned Completion Date	Product Type
<p><b>Internal Repair Methods for Damaged Tubes Due to FAC:</b> Repair methods will be developed to traverse along the length of a tube and perform internal repairs.</p>	2010	Technical Update
<p><b>Remote Repair of Damaged Underground Piping:</b> This project will develop welding tools and deployment capabilities for remote applications used in repair of underground piping.</p>	2010	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<b>Development of Stub Tube Weld Head:</b> Stub tube-to-header welding is commonly performed manually, often resulting in rejects. This project will develop automated technologies, which can substantially reduce reject rates.	2010	Technical Update

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

#### **Issue**

Corrosion in power plant piping, heat exchangers, boiler tubing, and other components costs power companies millions of dollars each year. 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. 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. Corrosion problems with high-cost impact in the fossil power industry will receive highest priority.

#### **Description**

This project addresses both corrosion and abrasive damage through the development of a fundamental understanding of these damage mechanisms affecting power plant components. High-temperature damage mechanisms also are being assessed, to improve operation and reduce damage at operating temperatures. Various coatings, including nanostructured coatings, will be investigated for mitigation of both corrosion and erosion in various components. Workshops on condenser tube failures and other topics are available on request.

#### **Value**

- Investigate new materials as they are developed and installed in power plants, to understand how they develop oxides, their rate of oxidation, and concerns about exfoliation of these oxides. 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. EPRI has developed a new model to help manage oxide inventory, providing direction on when oxides will exfoliate and specifically including newer alloy tube materials.
- Improve many aspects of power plant equipment condition, including oxidation, corrosion, and erosion resistance, with developments in nanostructured coatings.
- Better understand and control thick section corrosion fatigue damage in drums, which can be a life-limiting concern for plants.
- Minimize damage and address all metallurgical aspects of feedwater heater and tube corrosion with project-developed guidance.

#### **How to Apply Results**

Results delivered through guidelines, reports, workshops, and technical services 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.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
<p><b>Nanostructured Coatings for Waterwall Tubing:</b> A “state of knowledge” document was developed in 2006/07 to evaluate the potential use of nanostructured coatings for waterwall applications. This was used as a basis to secure a Department of Energy (DOE) project to begin design of specific nanostructure coating compositions and application techniques. In 2009, EPRI is scheduled to finalize laboratory corrosion testing of selected compositions. Utilities then will be asked to install test panels for service-related applications of the technology. The current project will be used to work with utilities to install the test panels and to report the results.</p>	12/31/2009	Technical Report
<p><b>Nanostructured Coatings for Turbine Blades:</b> Under support from the TI program, several nanostructured coatings have been designed to improve erosion resistance of steam and gas turbine applications. P87 and P65 will work together to coat a number of test blades and to install them first on stationary components, with the goal to eventually move them to rotating components in 2010. This project will support identification of a host site(s) and coating of several stationary components for assessment. The results will be reported as a technical update.</p>	12/31/2009	Technical Report
<p><b>Feedwater Heater Tube Manual and Metallurgical Guideline:</b> Damage in feedwater tubes is one of the more costly low-temperature corrosion issues experienced by utilities. A guideline will be developed to assess damage and metallurgical characteristics.</p>	12/31/2009	Technical Update
<p><b>Effect of Surface Modifications on Steam-side Oxidation:</b> Various surface modification techniques including peening, laser peening, and burnishing will be investigated in a laboratory environment to assess if these techniques offer improvements. Tests will be performed on at least two advanced austenitic stainless steel alloys.</p>	12/31/2009	Technical Update
<p><b>Thermal Barrier Coatings for Superheat/Reheat Pendant Tube Protection:</b> Various thermal barrier coatings (TBCs) will be assessed for superheat and reheat pendant tube protection applications. Thermal barrier coatings have been employed by the gas turbine industry for almost a decade now; these coatings operate at higher temperatures than would be used for SH/RH tubing, resulting in lives typically below 30K hours. Several TBCs will be evaluated in a laboratory to determine potential use of these alloys for SH/RH tubing applications.</p>	12/31/2010	Technical Update
<p><b>Oxidation of Advanced Fine-grained Austenitics:</b> Oxidation of advanced fine-grained austenitic alloys is a problem in many current installations. This project will assess the damage and develop predictive tools aimed at managing oxidation issues.</p>	12/31/2010	Technical Update
<p><b>Hard Coatings for Sootblower or Flyash Erosion Resistance:</b> In 2003/04, P87 investigated various hardfacing alloys for sootblower protection. This project will be an update of that work and will be more focused on coatings that may be used for sootblower and flyash erosion resistance, as opposed to welding alloys.</p>	12/31/2009	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<p><b>Coatings Development to Shed Slag:</b> Some coatings are better than others at shedding slag from boiler waterwalls. This project will investigate a series of coatings to determine their properties. A review document will provide information on existing coatings and future research that might be needed.</p>	12/31/2010	Technical Update
<p><b>High Temperature Strain Measurement Techniques for Extended Durations:</b> Several high-temperature strain gauge measurement techniques will be compared in a creep load frame, including capacitance, TML resistance gauges, Speckle, and two optical gauges (ARCMAC and DMI). The effort (initiated in 2008) will deliver a state-of-the-art review of the measurement techniques, as well as a guideline for applying them in a power plant environment.</p>	6/30/2010	Technical Update
<b>Future Year Products</b>		
Product Title & Description	Planned Completion Date	Product Type
<b>Coatings for Blade Attachments</b>	2010	Technical Update