79 Combustion Turbine (CT) and Combined-Cycle (CC) O&M

Program Overview

Program Description
This program provides comprehensive resources to address the O&M needs of conventional simple-cycle combustion turbines and advanced heavy-frame machines in simple- and combined-cycle operation. The main objectives are to manage equipment risks through root cause and engineered solutions, reduce life-cycle costs through repair technology and improved component design, and enhance overall plant operational flexibility by reducing combustor issues, mitigating cycling damage, or increasing performance. Program activities address monitoring and inspection, repair technique improvement, hot-section component life prediction, and plant O&M management tools. The model-specific design features are directly addressed in product development.

Industry Needs and Issues Addressed
- Cycling and high-temperature operations adversely affect component life and plant reliability and availability.
- Controlling the high costs associated with hot-section life cycle is critical.
- The risks associated with compressor failures, rotor cracks, and combustor dynamics need to be cost-effectively managed.
- Improved operational flexibility, such as NO_X (Dry Low-NOx [DLN]) combustor turndown and plant startup, would help plants address load demands.

Impact
- Reduce life-cycle combustion turbine/combined-cycle (CT/CC) plant operation and maintenance (O&M) costs by at least 25% without increased risks.
- Improve O&M costs through in-depth understanding of O&M issues at the model/sub-model-specific level.
- Gain objective, expert assessments of original equipment manufacturer (OEM) and independent offerings and O&M recommendations.
- Benefit from O&M experience and resources through collaborative interactions.

Key Accomplishments
- Model-specific repair guidelines for widely used 50/60-Hertz (Hz) machines
- Replacement part procurement guidelines for E- and F-Class models
- Compressor and rotor root cause analysis and O&M solutions
- Improved maintenance interval criteria for hot section components

Current Year Objectives
- New and updated repair guidelines for 50/60-Hz models
- New and updated procurement guidelines for D-, E-, and F-class models
- Root cause investigations of recurring failures and durability shortfalls
- Combustion system O&M guidelines

Industry Involvement
- Estimated 2009 funding: $3.1M

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Summary of Projects

Project Number	Project Title	Value
P79.001	Risk Management: Early Detection, Root Cause and Solutions	In-depth studies of high-risk component issues to identify root cause mechanism failures and to develop and demonstrate corrective/damage mitigation solutions.
P79.002	O&M Improvements: Life Prediction, Component Design and Repair	Model-specific repair, procurement , and damage tracking guidelines for hot-section, combustor, and compressor components.
P79.003	Operational Flexibility: Capacity, Performance, Combustion Dynamics and Emissions	Techniques for improving interrelated machine operational characteristics, such as tuning and turndown of DLN system and mitigation of cycling damage.
P79.004	Plant Productivity Support Tools & Training	O&M cost analysis software and overhaul planning tools for different models. Training courses are developed for the application of EPRI products.

Project Descriptions

P79.001 Risk Management: Early Detection, Root Cause and Solutions (067357)

Issue
The effective operation of complex, tightly integrated combustion turbines (CT) requires astute monitoring, regular inspection, understanding of the critical damage mechanisms/root causes, and engineered solutions to maintain high availability and reliability. This requirement is particularly true for advanced machines, where cascading failures can cause more than $10 million in equipment damage. These types of major equipment risks are largely not addressed by service agreements and only partially covered by insurance.

Description
This project helps members with the early detection of incipient damage and in-depth understanding of damage mechanisms and the underlying root causes driving accelerated deterioration and increased risk of outright failure. Cost -effective risk management needs to be tailored to the specific machine model and issue in the compressor, combustion system, or the hot section. The project develops and validates inspection and monitoring techniques, collects field experience, characterizes component design features, develops detailed engineering models, and evaluates damage mitigation and corrective design measures. In the compressor, work is aimed at understanding and mitigating the impacts of extensive rubbing, erosion/corrosion, deposit buildup, foreign object damage (FOD), and stall/flutter flow excitations contributing to blade and stator failures. In the combustion system, techniques to detect dry low-NO_x burner instabilities leading to fuel nozzle failure and downstream hardware damage are being developed. In the turbine hot section and rotor, material testing and design analysis are used to assess the risks from high-temperature creep/oxidation, thermo-mechanical fatigue cracking, and reduced fracture toughness of costly superalloy and CrMoV components.

Value
- Mitigate damage by using improved monitoring and inspection techniques to provide advance notice to CT owners of abnormal conditions and the opportunity to take countermeasures.
- Cost-effectively reduce the risk of high impact-failures by understanding damage mechanisms and their root causes, and adjusting maintenance accordingly.

- Develop, evaluate, and demonstrate engineered solutions, including design modifications that effectively address the root causes.

How to Apply Results
Monitoring techniques are customized to the model type and plant configuration. The plant or remotely located monitoring center installs the software with appropriate connections to the plant process data historian. Root cause failure/damage investigation reports provide the necessary technical background to define flaw size for inspection, adjust operating practices, and evaluate possible design modification. An engineered solution may require the involvement of the OEM, repair shop, or other service provider.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Compressor Dependability: Compressor blading maintenance guidelines addressing inspection and corrective actions to counter foreign object damage (FOD), corrosion and erosion pitting, and resonant frequencies threatening high-cycle fatigue failures. Extensive engineering analysis of FA compressors and the initial blade and stator stages using 450 Custom material is included.	12/31/2009	Technical Update
Rotor Cracking and Deterioration: Rotor material properties and detailed component-level damage analyses are employed to address turbine wheel rim cracking in cooling hole and blade attachments, providing guidance on critical flaw size and component modifications such as contouring and peening. For older rotors, investigations focus on the rate of material property deterioration, detectable service-induced damage, and wheel life estimations.	12/31/2009	Technical Update
Combustor Instability-Induced Failures: A diagnostic algorithm using data from a dry low-NO_x combustion dynamic monitoring system is used to detect early damage to fuel nozzles, liners, and other hardware from thermo-acoustic-driven pulsations and erratic fuel quality variations – a growing concern for international liquified natural gas (LNG) supplies. Field testing will establish the sensitivity (false alarm avoidance, degree of damage) of the diagnostic algorithm.	12/31/2009	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Advanced Instrumentation for Machine Dependability	2010	Technical Update
Component Damage and Failure Investigations	2010	Technical Update

P79.002 O&M Improvements: Life Prediction, Component Design and Repair (067358)

Issue
Combustion turbines (CT) require extensive repair and refurbishment at predetermined intervals due to very high temperature operation. Superalloy blades, vanes, and combustion hardware depend on effective repairs to achieve their stated economic life. Due to the high cost of repairs (an F-class first-

stage blade replacement can cost $2–4 million per row, for example) the need for in-depth guidance is critical. Fallout rates (i.e., for parts deemed not repairable at the prescribed strip/recoat interval) have exceeded 50% for certain high-temperature combustion turbine models, indicating a critical need for better maintenance interval criteria and hot-section design improvements. Repair service providers and aftermarket parts suppliers may offer competitive alternatives to the original equipment supplier for innovative design/repair solutions.

Description

Effective management of combustion and hot-section life-cycle costs focuses on three elements: optimizing the maintenance interval, extending service life by repair, and obtaining lower cost/longer life replacement hardware. Damage tracking guidance is based on extensive durability analyses providing objective estimations of creep, oxidation, and thermal mechanical fatigue damage to specific components locations as a function of operation. EPRI maintains and continues to expand a series of CT component repair guidelines covering combustion/hot-section hardware for 50/60-Hertz (Hz) conventional and advanced models. Currently available model-specific volumes cover:

- GE: 7B, 6B, 7FA, 9FA, 7E/EA, 9E
- Siemens-Westinghouse: W501A-D, W501D/D5A, W501F, V84.2, V94.2, V84.3A, V94.3A
- Alstom: 11N2, GT24
- Mitsubishi: M501F, M701F

A series of procurement guidelines for replacement of superalloy components provides the technical criteria for nondestructive examination, acceptable coatings, qualification/approval of master heats, dimensional conformity, manufacturing and heat treatment, metallurgical requirements, and quality assurance. Also included is repair technology development using novel welding, brazing, and geometry modifications. To facilitate the application of guidelines, EPRI routinely issues reports surveying the capabilities of repair shops and aftermarket parts suppliers.

Value

- Reduce fallout from repair cycles and possibly extend overall economic life using the damage tracking guidance to optimize maintenance intervals.
- Achieve cost savings from competent, cost-effective refurbishment services made possible by the repair guidelines.
- Lower replacement hardware costs by procuring more durable designs and competitive bidding.

How to Apply Results

Repair and procurement guidelines and related supplier capability surveys are used to support competitive bidding. The guidelines are designed to be incorporated in the company's technical specification bidding document. The repair criteria are used to safely guide refurbishment and identify key quality issues. Damage tracking guidance can used to make manual estimations of component maintenance intervals or incorporated in the plants automated monitoring system. Project information also is useful in managing long-term service agreements.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
CT Repair Guidelines: New and Updated Model-Specific Volumes: Each CT model is covered in a separate repair guideline volume. Supplemental information relating to compressor and hot-section coatings are covered in separate volumes. The 16-volume series is regularly updated and expanded to include new component features, general repair approaches, and quality assurance measures.	12/31/2009	Technical Update

Product Title & Description	Planned Completion Date	Product Type
Procurement Guidelines for Improved Components: New and Updated Model-Specific Volumes: Individual guidelines for model-specific parts (such as blades, vanes, ring segments, and select combustion hardware) detail dimensional conformity, metallurgical quality, production casting mechanical property testing, nondestructive examination, test reports and records, marking and packaging, and quality assurance. Model types addressed by the guidelines include: 6B, 7E/EA, 9E, 7FA, 9FA, V84.3A, and V94.3A.	12/31/2009	Technical Update
Repair Shop and Alternative CT Component Supplier Capabilities - Update: EPRI routinely surveys repair shop and alternative part supplier capabilities. The multi-volume report covers both North American and international repair service providers and alternative part suppliers. Topics include experience level with specific model-parts; unique component design features or repair approaches; and near-term plans for new offerings, especially related to advanced F-class models.	12/31/2009	Technical Update
Component Durability Analysis and Damage Tracking: Component durability models consist of 3-D aerothermal stress finite element modeling, which captures all the design detail including advanced cooling schemes and protective coatings. Steady-state and transient analyses, coupled with metallurgical examination of service-aged components and machine testing, provide an in-depth understanding of the governing damage mechanism and the weak-link locations. Insights from the models are used to improve repair procedures, optimize maintenance intervals, and assess design modifications.	12/31/2009	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
CT Repair Guidelines: New and Updated Model-Specific Volumes	2010	Technical Update
Procurement Guidelines for Improved Components: New and Updated Model-Specific Volumes	2010	Technical Update
Component Durability Analysis and Damage Tracking	2010	Technical Update
Repair Shop and Alternative CT Component Supplier Capabilities - Update	2010	Technical Update
Advanced Repair Development and Qualification	2010	Technical Update

P79.003 Operational Flexibility: Capacity, Performance, Combustion Dynamics and Emissions (100579)

Issue

Plants required to cycle generally suffer from accelerated degradation, reduced availability, and increased operation and maintenance (O&M) costs. The challenge in cycling combustion turbine (CT) plants lies in the interrelationship of capacity, performance, and emissions combined with high transient stresses in hot-section components. The combustion system often is the limiting factor in turndown, while thick-walled components in downstream combined-cycle (CC) equipment can slow startups. The NO_X (DLN) combustor is particularly sensitive to changes in fuel quality and ambient conditions, which is a concern for LNG global fuel supply.

Description

The project examines the impact of design limitations on various operational flexibility issues, leading to solution developments and field validation. The near-term focus is on combustor dynamics and emissions of particular concern for the DLN and conventional diffusion-flame designs using extensive water/steam injection. Techniques for monitoring damaging dynamic events and procedures for improved tuning are helping to demystify premixed combustion systems. All aspects of combustion inspection (CI) maintenance, including nozzle flowing, optimal maintenance intervals, and extended service hardware modifications, will be addressed. Other supplemental work addresses fuel impacts, such as the consequences of firing syngas or liquid fuels derived from coal or various green biosources. The project has developed extensive background information about capacity enhancement techniques, such as foggers, chillers, and evaporative coolers. Modification of the heat recovery steam generator (HRSG) and related water chemistry concerns are addressed in Program 88.

Value

- Improve O&M of conventional and dry low-NO_X combustors by using model-specific guidance.
- Understand the limitations of fuel interchangeability and possible issues with broader fuel supply sourcing.
- Boost MW production by gaining extensive background on capacity enhancement techniques.
- Improve overall operational flexibility by introducing field-validated plant modifications.

How to Apply Results

The guidelines and reports are used in conjunction with combustor inspections and improvements to system operation, such as overseeing the regularly scheduled refurbishment or adjusting fuel splits. Reports provide the necessary understanding to anticipate possible fuel impacts and methods to accommodate wider quality variations via monitoring, combustor adjustment, and equipment modifications. Reports help identify possible equipment and control modifications to enhance certain aspects of improving plant operational flexibility.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
DLN Combustor O&M Guidelines: New and Updated: Combustor tuning, monitoring, and overhaul guidelines are available for the GE DLN 1.0, 2.0, and 2.6 versions. Work continues to enhance these guidelines and add new DLN systems for other gas turbine suppliers, especially in re-flowing criteria for nozzles and other hardware. Modifications and adjustments to enhance combustor turndown while maintaining emissions and avoiding instabilities are included. This understanding of combustor behavior will be extended to adjustments needed to accommodate the impacts of wide Wobbe fuel gas such as LNG.	12/31/2009	Technical Update
Plant Operational Flexibility Modifications: Reports detail offerings and experiences in improving plant operational flexibility and documenting modifications to the CT and steam cycle. Plant modifications to improve startup time rates, stable low-load operation, part-load performance and emissions, and general equipment wear and tear are identified. Case histories and plant data establish the effectiveness of such modifications.	12/31/2009	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
DLN Combustor O&M Guidelines: New and Updated	2010	Technical Update
Plant Operational Flexibility Modifications	2010	Technical Update
Capacity Enhancements: New Techniques and Operational Impacts	2011	Technical Update
Plant Performance Degradation and Efficiency Recovery/Improvements	2011	Technical Update

P79.004 Plant Productivity Support Tools & Training (100574)

Issue

Plant managers, engineers, and operators need to continually re-examine the effectiveness of their operation and maintenance (O&M) procedures and identify areas for improvement. This includes maintenance timing, risk management, staff renewal, parts sparing, overhaul planning, and optimal budgeting. Information from outside the company often is required for effective benchmarking and to help define effective, achievable goals.

Description

This project addresses some of the key combustion turbine/combined-cycle (CT/CC) O&M concerns not covered in other parts of the program. A guidebook covering general CT O&M costs and operating practices is updated periodically. Reliability, availability, and maintenance (RAM) plant data help establish meaningful benchmarks that can be related to equipment type and plant operating mission. The INTURB CT owner's directory facilitates contacting peers to share information about model-specific reliability. A series of O&M guidelines address axial compressor performance, predictive maintenance

implementation, and selective catalytic reduction (SCR) systems. A series of software packages, called the Gas Turbine Overhaul Plan (GTOP), provide model-specific detailed disassembly, inspection, and re-assembly task breakdowns. Current GTOP models include the GE Frame 7B, 6B, 5, 7FA, 9FA; Siemens-Westinghouse W501AA-D, V84.2; and Alstom GT11N/N1, N2, 11D, with others planned. The CTCC O&M Cost Analyzer enables overall cost assessment of maintenance strategies, including service agreements, operational cost impacts, and self-maintenance options. Training courses and workshops help apply the program products.

Value

- Manage outages more effectively by using a detailed, model-specific overhaul plan with task-by-task breakdown structure.
- Benchmark and develop best practices by applying RAM data and sharing information with peers.
- Develop detailed modeling and costs for examining operational impacts and changes in maintenance strategies using the CTCC O&M Analyzer.
- Identify and troubleshoot a range of equipment problems by employing the plant equipment guidelines.

How to Apply Results

GTOP software is used directly in the outage planning process. The task database can be transferred to other popular maintenance management software. O&M guidelines are kept at the plant as a readily available reference. EPRI training improves staff general technical understanding and application of specific EPRI products. The CTCC O&M Analyzer typically requires 2–3 hours of web-based training, after which staff can evaluate specific machine life-cycle economics.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Web-Based CT Owners INTURB Directory: Annual Update: This interactive, searchable database contains information on more than 6,100 sites and 3,400 contacts worldwide to promote communications between owners and operators of gas turbines. Users can update information for their own company's sites and contacts.	12/31/2009	Technical Resource
CT/CC O&M Cost Analyzer: Updated Version: Excel spreadsheet-based software estimates the O&M costs for simple-cycle and combined-cycle plants for user-specified operating scenarios. CT model-specific maintenance costs are based on component replacement and repair costs, life estimates, and maintenance intervals. (Product shared with Program 80, Project 80.003)	12/31/2009	Software
Training Courses and Workshops for Improved O&M: Training course materials are developed to support the application of program products. The Hot Section Life Management course covers superalloy repair and coating processes combined with considerations for model-specific component features. A complementary course addresses hot-section component procurement, reviewing the design and hardware manufacturing with a form-fit-function perspective. Another course addresses combustion system overhaul and tuning procedures. Webcast training sessions also are available for the Gas Turbine Overhaul Plan and CT/CC O&M Analyzer software.	12/31/2009	Workshop, Training, or Conference

Product Title & Description	Planned Completion Date	Product Type
Gas Turbine Overhaul Plans: New and Updated: A database of approximately 300 tasks covers detailed steps in machine disassembly, inspection, and re-assembly suitable for managing a combustion inspection, hot gas path inspection, or major overhaul. Man-hours, tooling, and craft type are included in each task. The software platform is Microsoft Project, but the task database is transferable to other planning software. Maintenance procedures and inspection forms can be linked to create an overhaul record.	12/31/2009	Software

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Gas Turbine Overhaul Plan (GTOP) for Model Specific	2010	Software
Web-Based CT Owners INTURB Directory: Annual Update	2010	Technical Resource
Training Courses and Workshops for Improved O&M	2010	Workshop, Training, or Conference
Equipment O&M Guidelines: New and Updated	2010	Technical Update
CT/CC O&M Cost Analyzer: Update Version	2010	Software