PWR Steam Generator Management (QA)

Program Overview

Program Description

Many factors affect materials degradation in steam generators, including water chemistry, inspection limitations, material performance issues, and the presence of foreign objects. Greater understanding of these factors and their integrated impacts will lead to more effective tools to predict the potential for degradation and more effective inspection and mitigation techniques to identify and address degradation.

The Steam Generator Management Program (SGMP) conducts research to ensure the safe, reliable, and economic operation of steam generators in pressurized water reactor plants. Research activities target identification and mitigation of various forms of steam generator degradation, foreign object assessments, optimized operation of replacement steam generators, water chemistry, in-service inspections, and tube integrity.

Research Value

The Steam Generator Management Program drives greater consistency in managing steam generator issues across the nuclear fleet. The program develops guidance for existing issues such as degradation in steam generators with original Alloy 600 MA tubes, as well as emerging issues such as the early and reliable detection of degradation in steam generators with the more corrosion-resistant Alloys 600 TT and 690 TT tubes. SGMP participants gain access to the following:

- Guideline documents that reduce the potential for steam generator tube ruptures and forced leakage outages, which can cost an estimated $5 to $20 million per event
- Better tools for integrity assessments, reducing unnecessary examinations that can cost an estimated $1 to $2 million per plant
- Chemistry controls that can delay the onset of corrosion and mitigate steam generator fouling
- A database of worldwide steam generator information related to degradation, used to assist utilities with decisions on steam generator operation and maintenance

Approach

The Steam Generator Management Program applies an integrated approach for managing steam generator materials degradation in pressurized water reactors. The program develops guidance through improved understanding of how multiple variables impact steam generator operation and maintenance, including thermal hydraulics, water chemistry, tubing materials, inspection techniques, and tube-plugging/repair criteria.

- Coordinate industry response to unanticipated technical and regulatory issues that affect the operation of steam generators
- Develop water chemistry control techniques to minimize corrosion product transport, fouling, and corrosion damage to steam generator tubes
- Maintain steam generator degradation database to catalog industry experience with degradation mechanisms and mitigation options
- Develop faster, more accurate methods for examining steam generator tubes, plugs, tube support structures, secondary side deposits, and foreign objects
- Conduct thermal hydraulic studies to evaluate conditions in operating steam generators that could lead to tube wear, foreign object damage, flow-induced vibration damage, and reduced performance due to deposit buildup

SGMP closely collaborates with other EPRI programs, including Materials Reliability, Nondestructive Evaluation, and Chemistry, to ensure appropriate technologies and technical guidance are effectively integrated into research activities.

Accomplishments

The Electric Power Research Institute's (EPRI's) Steam Generator Management Program supports nuclear power industry efforts to minimize the potential for steam generator tube ruptures, forced leakage outages, and other steam generator integrity issues. Accomplishments include both technology development and technical support, spanning more cost-effective nondestructive evaluation techniques for steam generators to technical justification for regulatory issues.

- Developed and conducted a Steam Generator Engineer Training course and compiled companion training materials that can be incorporated into plant training programs
- Updated guideline and supporting technical documents implementing the requirements of NEI 97-06, which imposes industry requirements for a nuclear plant's steam generator program
- Conducted research in response to the fatigue issue at Cruas Nuclear Plant (France) to assess the significance of chimney region and tube support plate buildup on steam generator tube degradation
- Developed detection guidance for various types and sizes of steam generator foreign objects
- Updated the *PWR Water Chemistry Guidelines*, which define needed requirements and provide guidance in optimizing a plant's chemistry program
- Developed new applications for dispersant use beyond online addition to significantly reduce steam generator fouling: dispersant addition during steam generator wet layup as well as during the long-path recirculation cleanup of the condensate and feedwater systems just prior to plant startup
- Analyzed the impact of advanced amine use on iron transport, flow accelerated corrosion, and steam generator fouling in pressurized water reactor (PWR) secondary systems
- Developed a technical basis for modifications to water chemistry guidelines to reflect alloy-specific improvements in degradation resistance
- Conducted research on electrochemical kinetics of Ni and Pb to understand the mechanics of Pb stress corrosion cracking

Current Year Activities

Steam Generator Management Program research and development for 2011 will focus on continued development of dispersant applications; advanced inspection and inspection analysis methods; root causes of steam generator degradation; and guideline revisions related to water chemistry. Specific efforts include the following:

- Publish *PWR Primary-to-Secondary Leak Guidelines, Revision 4*
- Develop a model for assessing tube wear due to foreign objects
- Develop a technique to more rapidly perform required eddy current technique equivalencies
- Develop PC-based software to perform site-specific data analyst performance demonstrations
- Develop experience-based models that can be used to predict the rate of deposit buildup and the rate of tube corrosion under the deposits as a function of time
- Conduct performance demonstration of a circumferential primary water stress corrosion cracking data set to establish total system uncertainties for eddy current inspection techniques
- Conduct field trial of dispersant application during the long-path recirculation cleanup process
- Improve understanding of Pb stress corrosion cracking fundamentals in order to identify possible field mitigating actions

Selected reports and products may be prepared in whole or in part in accordance with the EPRI Quality Program Manual that fulfills the requirements of 10CFR50 Appendix B, 10CFR21 and ANSI N45.2-1977. Reports and products developed under the EPRI QA program will be marked and identified as such.

Estimated 2011 Program Funding

$7.4 million

Program Manager

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Summary of Projects

Project Number	Project Title	Description
P41.01.02.01	Materials Performance and Thermal Hydraulics (base)	This project conducts experiments and develops computational simulations that more accurately estimate foreign object movements and tube wear rates from steam generator foreign objects. This project also performs stress corrosion cracking tests that can be used to estimate steam generator tube degradation.
P41.01.02.02	Nondestructive Evaluation R&D (base)	This project develops tools such as software algorithms, improved inspection techniques, and database libraries to enhance the accuracy and efficiency of steam generator inspections. This project also creates realistic stress corrosion flaw samples in steam generator tubing for use in qualification of inspection techniques.
P41.01.02.03	Advanced Water Chemistry (base)	This project develops guideline documents, chemistry technologies, and predictive models to provide utility chemists with resources to optimize chemistry for safe, reliable, and long-term steam generator operation.
P41.01.02.04	Steam Generator Degradation Database (base)	EPRI has developed a web-accessible database of worldwide steam generator information, the Steam Generator Degradation Database, that is available to all EPRI members. This project maintains this database, which is essential for meeting utility information needs, with complete and accurate data, reported in a consistent manner.
P41.01.02.07	Supplemental Research and Emerging Issues (supplemental)	The products resulting from base-funded projects often lead to further research that addresses a specific issue for a subset of the original funding group. Such research may include additional capabilities for available software products, database maintenance for alternate tube repair criteria, and reviews of newly developed chemical additives. The industry also occasionally encounters operational and regulatory issues not anticipated and included in annual plans. Such emerging issues can be addressed and funded through this project.
P41.01.02.08	Structural Integrity Assessment and Nondestructive Evaluation Field Support (QA)(supplemental)	This project develops products to ensure steam generator tube integrity through thorough inspections, condition monitoring, and operational assessments. Cornerstone products include the *SG Examination Guidelines* and its qualification program, the *SG Integrity Assessment Guidelines,* the *SG Primary-to-Secondary Leakage Guidelines,* and the *SG In Situ Pressure Test Guidelines*.

Materials Performance and Thermal Hydraulics (base) (061428)

Key Research Question

Foreign objects and tube wear can threaten safe and reliable steam generator operation. An understanding of these phenomena is needed to develop predictive tools and take actions to minimize the potential for degradation that exceeds tube structural limits. Prediction tools and on-line measurement techniques also are needed to enable utilities to manage issues resulting from buildup on tube support plates. Finally, corrosion studies on steam generator tubing materials are needed to determine the effect of various steam generator environments on the rate of tube degradation and allow accurate long-term predictions on the initiation and growth of tube degradation.

Approach

This project conducts experiments and develops computational simulations that more accurately estimate foreign object movements and tube wear rates from steam generator foreign objects. Models are developed to predict tube support plate build up as a function of time. This project also performs stress corrosion cracking tests that can be used to estimate steam generator tube degradation.

Impact

- Determine maximum inspection intervals based on predictions of tube wear depths
- Provide guidance on long-term tube repair decisions and strategies
- Improve understanding of stress corrosion cracking

How to Apply Results

Plant engineers use EPRI reports to evaluate potential steam generator tube wear damage from foreign objects and wear at steam generator support structures. Plant engineers also use research results to better evaluate the potential for stress corrosion cracking in 600TT and 690TT tubes.

2011 Products

Product Title & Description	Planned Completion Date	Product Type
Steam Generator Management Program: Prediction of Tube Support Plate Build Up	12/23/11	Technical Report
Steam Generator Management Program: Conditions Causing Lead Stress Corrosion Cracking of Steam Generator Tubing	12/23/11	Technical Update

Nondestructive Evaluation R&D (base) (061427)

Key Research Question

Current inspection methods for steam generator tubes are limited in their ability to detect and size tube degradation. For utilities with replacement steam generators, inspection limitations may limit the length of the inspection interval, eliminating possible cost savings. In addition, inherent errors and inconsistencies associated with manual data analysis can potentially be eliminated through the development and qualification of automatic data analysis algorithms.

Documenting the performance of NDE techniques at different locations and for different forms of degradation requires a large variety and number of realistic flaw samples. Fabrication of laboratory-induced flaws is often needed when tubes removed from service do not provide an adequate number of realistic flaws.

Approach

Tools will be developed to improve the accuracy and efficiency of steam generator inspections. Tools may include software algorithms for automatic analysis of inspection data, a database library for documenting the performance of automatic data analysis software, procedures for determining examination technique equivalency, guidance for improved data analysis, and improved inspection techniques. This project will fabricate tube flaw samples for current and new generation steam generators. Samples of the most generic flaw types and configurations will be fabricated that replicate service-induced stress corrosion cracking.

Impact

- Potentially reduce steam generator inspection costs and duration
- Improve steam generator flaw detection and sizing accuracy to justify longer inspection intervals
- Provide realistic flaw samples to validate the performance of NDE techniques for field use

How to Apply Results

With improved flaw detection and flaw-sizing accuracy capabilities, nuclear plants could potentially justify longer operating intervals. Algorithms for automatic analysis of inspection data could be used by nondestructive evaluation vendors to improve inspection speed and accuracy during steam generator inspections. Utilities will implement inspection techniques qualified through use of flaw samples developed under this project.

2011 Products

Product Title & Description	Planned Completion Date	Product Type
Accurately Size Foreign Object Wear from the Steam Generator Tube Secondary Side: As a result of a feasibility study, develop a technique to accurately size foreign object wear from the secondary side of the steam generator. A prototype will be developed and tested during this phase of the project.	04/01/11	Technical Report
Evaluation of NRC/ANL Data Analysis Algorithms: Algorithms for analysis of steam generator tube eddy current data developed by Argonne Laboratories will be evaluated for potential enhancement to AutoAnalysis algorithms.	03/31/11	Technical Report
Development of AutoAnalysis Algorithms for SG Tubing: AutoAnalysis algorithms for steam generator tubing eddy current testing will be developed for enhanced detection of degradation. Algorithms will be available for implementation in commercial automated analysis software products.	04/30/11	Software
Steam Generator Eddy Current Simulation Tool Ver. 3: Develop an accurate computational model for simulating signals representing steam generator eddy current degradation and incorporate the model into a user friendly software tool.	03/30/11	Software
Fabrication of Steam Generator Tubing Samples	12/31/11	Technical Report

Advanced Water Chemistry (base) (052334)

Key Research Question

Corrosion product transport into steam generators can foul tube surfaces and create crevice environments for the concentration of corrosive impurities. Improved water chemistry control can minimize this transport mechanism, leading to reduced fouling and corrosion damage within the steam generators.

Approach

Secondary and primary water chemistry guidelines are developed and periodically reviewed and revised as needed to reflect technology developments and industry experience. Advanced technology developments are incorporated in application sourcebooks, which provide assistance to plant chemists on water chemistry control, including improved amines, dispersant, molar ratio control, and intergranular stress corrosion cracking inhibition (boric acid and TiO_2 addition). The influence of amines and dispersants on corrosion product deposition and removal from steam generators will be investigated, as well as the role of lead in stress corrosion cracking.

Impact

- Industry guidance in primary chemistry, secondary chemistry, steam generator lay-up, and hideout return
- Continued assessment of dispersant application to mitigate steam generator fouling
- Improved understanding of high-temperature lead chemistry as a means to develop remedial strategies against lead-induced stress corrosion cracking

How to Apply Results

Plant chemists incorporate EPRI chemistry guidance into plant operating procedures to minimize steam generator tube corrosion and steam generator tube fouling. In addition, plant chemists will review the results of EPRI studies on various additives for controlling steam generator tube corrosion and fouling to assess application at their plants.

2011 Products

Product Title & Description	Planned Completion Date	Product Type
Development of Predictive Models for Deposit Accumulation and Corrosion on the Secondary Side of Steam Generators: Experience-based empirical models can predict the probable rates of deposit accumulation and tube corrosion at support intersections and at top of tubesheet areas of steam generators. This project will build on completed work on a quantitative model characterizing line contact support plate fouling, which was funded by the Electric Power Research Institute (EPRI) Technology Innovation program.	06/30/11	Technical Report
MULTEQ Database Update: MULTEQ is the leading tool for understanding the primary and secondary chemistry environment. The MULTEQ database is continually reviewed and revised by a select committee of experts. This project will provide the latest update and improvements to the MULTEQ database.	12/30/11	Technical Update
Evaluation of Additives for Inhibiting PbSCC: The objective of this work is to identify possible field remedial actions that can be implemented to mitigate lead stress corrosion cracking (PbSCC). Electrochemistry will be used to evaluate the effectiveness of additives that slow plating kinetics and precipitate Pb in removing Pb from solution.	12/30/11	Technical Report
PWR Monitoring and Assessment: This product will investigate and identify correlations between chemistry parameters and operating experiences, including benchmarking. In addition, it will provide supporting information to strengthen and improve the technical guidance documented in the Electric Power Research Institute (EPRI) pressurized water reactor (PWR) water chemistry guidelines.	12/30/11	Technical Update

Steam Generator Degradation Database (base) (052592)

Key Research Question

Utility management and steam generator engineers can make more effective operational and maintenance decisions if fully informed by industry steam generator operating experience. A common source of up-to-date and easily retrieved steam generator information, including degradation mechanisms, can provide this capability.

Approach

EPRI has developed a web-accessible database of worldwide steam generator information, the Steam Generator Degradation Database (SGDD), that is available to all EPRI members. This project maintains this database, which is essential for meeting utility information needs, with complete and accurate data, reported in a consistent manner.

Impact

SGDD helps to ensure the safe and reliable operation of steam generators by providing data to plant engineers to help in determining inspection scope, planning for tube repair activities, and determining the effectiveness of various steam generator corrective action programs (for example, chemical cleaning).

How to Apply Results

Steam Generator Database information assists plant engineers in preparing various steam generator assessment documents. Steam generator experience is essential in determining if negative industry events could occur at a plant and in planning for potential events that affect steam generator safety or operation.

2011 Products

Product Title & Description	Planned Completion Date	Product Type
Steam Generator Degradation Database, Version 7.1	12/23/11	Software

Supplemental Research and Emerging Issues (supplemental) (058768)

Key Research Question

Research is often needed to address issues of interest to a smaller subset of utility steam generator operators or to address emerging issues that require urgent attention.

The products resulting from base-funded projects sometimes lead to further research that addresses a specific issue applicable to only certain nuclear plants; concurrently, not all steam generator operational and regulatory issues can be anticipated and included in annual plans. Flexibility is needed within the steam generator research scope to respond to these issues, which could include development of additional capabilities for software products, databases to support alternate tube repair criteria, and reviews of newly developed chemical additives.

Approach

Projects without generic application to all steam generator owners can be pursued through this project, which enables individual utilities or multiple utilities to define and fund targeted research efforts. For example, EPRI software codes have been developed to assess the thermal hydraulic conditions present in steam generators and to determine the rate of tube wear from both steam generator support structures and foreign objects. These codes are maintained and updated based on input from a user group that captures lessons learned and improvement ideas.

This project also manages an Emerging Issues fund to address unanticipated and emerging issues of high priority throughout the year. The Steam Generator Management Program (SGMP) Integration Committee evaluates and determines candidate emerging issues to be addressed by this fund.

Impact

- Address plant-specific research needs and generic emerging issues in a timely manner
- Address research needs of interest to a subset of utilities
- Eliminate or reduce impact of emerging issues on ongoing or planned projects

How to Apply Results

Information will be distributed to SGMP members via information letters, interim guidance, technical reports, and workshops. For targeted research projects, results will be provided to those companies funding the work. The method of applying the research would depend on the specific product.

Structural Integrity Assessment and Nondestructive Evaluation Field Support (QA) (supplemental) (061426)

Key Research Question

Nuclear plant owners and operators maintain steam generator programs to resolve current and near-term engineering, regulatory, and inspection issues. A principal concern is steam generator tube integrity. Other issues of concern include divider plate cracking, the detection and sizing of tube wear caused by foreign objects, improved leak rate modeling, and inspection system uncertainties for all degradation mechanisms.

Approach

This project develops products to ensure steam generator tube integrity through thorough inspections, condition monitoring, and operational assessments. Cornerstone products include the *SG Examination Guidelines* and its qualification program, the *SG Integrity Assessment Guidelines,* the *SG Primary-to-Secondary Leakage Guidelines,* and the *SG In Situ Pressure Test Guidelines*.

Impact

- Minimize the potential for steam generator tube ruptures and forced leakage outages, which can cost $5 to $20 million per event
- Develop better tools for integrity assessments, which can reduce unnecessary examinations costing $1 to $2 million per plant

How to Apply Results

Results are detailed in the SGMP guidelines, whose implementation is mandated by industry initiatives such as NEI 97-06 and NEI 03-08. Members use this information to develop in-house procedures in compliance with Technical Specifications and NEI 97-06 requirements.

2011 Products

Product Title & Description	Planned Completion Date	Product Type
Rev. 4 of In Situ Pressure Test Guidelines: Guideline document that provides requirements for performing in situ pressure testing of steam generator tubes. This document is a required guideline for implementation of NEI 97-06.	07/31/11	Technical Report
Rev. 8 of SG Examination Guidelines: Guideline document that supports requirements of NEI 97-06 and NEI 03-08 for nondestructive evaluation of steam generator tubing.	12/23/11	Technical Report
Steam Generator Management Program: Steam Generator Secondary Side Corrosion	09/30/11	Technical Report
Steam Generator Management Program: Onset of Fatigue Cracking	12/23/11	Technical Report
Steam Generator Management Program: PWR Primary-to-Secondary Leak Guidelines, Revision 4	12/23/11	Technical Report