DARLINGTON STEAM GENERATOR LIFE ASSURANCE PROGRAM*

by

Eric Jelinski, Ontario Hydro - Darlington Nuclear Generating Station

Mike Dymarski, Ontario Hydro - Darlington Nuclear generating Station

Carmina Maruska, Ontario Hydro - Nuclear Technology Services

Eric Cartar, Ontario Hydro - Nuclear Technology Services

CA9800475

ABSTRACT

The Darlington Nuclear Generating Station belonging to Ontario Hydro is one of the most modern and advanced nuclear generating stations in the world. Four reactor units each generate 881 net MW, enough to provide power to a major city, and representing approximately 20% of the Ontario grid. The nuclear generating capacity in Ontario represents approximately 60% of the grid.

In order to look after this major asset, many proactive preventative and predictive maintenance programs are being put in place. The steam generators are a major component in any power plant. World wide experience shows that nuclear steam generators require specialized attention to ensure reliable operation over the station life.

This paper describes the Darlington steam generator life assurance program in terms of degradation identification, monitoring and management. The requirements for chemistry control, surveillance of process parameters, surveillance of inspection parameters, and the integration of preventative and predictive maintenance programs such as water lancing, chemical cleaning, RIHT monitoring, and other diagnostics to enhance our understanding of life management issues are identified and discussed.

We conclude that we have advanced proactive activities to avoid and to minimize many of the problems affecting other steam generators. An effective steam generator maintenance program must expand the knowledge horizon to understand life limiting processes and to analyze and synthesize observations with theory.

INTRODUCTION

World wide utility experience with steam generator performance has been less than satisfactory for the majority of utilities. The Darlington Nuclear Power Generating station is a four unit station with units placed in service in the year 1990, 1992, and 1993. The expected station life is 40 years. Recognizing that the steam generators are a major capital component of a nuclear electric generating unit, Darlington staff prepared a steam generator life management strategy aimed at achieving a 40 year steam generator life.

The process of preparing a life assurance plan required an understanding of the design, the fabrication, the installation, and the operation and maintenance activities. . The evaluation of the degradation mechanisms, inspection and repair techniques revealed areas where proactive work was required. A benefit / cost evaluation of options has identified life management activities that are considered most worthwhile.

DESIGN FEATURES

The Darlington steam generators are the largest built for any CANDU unit. There are 4 steam generators in each of the four units on site. The key design features include:

- Vertical inverted U-tube heat exchangers with integral preheater,
- I-800 tubes, 5/8" OD, 4663 tubes per steam generator,
- tube/tubesheet joint is hydraulically expanded,

* Prepared for the CNS International Conference on Candu Maintenance

- 410 SS lattice bars tube supports,
- 410 SS flat bars and arch bars in U-bend (this support is a new design for CANDU),
- All ferrous secondary side system.

DEGRADATION MECHANISMS

We have analyzed the degradation mechanisms and determined that the major vulnerable areas that may impact on long term reliable performance are:

- Water chemistry on the secondary side. This is the single most important aspect of boiler life assurance based on industry experience with limits to steam generator life.
- Loss of heat transfer performance due to tube fouling resulting in an increase of the Reactor Inlet Header temperature approaching limits of operation. This is unique to CANDU. Deterioration of the divider plate may also be a significant contributor to increasing RIHT.
- Tube pitting and stress corrosion cracking, and intergranular attack are a function of chemistry and tube materials.
- Fretting and fatigue induced by high flows.
- Primary divider plate integrity and leakage concerns.

Contributing factors to each of the degradation mechanisms are deposits on: tubes, tube supports, and the tubesheet that result in degradation mechanisms: stress corrosion cracking, intergranular attack, pitting, and corrosion fatigue. Contaminants such as lead, sulfur, chlorides, copper, sodium, silica must be minimized. Air ingress must be minimized. Oxygen must be low, but not to low to avoid erosion-corrosion. It is also noted that the I-800 alloy tubing is vulnerable in highly caustic or acidic crevice conditions.

MANAGEMENT ACTIONS

The management and staff at Darlington recognize that deliberate proactive actions are necessary by individuals dedicated to the life management strategy to ensure strategic activities are completed as scheduled.

The first step is to render a corporate cultural change recognizing the importance of a long term proactive maintenance program to enable the formation of a team who have responsibility to champion steam generator equipment performance and integrity. This includes the responsibility to budget a program, to identify a strategy, a 10 year plan, a one year plan and outage-specific plans for steam generator work. This required a clear assignment of responsibilities for specific activities, procedures, tools and training developed ahead of time.

Feedback of results and evaluation of future courses of action closes the loop in terms of comparing "as found" to the expected. This identifies the need for any course correction or further evaluation of the strategy.

PREVENTATIVE ACTIONS

Our analysis and characterization of the degradation mechanisms for I-800 in the aggressive environments indicates that we must take a variety of proactive preventative measures aimed at two main areas: reduction of deposits and control of impurities.

These measures include high AVT (all volatile treatment) with high hydrazine chemistry using hydrazine and ammonia. The implementation of programs to reduce condensate oxygen at all times; and, to rapidly search and repair condenser leaks even if impurity levels are below specs.

We also intend to have corrosion product transport (CPT) monitoring. We currently have monitors in Unit 2. It is planned to have CPT's in all Units.

We review the Chemical Control Laboratory results and operating conditions daily of the feed water / steam cycle and the water treatment plant.

During outages we apply hot soaks and maintain a good lay-up chemistry. On start-up we drain and flush each steam generator and have a power hold at 30% to maximize impurity removal.

We have also initiated programs to remove components and materials bearing lead and copper alloys from systems tied to the secondary side.

PREDICTIVE AND MONITORING ACTIONS

The predictive and monitoring actions is a large work program having the following elements:

- Enhanced tube bundle inspection program using, visual, eddy current and other NDE techniques. Both the primary side and secondary sides are inspected. Sludge build up is quantified to the best extent possible.
- Tube removals for analysis of deposits, metallurgy and any other phenomenon.
- Chemical environment monitoring: hideout return studies, wet lay-up monitoring, deposit analysis.
- We have measured the downcomer flow in one steam generator. and compared results with model predictions.
- We have started a comprehensive monitoring program of process parameters.

CORRECTIVE/MODIFICATION ACTIONS

In the area of corrective actions we have started a program of waterlancing all steam generators each unit on a four year cycle. The timing for chemical cleaning is being evaluated.

Modifications have been made to reduce the oxygen levels in the condensate by relocating the condensate make-up water connection.

Copper heat exchanger coils have been replaced by all ferrous heat exchangers in the building heating system. The building heating system is another potential source of impurities capable of causing steam generator problems.

We also purchased maintenance tools consisting of a fully automated waterlancing system, welded tube and tubesheet plugs and mechanical plugs and automated equipment for installing plugs. Mockups simulating the steam generator secondary and primary side configurations have been purchased for training purposes.

The following table puts our steam generator life assurance actions into perspective.

RECENT EXPERIENCE

The Darlington Unit 4 steam generators were inspected and cleaned in the 1995 spring outage. Inspection results showed the boilers were relatively clean and free of deposits (consistent with good chemistry operation). Outage activities included visual inspection and waterlancing of the tubesheets on 4 boilers. One boiler was subjected to a U-bend visual inspection, bobbin probe eddy current inspection on 445 tubes, specialized probe inspection on 25 tubes, primary and secondary side tube removals, and welded and mechanical plugging of tube ends. The activities of waterlancing, tube removals and tube plugging, and use of some specialized inspection probes were first-time applications and field demonstrations of recently developed capabilities. The experience gained this year will permit refine-

Degradation Modes	Preventive Methods	Predictive Methods	Corrective/Modification Methods
Loss of Heat Transfer Performance	Good Chemistry Performance	Comprehensive RIHT Monitoring Program ID/OD Deposit measurements	Chemical Cleaning Divider Plate Repair
Tube Pitting	Good Chemistry Performance	Non Destructive Examination - Eddy Current - Chemical environment monitoring	Tube Plugging
Tube Stress Corrosion Cracking/Intergranular Attack	Good Chemistry Performance	- NDE , (bobbin and advanced probes) - Metallography - Chemical environment monitoring	Tube Plugging
Tube /Support Fretting	Improved Design FIV Analysis	NDE - E/C and Visual	Tube Plugging
Tube Fatigue	As above	NDE - Specialized E/C probes	Tube Plugging
Divider Plate Problems		Visual	Repair
Deposits - Tubesheet - Lattice Bars - U-bend - Tube surfaces	Good Chemistry Performance - reduction of oxygen levels - lay-up chemistry	CPT Monitoring Downcomer flow UT measurements Deposit build-up measurements	Water Lancing Chemical Cleaning
Impurities /Contaminants	Good Chemistry Performance - hot soaks - lay-up chemistry - drain/flush Material Control	Chemical environment monitoring On-line Monitoring Daily review of results	Quick response to problems: e.g.: Water Treatment Plant, Condenser leaks, Modifications to secondary side system, Lead and copper reduction programs

ment of the procedures and tools to ensure their availability for future planned (and unplanned) boiler outage work.

The results of laboratory metallurgical assessment of the tubes removed from Darlington Unit 4 this year are interesting. For example, there is evidence of tube surface rubbing at some tube supports. It is difficult to say whether this is a concern, as there is no comparable data for tubes removed so early in a steam generator's life (i.e. after approximately 1.5 years of service). Future outage plans will include inspections focusing on this phenomenon.

SUMMARY AND CONCLUSIONS

We believe that we have a thoroughly reviewed steam generator life assurance program. We have the benefit of knowledge from older CANDU units, and also the benefit from the knowledge of world-wide experience.

The operation and maintenance of steam generators must be controlled to a very narrow operating regime in order to ensure that degradation is either minimized or managed for a power plant to be viable.

We recognize that a full and complete understanding of the operating regime can not be guaranteed, therefore it is necessary to ensure that we are constantly expanding our knowledge horizon to understand life limiting processes by analyzing and synthesizing observations with theory, understanding the synergistic effects, understanding limitations of inspections and analysis, reviewing other's experience, continuously validating the strategy in order to maintain the program

DARLINGTON STEAM GENERATOR LIFE ASSURANCE

EPRI Steam Generator
Strategic Management Workshop
St. Louis, Missouri
May 10 - 12, 1995

E. Jelinski, Ontario Hydro
C. Maruska, Ontario Hydro

Purpose

1) To ensure that Darlington Steam Generators will operate for the 40 year station life. To be achieved by implementing a proactive maintenance program.
2) To avoid surprises!

This presentation will be divided into three parts:

I - What we have!

- Brief description of the design features of Darlington steam generators

II - What can go wrong!

- List of the degradation mechanisms that could affect Darlington steam generators

III - What we can do about it!

- Management actions
- Preventive actions
- Predictive and Monitoring actions
- Corrective and Modification actions

We will place emphasis in this talk on the success achieved to date for each of these actions and how this has influenced future actions.

Design features of Darlington steam generators

- Vertical inverted U-tube heat exchangers with integral preheater (steam generators are large for CANDU)
- 4 Steam Generators per unit (4 units on site)
- I-800 tubes, 5/8" OD, 4663 tubes per SG
- Hydraulically expanded tube/tubesheet joint
- 410 SS lattice bars tube supports
- 410 SS flat bars and arch bars in U-bend (this support is a new design for CANDU)
- All ferrous secondary side system

Degradation Mechanisms

- Loss of heat transfer performance (in CANDU this results in an increase of the Reactor Inlet Header (RIH) temperature)
- Tube pitting
- Tube SCC/IGA
- Tube/ support fretting
- Tube fatigue
- Primary divider plate integrity and leakage concerns

Degradation Mechanisms - Main Contributing Factors

- Deposits on: tubes, tube supports, tubesheet
- Contaminants: lead, sulphur (specially reduced species), chlorides
- Oxidizing species: oxygen, copper
- I-800 is specially vulnerable in highly caustic or acidic crevice conditions

Management Actions

- Creation of group at Darlington to champion steam generator equipment performance and integrity
- Clear assignment of responsibilities
- Corporate/station culture change

- Procedures, tools and personnel training developed ahead of time
- Feedback of results and evaluation of future course of action

Preventive Actions: Reduction of Deposits

- High hydrazine chemistry (hydrazine/ammonia)
- Implementation of programs to reduce condensate oxygen (long and short term and ongoing)
- Implementation of programs to rapidly search and fix condenser leaks (even if impurity levels are below specs.)
- Corrosion Product Transport (CPT) monitoring (monitors are currently being commissioned in Unit 2)

Preventive Actions: Control of Impurities

- Chemical Control - Lab results and operating conditions reviewed daily
- Hot soaks
- Good lay-up chemistry
- Drain/flush steam generator on start-up
- Hold point (30% power) on start-up to maximize impurity removal
- Lead and copper reduction programs
- Ongoing improvement WTP performance
- Characterization of critical degradation mechanisms and aggressive environments for DNGS I-800 tubing

Predictive/Monitoring Actions

- Enhanced tube bundle inspection program: NDE inspections, tube removals for metallurgical analysis, comprehensive secondary side visual inspections, FIV bar gap measurements
- Chemical environment monitoring: hideout return studies, wet lay-up monitoring, deposit analysis
- Steam generator deposit build-up measurements
- Downcomer flow UT measurements
- Comprehensive RIH temperature monitoring program

Corrective/Modification Actions

- Tubesheet waterlancing currently being planned every four years
- Evaluation of chemical cleaning (timing and method for RIHT concerns)
- Modifications of secondary side system to reduce condensate oxygen levels (e.g. relocation of condensate make-up water connection, make-up water deoxygenation)
- Conversion of secondary side HX (building heating) to ferrous to eliminate copper

Purchase of maintenance tools ~ $4 million

Darlington NGS Continuous Improvement Program

Expand knowledge horizon to understand life limiting processes

- Analyze and synthesize observations with theory
- Understand synergistic effects
- Understand limitations of NDE and Metallurgical analysis
- Review other's experience
- Continuously validate strategy
- Continuously improve the program

Summary of Life Assurance Actions			
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Tube Stress Corrosion Cracking/Intergranular Attack	Good Chemistry Performance	NDE - E/C (bobbin and advanced probes) - Metallography Chemical environment monitoring	Tube Plugging
Tube /Support Fretting	Improved Design FIV Analysis	NDE - E/C and Visual	Tube Plugging
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Impurities /Contaminants	Good Chemistry Performance - hot soaks - lay-up chemistry - drain/flush Material Control	Chemical environment monitoring On-line Monitoring Daily review of results	Quick response and fixing of problems e.g.: - Condenser leaks - WTP Modifications to secondary side system Lead and copper reduction programs