LIFE CYCLE MANAGEMENT (LCM) PLANNING FOR MAIN CONDENSERS AND ISOLATION VALVES

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ABSTRACT

Life Cycle Management (LCM) planning is intended to provide an effective long-term planning tool with which to minimize unplanned capability loss and optimize maintenance programs and capital investment consistent with plant safety and an identified plant operating strategy. Such an operating strategy might include license renewal or retaining the option for license renewal. An LCM Plan addresses such issues as aging management, preventive maintenance, technical obsolescence, and the replacement or redesign of a system, structure, or component (SSC) important to safety and plant operation. In short, LCM Planning is viewed as a viable process with which to systematically identify and examine important SSCs; optimize their contribution to plant safety, reliability, availability and value; and prepare long-term maintenance management plans for them.

In 1998, EPRI initiated the development of a new LCM planning process in cooperation with two utilities, Northern States Power Company and Duke Power Company. The first phase of the EPRI project established a methodology to systematically evaluate SSCs for the purposes of LCM planning, generated an SSC selection process, and developed software tools for LCM planning. It also successfully validated the software tools by demonstrating the process for three selected systems at each of two plants.

The second phase of this EPRI LCM planning demonstration program has the objective of applying the LCM planning process and tools developed in the first phase of the project to three selected SSCs at each of two additional plants, the VC Summer Station and the Wolf Creek Nuclear Power Plant.

This paper provides a brief discussion of the applied process and results in terms of evaluated alternative plans and optimum LCM plan for one example SSC for each of the two plants.

INTRODUCTION

Life cycle management (LCM) is the process by which nuclear power plants integrate operations, maintenance, engineering, regulatory, environmental, and economic planning activities in a manner that (1) manages aging and obsolescence, (2) optimizes operating life (including the options of early retirement and license renewal), and (3) maximizes the return on investment while maintaining plant safety. In January of 2001, EPRI published Report number 1000806 "Demonstration of Life Cycle Management Planning for Systems, Structures, and Components -- with Pilot Applications at Oconee and Prairie Island Nuclear Stations" [1]. This EPRI report includes a detailed description of an LCM planning process (including an SSC screening/selection process) and summaries of the six LCM plans developed for the two plants. In the next phase of the LCM planning project, two additional utilities, South Carolina Electric and Gas and Wolf Creek Operating Company participated. Each selected three systems for LCM planning. The six pilot SSCs are the Main Condenser, Chilled Water and Radiation Monitoring Systems for VC Summer and the Reactor Protection System, Emergency Diesel Generators and the Main Steam and Feedwater Isolation Valves for Wolf Creek. This paper describes the applied process, the results of LCM planning for the Main Condenser at VC Summer and the Isolation Valves at Wolf Creek.

LCM PLANNING PROCESS OVERVIEW

In order to facilitate a better understanding of the LCM planning process, the methodology described in detail in the EPRI report [1] and applied to the demonstration LCM plans is summarized here.

Following the screening and final selection of the candidate SSCs, the LCM planning technical evaluation begins, consisting of the following basic steps:

- ☐ Compiling and reviewing the plant operating and performance history for the SSC
- ☐ Compiling and reviewing the industry operating and performance history for the SSC
- ☐ Compiling and reviewing the current maintenance plan for the SSC
- ☐ Performing an aging, obsolescence and performance assessment

- Identifying candidate LCM approaches compatible with plant operating life strategies:
  - No changes to the current maintenance plan
  - Make design changes or modifications
  - Designate the component as run-to-failure
  - Optimize the current maintenance plan
  - Replace or refurbish parts or components
- Specifying alternative LCM plans
- Obtain/develop failure rate and cost data for the alternative LCM plans
- Assess performance and cost of alternative LCM plans
- Select optimum LCM plan alternative for the SSC

For the two LCM planning demonstration examples, the applied process steps are illustrated, along with the lessons learned and discussion of the plant specific information sources, databases and personnel interviews that led to the successful conclusion of the project.

LCM PLAN FOR THE MAIN CONDENSER AT VC SUMMER

The main condenser was determined to be an important candidate for LCM planning because of concerns for the continued performance margin, reliability and the potential consequence of on-line failures in view of the planned license renewal for the plant. While the main condenser has been performing well since initial operation, a power uprate project, the preventive plugging of perimeter tubes and recent evidence of excessive fouling and increasing tube leakage have affected the performance margin.

The condenser tubes are stainless steel. Other components such as the shells, tube sheets, water boxes and cross-around pipe consist of carbon steel. The tubes are staked to reduce vibration and deflection and the tube-to-tubesheet connection is a double grooved and rolled joint. The tubes are sloped to permit draining and the waterboxes are removable from one end to facilitate condenser re-tubing. Table 1 summarizes the principal design and performance data for the condenser. The critical components of the condenser for LCM planning consist of the pressure boundary shell, the hotwell, the tubes and tube sheets, the water boxes, the turbine neck expansion joints (dog bones) and the cross-around pipe. A failure of these components likely will lead to a forced plant shutdown or a significant power reduction.

Table 1. Main Condenser Principal Design and Performance Data

Manufacturer:	Southwestern Engineering (now Thermal Eng.)
Type:	2-pass, split flow, 4 water boxes
Size:	30’-2” wide x 44’- 2 1/2” long
No. of Tubes:	46,300
Tube Material:	Stainless, A249-304
Tube Size and Wall:	1 1/8” OD x 0.028” wall x 44’- 21/2” long
Tube Sheet Material:	A-285-C carbon steel
Tube Sheet Thickness:	1 ¼”, 1.135” diameter tube holes
Tube Attachment:	Rolled-double groove
Tube Supports, Spacers:	Supports are spaced at 2’-9” to 3’-1”, 5/8”wall
Condenser Shell Wall Material:	A-285-C carbon steel
Condenser Shell Wall Thickness:	5/8”
Shell Bottom Wall Thickness:	5/8”
Corrosion Allowance:	None, ¼” on tube sheet
Shell Coatings, Inside-outside:	None inside, heavy yellow coating outside
Water Boxes Shell and Bottom T:	5/8” shell, 1” bottom
Rated MWth:	2,775 MWth, 2,910 MWth uprated
Circulating Water Flow:	538,416 gpm maximum with 3 pumps
Inlet-Outlet Temperature (maximum):	88° F Inlet, 25 °ΔT, 113° Outlet max
Delta T at 100%:	25° F (25.8° measured)

Compiling and reviewing the plant operating and performance history for the Main Condenser

Even though the condenser is not safety related, the operating history of the condenser is very well documented and includes written records of past events, root cause determinations, “Engineers Technical Work Records”, Abnormal Condition or Event Evaluations, Engineering Information Requests as well as the Work Orders. From the review of these documents, a fairly concise summary of important operating and maintenance events could be constructed. The principal events and degradation causes and a work order review are summarized below:

☐ **Fouling**

The cooling water for the condenser is drawn from the lake and discharged in a once-through cycle. At full power, the flow velocity in the tubes is maintained at around 7.0 feet per second. At this velocity, silt, algae, macro-fouling and MIC are unlikely to flourish in the tubes. Organic fouling, however, has been experienced and the plant has installed an "Amertap" on-line ball cleaning system to maintain cleanliness inside the tubes. In the past, mechanical scrapers and brushes have been used to clean the tubes during refueling, causing scoring of the inside tube surfaces. For the last three refueling outages, the plant switched to a less damaging cleaning process, utilizing hydrolasing with a high-pressure water jet of filtered lake water.

On the secondary side, the plant is maintaining feedwater chemistry to keep the steam generators and the condenser tube external surfaces clean. Inspections have verified that the secondary side condenser internals (tubes OD, tube sheets, condenser walls) are clean and there are no signs of erosion, vibration damage or corrosion.

☐ **Insulation Failure**

The two low-pressure feedwater heaters located in each of the two condenser necks are insulated with stainless steel sheet metal to protect the heaters from direct steam impingement. The banding and riveting holding the insulation in place has failed on several occasions and panels have torn loose. Failed parts propelled by the steam exiting the turbine have impacted the exposed tube bundle. As a result, several tubes have been damaged, including complete severance of some. As a precautionary measure, the top two rows of tubes as well as the outer perimeter row have been plugged (approximately 1,310 tubes). Additionally, a total of 180 tubes have been plugged during the last three outages as a result of tube leakage or wall thickness reduction below 60%. This amounts at present to a total of 1,490 plugged tubes or 3.22 percent of the 46,300 tubes.

☐ **Tube Leaks**

Some tube leaks occurred while the plant was operating, necessitating on-line repair. Because the condenser has a split shell design, one loop can be isolated and drained, while the plant continues to operate at 40% power. The effort to find, repair (plug) the tube or the tube sheet joint and get the loop back online can take 48 hours or more. During RF 10, the tubes were cleaned by hydrolasing, using the "Shotgun" method. This process uses a water lance by inserting the lance into each individual tube end. The high-pressure water slug creates a very low pressure region just behind the slug, causing the tube end to pull away from the tube sheet, opening up the rolled joint. Furthermore, during tube sheet cleaning with the water jet, the high pressure water is forced into the narrow joint gap between the tube OD and the tube sheet hole, deforming the tube slightly and causing the joint to open up. These two processes resulted in a significant number of rolled joint leaks, which were subsequently repaired by re-rolling the joint.

☐ **Expansion Joint Failure**

The turbine exhaust to condenser neck expansion joints (called "Dog Bones" because of their cross-sectional shape) are made of neoprene with polyester fill and are subject to aging as a result of continuous exposure to the steam environment. One of the dog bones has previously failed (1987), resulting in a plant shutdown under a loss of condenser vacuum. The current service life of the dog bone is determined to be 6 years, such that replacement is necessary every 4th refueling outage.

☐ **Condenser Tube MIC**

In 1994, during the RF 8 outage, VC Summer replaced the steam generators, which required an extended outage of 98 days. During this period, the condenser was drained, but no preventive lay-up procedures were implemented. This is an important observation, because tube degradation and leakage commenced after the RF 8 outage. Dry layup has not been implemented during regular refueling outages, but the condenser is drained.

During start-up from the RF 8 outage, some tubes were found to be leaking. Examination by Eddy Current Examination (EC) during the RF 9 outage determined that between 60% and 90% of the tube wall thickness had been corroded away on certain tubes. Additional tube leaks were identified during the start-up from the RF 10 outage. A serious investigation into the root cause of the tube failures was launched during the RF 11 outage, when EC of a random 10 % of the tubes detected a significant number of degraded tubes. One of the degraded (through-wall) tube samples was pulled and a laboratory analysis was performed. The analysis confirmed the root cause as MIC with the typical evidence of tunneling through the wall [2]. The origin of MIC in the condenser tubes was determined to be due to the standing raw water in the bottom of the tubes during the refueling outages, exacerbated by the presence of scraper ridges. The indications are located at the six o'clock position of the tube, suggesting that the corrosion degradation was initiated under deposits or from the presence of precipitates from standing water [3].

☐ **Work Order Review**

The Summer station has a Work Order database (CHAMPS) that allows retrieval and sorting of work orders for the specific component numbers. A search was conducted for the years 1997 to 2000. Over 200 hits were identified and this listing was narrowed to the significant work orders for which substantial resources were expended (typical of corrective maintenance activities) or which are repetitive, signified by periodic preventive maintenance activities. Examples of the activities thus selected are summarized on Table 2. Copies of the actual work orders were then reviewed to extract the work details, frequency and cost and resource data, such as man-hours.

Table 2. Main Condenser Work Order Summary

TYPE	DESCRIPTION	PROCEDURE	MAN HOURS
C	Repair LP Condenser Tube Leaks		398
C	Repair Tube Leaks in WB 1 and 4		182
C	Repair Tube Leak in Waterbox 1		64
P	Perform Visual Inspection, Waterside	CP-622	0.5
P	Perform Visual Inspection, all	CP-622	2.0
P	Main Condenser Inspection, CW	MMP0190.13	24
P	Condenser Inspection, Shell	MMP0190.13	3
P	Inspect and Clean Hotwell	MMP0190.13A	39
P	Perform EC, Waterbox 1 Tubes	Vendor	190
P	Perform EC, Waterbox 2 Tubes	Vendor	162
P (C)	Inspect and Plug Tubes, WB 1		156
P (C)	Leaktest and Install Plugs	Visual	61
P (C)	Inspect and Plug Tubes, WB 2		149

P = Preventive C = Corrective P (C) = Can be either

Compiling And Reviewing Industry Operating And Performance History

Because the condenser is not a safety-related component at most plants, the reported failures in NPRDS are limited and not particularly useful. Since the condenser is now within the scope of the Maintenance Rule (10CFR50.65), events are reported under the new EPIX system. The database contains 36 hits over the last three available years, 1997 to 1999. This averages to about 0.1 failures per year. Under EPIX only Functional Failures are reported, implying complete loss of function during operation. The following are the principal failure modes and reported frequency:

Pipe, Pump or Valve Failure (all causes)	9 hits
Tube Failure, erosion, corrosion	8 hits
Human Error	6 hits
Tube Failure, structural	5 hits

All the events resulted in lost power production and for those events for which the actual EFPH were reported, the average loss is 26.5 EFPH. The lost power generation cost therefore averages about $600,000 per event, using a 1000 MWE plant at 23.00 $/MWH.

EPRI has sponsored many projects to collect and disseminate operating experience, best practices and guidelines for the operation and maintenance of condensers [4, 5, 6, 7, 8]. One of the oldest references [6, page 4-39] from 1987, recommends strongly that condensers be protected by a comprehensive lay-up program during outages or shutdowns as short as 2 days, to avoid biological fouling and stress corrosion cracking. With respect to MIC in stainless steel condenser tubes, specific case histories have been presented at the EPRI condenser technology seminars. Of particular note are the following case histories:

- Palisades Main Condenser, 1996, Type 439 Stainless Steel Tubes
  The plant uses once-through Lake Michigan water. During two extended outages, the condenser was drained, but water remained standing in the tubes. Two leaking tubes were removed for analysis. The laboratory analysis concluded that the tubes had experienced under deposit MIC, resulting in tube failure within two years.
- Dresden Unit 3 Main Condenser, 1997, Type 304 Stainless Tubes
  Two tubes were removed from the Dresden condenser, following detection of indications by EC. Prior to the EC, the tubes were cleaned using a "Calbuster" scale removing device and metal scrapers. About 43 % of the 18,483 tubes examined contained indications greater than 50% through wall. The laboratory analysis concluded that the tube degradation is a result of ID initiated MIC.
- Wolf Creek Main Condenser, 1998, Type 304 Stainless Tubes
  In response to a significant increase in tube leakage, the plant performed an essentially 100% EC tube inspection of the HP and LP sections. Two tube sections with through-wall indications were pulled and a failure analysis was performed. Comparison of the failure analysis report with industry literature indicates a textbook case of stainless steel MIC ID pitting. The plant uses once-through circulating water from the adjacent lake and has not practiced condenser lay-up during outages.

- Clinton Main Condenser, 1999, Type 304 Stainless Steel Tubes
  Four tube samples removed from the Clinton condenser were investigated by failure analysis to determine the root cause of significant ID pits. The analysis found that the ID indicated ring-like deposits, indicative of MIC and that the pits were randomly dispersed longitudinally and circumferentially. The report only hints that lay-up and circulating water treatment with chlorine may not have been adequate to prevent MIC.
- Microbiologically Influenced Corrosion of Stainless Steel by Water Used for Cooling and Testing, Nickel Development Institute, November 1997.
  This paper [9] describes an additional three cases where MIC was the root cause of failed stainless steel condenser tubes in utility and process condensers. The three cases had a common attribute: Raw water used for cooling, wet lay-up, hydrolasing or testing was in stagnant contact with the stainless steel tubes (304, 304L, 316, 316L) for extended periods at temperatures favorable to the establishment and growth of microbiological deposits.

Reviewing Generic Communications

A search was conducted of the NRC Generic Communications Database, using the keywords Condenser, Degradation, Service Water and Cooling Water to identify applicable regulatory communications. Because the condenser typically is not safety-related, applicable generic communications are limited. From the initial listing , the only item of interest with respect to the condenser is: "Inadequate Lay-up of Equipment during Extended Shutdown", IE-85-056 [10]. The Notice does not address condensers specifically, but the need to protect equipment against degradation during extended outages.

Compiling, Reviewing And Evaluating The Current Maintenance Plan

This task includes the compilation of the current maintenance activities performed for the main condenser and then bench marking those activities to the industry standards and practices. In this way, potential opportunities for enhancements can be identified, or excessive tasks can be eliminated or modified. There are two generic references available [6, 8] for the maintenance of surface condensers, both published by EPRI. The first [6] was issued in 1987 and provides a benchmark for condenser maintenance in the area of leak detection, corrosion and condition monitoring, condenser lay-up, on-line and off-line tube cleaning, tube end erosion-corrosion countermeasures and control of bio-fouling.

The more current PM Basis document [8] provides recommendations for preventive maintenance activities and suggested frequency, as well as aging management activities. Table 3 is an illustration of the comparison of the generic recommendations with the currently applied practices at VC Summer:

Table 3. PM Basis Comparison

GENERIC PM TASK EPRI TR-106857-V34	TASK FREQUENCY	VC SUMMER TASK PROCEDURE NO.	VCS TASK FREQUENCY
Performance Monitoring	Weekly		
Monitor, trend, track tube side <P		Monitor condenser back press.	On-line
Monitor, track, trend <T		Circ. water inlet-outlet temp.	Daily
Monitor Cathodic Protection		No Cathodic Protection	NA
Monitor condenser cleanliness		By ΔT versus MWE curve	Daily
Sample fluids		Na is monitored for tube leaks	On-line
Monitor turbine back pressure		Condenser vacuum is monitored	Daily
Monitor, trend air in-leakage levels		Dissolved O2 and offgas flow	On-line
NDE Inspection	2 years		
Eddy Current		EC Sampling of tubes (vendor)	Each refuel
Ultrasonic thickness		UT of tube-sheet (RF 11)	Last refuel
Borescope		Visual and video-scoping	Each refuel
Waterbox Inspection	Each refuel		
Inspect for erosion/corrosion, cracks		MMP190.013	Each refuel
Inspect for fouling		CP-622 Clam Inspections	Each refuel

As can be seen from the table entries, the VC Summer condenser preventive maintenance program addresses all of the EPRI PM Basis recommendations. However, important diagnostic tasks (such as regular bio-assays) for the detection and confirmation of MIC are absent from the EPRI PM basis recommendations and most importantly, recommended preventive measures for lay-up during outages, are missing.

Current maintenance activities were reviewed, as well as the associated work orders implementing the activities. Most of the information was gathered through interviews with the system engineer and review of the procedures and typical work orders. The data was then transferred to the "Main Condenser Maintenance Activity Data Sheet". The data gathered provides the basis for LCM planning and the analysis of alternative LCM plans. An edited example of the data collection and the type of maintenance data required for LCM planning is shown on Table 4.

Table 4. Maintenance Activity Listing And Data For The VCS Main Condenser

ITEM	ACTIVITY DESCRIPTION	NO. OF COMP N	ACTUAL LABOR HRS	ACTUAL LAB. COST $/HR	MAT. COST $$	ACT. FREQ OR FAIL. RATE FR	LCM PLAN ALTERNATIVES		
							A BASE CASE	B MIC PM	C Replace Tubes
1.0	Condenser Tubes								
1.1	Video Scoping (before/after cleaning)	1	8	51.50	0	0.666	√	√	√
1.2	Visual Insp. (before/after cleaning)	1	4	32.00	0	0.666	√	√	√
1.3	100% Tube Cleaning	1	24	32.00	100000	0.666	√	√	√
1.4	40% Eddy Current of Tubes	1	0	0	133000	0.666	√	No	No
1.5	EC Tube Wall Trending, CORESTAR	1	40	100.00	0	0.666	√	√	√
1.6	Tube Sampling for Lab Analysis	1	8	32.00	2000	0.666	√	√	√
1.7	Leakage Dye Test	1	40	32.00	32000	0.666	√	√	√
1.8	Tube Plugging On-Line	1	200	32.00	500	1.00*	√	√	To 2017
1.9	Tube Plugging in Outage	1	40	32.00	1250	0.666	√	√	To 2017
1.10	Tube Sheet Mapping (Verify Plugs)	1	40	32.00	0	0.666	√	√	√
1.11	Complete Tube Replacement	1	0	0	8x10+6	once	2010	No	No

*Denotes a Frequency Reduction Factor of 4.0 for MIC Program (Alternatives B and C)

Condenser performance is monitored under the plant's Maintenance Rule program. The condenser has been determined as Important to the Maintenance Rule (ITMR) and is covered by the Condensate System (CO) performance criteria (Plant Level Criteria) as follows:
< 2 Scrams per 7,000 hours of operation
< 3% Unplanned Capability Loss Factor (UCLF) in a rolling 12 month period
< 2 MPFF per 18 month period

The condensate system is an operating system and is defined as risk significant for VC Summer. It is currently in the A(2) performance category but has been placed on the watch list (yellow condition) due to the identified MIC pitting.

Performing Aging, Obsolescence And Performance Assessment

The key performance issues for the condenser are cleanliness control to maintain adequate heat transfer capability during operation and control of tube degradation to avoid unscheduled power reductions or outages.

Because of the once-through system design, on-line chemical treatment (chlorination, biociding) of the circulating water is of very limited value in view of the low chemical concentrations that may be applied under environmental regulations. Isolating and treating one loop at a time also has a limited value and would require power reduction to 40% during the 24 hour treatment cycle and the treatment for disposal of the chemical solution, at a total cost of about $300,000 for one loop. Maintaining the on-line AMERTAP system in top condition or replacing it with a reliable alternate design is therefore an important consideration to assure continued reliable cleanliness control.

With respect to tube degradation, the plant has initiated an aggressive program to quantify the problem and to better trend future tube performance. However, the current program steps could be enhanced to prepare for effective MIC management. The following activities need to be considered:

- Develop a contingency for the EC examinations in RF 12 to expand the coverage to essentially 100% of all tubes.
- Develop a comprehensive lay-up procedure for the condenser for normal refueling outages and for unplanned outages exceeding two days.
- Develop a standard MIC testing program for implementation
- Develop a plan to hydrolase the carbon steel components within the condenser, such as the waterboxes, the tube sheets and the cross-around piping.
- Develop a tube sleeving contingency to restore leaking or severely corroded tubes to functional status.

- Investigate the options for tube replacement, including complete re-tubing with titanium tubes, tube bundle replacement and other methods (such as tube coatings).
- Maintain the AMERTAP system in top operating order to facilitate periodic on-line tube cleaning.

An analysis has been performed to quantify the potential continued tube degradation if MIC cannot be brought under control. An annual loss of 40 tubes (0.1%) is postulated such that the remaining performance margin at worst case operating conditions will be exhausted and lost power generation will occur due to forced power reductions during hot summer days. The effect of this lost generation is modeled as part of the evaluation of LCM alternatives.

Aging of passive components, particularly in view of the planned license renewal for the plant, is an important consideration for LCM planning. As shown in the Table 5 (abbreviated), a comprehensive evaluation is performed to:

- Identify the plausible degradation mechanisms, as published in relevant industry literature [6, 8, 11]
- Identify and assess the aging management programs currently in practice
- Determine potential deficiencies and recommend solutions or enhancements

The aging management evaluation concluded that there are no basic shortcomings of the current VCS condenser maintenance program. However, in view of the emerging MIC issue and the plant's desire to operate for an extended license renewal period, there are a number of enhancements to existing programs as well as a number of recommendations to prepare for the longer operating period. These are the recommended enhancements shown on Table 5. The LCM planning process includes these enhancements in the License Renewal Alternatives.

Table 5. Aging Management And Assessment Matrix, Main Condenser

COMPONENT	DEGRADATION MECHANISM	CURRENT AGING MANAGEMENT PROGRAM	RECOMMENDED ENHANCEMENTS
Tubes	Erosion-Internal	Sampling EC inspection Tube cleaning, hydrolasing Controlled flow velocity Cleaning of waterboxes Amertap on-line cleaning system	When EC detects a general tube wall loss, ID caliper measurements are recommended to verify.
	Erosion-External	MMP-190.013 Inspection Procedure Sodium indicator in condensate	
	MIC	Sampling EC Inspection Tube Cleaning, Hydrolasing Tube Plugging	Develop MIC management program Outage lay-up, clean water Increase EC to 100%
	Cracking (SCC, Fatigue, impact)	MMP-190.013 for damage Monitoring sodium for leaks Sampling EC Inspection	
	Bio-Fouling	Tube Cleaning, Hydrolasing Waterbox Cleaning, Inspection AMERTAP on-line Cleaning	Consider hydrolasing the waterboxes
Tube Sheet Joint	Galvanic Corrosion Tube Deformation	Visual Inspection Leak Testing after cleaning	
Tube Sheets	Corrosion	MMP-190.013 for defects/inspection	UT wall thickness surveys (every 6 years)

Identify Possible Alternative LCM Plans Compatible With Plant Operating Life Strategies

Two operating term LCM strategies have been established for the VC Summer plant to evaluate the defined LCM Alternative Plans as follows:

- Strategy 1: Operate the plant for its currently licensed period of 40 years
- Strategy 2: Operate the plant for 60 years under a License Renewal Program

The LCM Plan Alternatives to be considered for the main condenser are characterized and described below:

- Alternative A-1: Under the current 40-year operating term, the condenser would continue to be operated under the current maintenance program until the plant is retired in 2022. Tubes would be plugged as required, until continued tube plugging can no longer support full power operation of the plant. When the cost of power replacement and the resulting unavailability becomes unacceptable, the condenser will be re-tubed (in 2010) with stainless steel (in-kind replacement) to last until the scheduled retirement date in 2022. This alternative is not appropriate as an LCM plan for the license renewal strategy (Strategy 2)

- Alternative B-1: Operate the plant for 60 years under an aggressive aging management plan, including a MIC management program and condition monitoring of the important condenser components. It would also include replacement of the "Dog Bones" with a non-age sensitive stainless steel design. The heater insulation will be reinforced or protective grates are installed and the 1310 tubes unplugged to gain the 3% extra heat transfer surface, such that power reductions will not be needed. This alternative does not require re-tubing, but assumes that only 10 tubes will fail each year, compared to 40 tubes per year for the Alternative A.
- Alternative B-2: This Alternative is identical to Alternative B-1, except that the useful operating life is presumed to be only 40 years. The analysis will determine if the investments made in Alternative B-1 will be of economic prudence, in case license renewal is abandoned at the last minute.
- Alternative C-1: This Alternative is similar to the Alternative B-1, except that the tubes are replaced with titanium tubes at a time when license renewal has been granted and a decision to proceed has been made (2022-5=2017). The titanium tubes are essentially immune to MIC and other forms of corrosion and would obviate the need for condenser lay-up and reduce the incidents for tube leakage. The model also assumes a reduction factor of 4.0 of tube leakage incidents until the titanium tubes are installed.
- Alternative C-2: This Alternative is identical to Alternative C-1, except that the useful operating life is terminated at 40 years, despite the installation of titanium tubes in 2017.

The activities associated with each of the alternatives, together with the projected timing, frequency and cost are then entered into the LcmPLATO database for computation of the Net Present Value cost for each of the Alternatives. The failure data, costs and frequency of the activities to be modeled for the Alternatives have been collected as part of the individual assessment tasks.

Assess Performance And Cost Of Alternative LCM Plans

The following Table 6 compares the total NPV costs for each of the analyzed cases. Figure 1 provides a comparison of the cost components for the three 40-year cases. It is obvious that the implementation of a successful MIC plan would avoid a tube replacement and costly lost power generation.

Table 6. NPV Cost Comparison Of Alternatives

LCM PLAN ALTERNATIVES	NPV COST TOTAL 40 YEARS	NPV COST TOTAL 60 YEARS
Alternative A-1, In-Kind SS Tube Repl., 40 Years	**$ 20,000,000**	
Alternative B-1, MIC Plan, 60 Years		**$ 6,800,000**
Alternative B-2, MIC Plan, 40 Years	**$ 4,800,000**	
Alternative C-1, Titanium Tubes, 60 Years		**$ 11,600,000**
Alternative C-2, Titanium Tubes, 40 Years	**$ 11,200,000**	

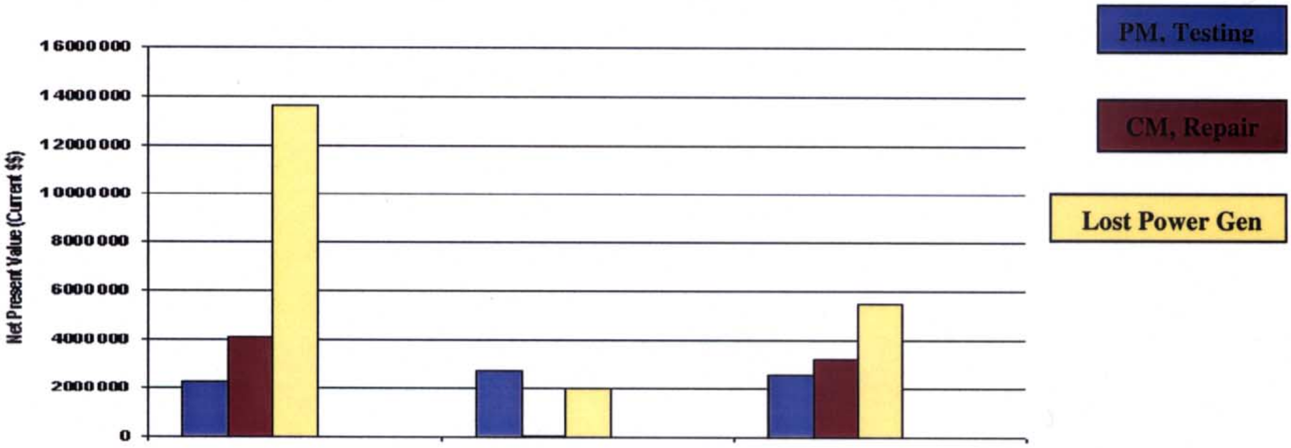

Figure 1. Comparison of Alternatives A-1, B-2 and C-2 Respectively by Cost Category

Main Condenser LCM Planning Recommendations (Optimum LCM Plan)

Examination of the economic analysis results would conclude that an aggressive MIC plan is the prudent course of action for both the 40 and 60-year strategies. If MIC cannot be brought under control, the contingency of replacing the tubes with either stainless steel (for a 40-year strategy) or titanium tubes (for a 60-year strategy) is available. The tube replacement decision need not be made until MIC tube degradation trending shows a potential threat to continued full power operation.

LCM PLAN FOR THE MAIN STEAM AND FEEDWATER ISOLATION VALVES

A screening process was used to select and rank the Wolf Creek Nuclear Plant SSCs for LCM planning. Sixty-two SSCs were selected and ranked. The plant's hydraulic valves were included in the highly ranked SSCs. The hydraulically operated main steam isolation valves (MSIVs) and main feedwater isolation valves (MFIVs) were selected for LCM planning because of the ongoing effort to replace/refurbish the environmentally qualified (EQ) components of the hydraulic actuators.

The Main Steam System conveys steam from the steam generators to the turbine-generator system. The system consists of main steam piping, atmospheric relief valves, safety valves, and main steam isolation valves (MSIVs). One 24-inch MSIV is installed in each of the four main steam lines. The MSIVs prevent uncontrolled blowdown from more than one steam generator. The Feedwater System receives condensate from the condensate system and delivers feedwater through four 14-inch feedwater lines to the steam generators. One 14-inch main feedwater isolation valve (MFIV) is installed in each of the four main feedwater lines outside the containment and downstream of the feedwater control valve. The MFIVs are installed to prevent uncontrolled blowdown from more than one steam generator in the event of a feedwater pipe rupture in the turbine building.

The MSIVs and MFIVs are bi-directional, double disc, parallel slide gate valves. The MSIVs have a bolted bonnet design. The MFIVs have a pressure sealed bonnet design. Stored energy for closing the MSIVs and MFIVs is supplied by accumulators that contain a variable mass of high-pressure hydraulic fluid and a fixed mass of high-pressure nitrogen. For emergency closure, a solenoid is energized that causes the high-pressure hydraulic fluid to be admitted to the top of the valve stem driving the piston and dumping the fluid below the piston to a fluid reservoir. Two separate pneumatic/hydraulic power trains are provided for each valve.

Compiling And Reviewing The Plant Operating And Performance History

A review of the operating history for the past four to six years provided a representative "snap-shot" of the maintenance and engineering activities for the valves that could be used in establishing performance trends. The time-period included a rebuild of all the valve actuators. The EPRI Mechanical Tools document [12] was reviewed to identify the aging effects/mechanisms that may affect the condition of the MS/MFIVs pressure boundary components. The work orders and age-related degradation causes are summarized below

☐ **Work Order Review**

Listings of the MS/MFIV work order records were compiled for the time period. Approximately 60% of the work orders were issued for the four MSIVs. The data showed that, with the exception of one year, the trend for the MSIVs was relatively constant at approximately 80 work orders per year, whereas, the data showed a moderate decrease in the number of work orders for the MFIVs. The MSIVs experienced a small increase in PM activity and a small decrease in CM activity. There was a more significant increase in MFIV PM activity and decrease in CM activity. For both the MSIVs and MFIVs, there is a small decline in modification activity.

☐ **General Corrosion**

The external surfaces of the MS/MFIV passive components are susceptible to general corrosion. At ordinary temperatures and neutral or near-neutral media, oxygen and moisture are the primary factors for general corrosion.

☐ **Crevice Corrosion**

Crevice corrosion occurs in the crevices or shielded areas that allow a corrosive environment to develop within the crevice. The nature of the crevices, especially for those very small in size, is such that low flow or stagnant conditions can exist in the crevice regions even under system flowing conditions.

☐ **Pitting Corrosion**

Pitting may be initiated when oxygen levels are above 100 ppb in conjunction with impurities such as chloride, fluoride, sulfate or copper. Areas where crevices exist are particularly susceptible to pitting corrosion.

☐ **Erosion-Corrosion**

The extent of erosion-corrosion is influenced by fluid flow velocity, temperature and fluid chemistry and material susceptibility. Flow rates are greater than the 6 ft/sec needed for erosion-corrosion of carbon and low alloy steels.

☐ **Loss of Pre-Load**

Loss of pre-load may be attributed to embedment, cyclic load, gasket creep, and/or thermal effects.

- ☐ **Cracking**
  The valve bonnet bolting is not intentionally exposed to water or steam, but may be inadvertently exposed from gasket leaks. Leakage combined with contaminant species, such as sulfides or chlorides may result in SCC. Decomposition products from lubricants and sealant compounds injected into leaking closures may produce environments capable of causing SCC.

Compiling And Reviewing Industry Operating History

NPRDS and EPIX failure reports were obtained for the MSIVs and MFIVs. The failure data per year for all plants were determined. It could be concluded from the failure reports that most of the failures were associated with the hydraulic actuators. However, in most cases, the failure discussions were brief and it was not always possible to identify the failed component or the failure cause.

Generic Communications (NRC) Review

A search was conducted of the EPRI Generic Communications Database, using the valve component names as keywords. The listing was screened to select the applicable NRC communications. Most of these communications were issued before 1996. Where necessary, the plant had modified plant procedures to address the identified issue(s). Generic Letter 91-017 [13] appeared to be the only communication involving an ongoing issue affecting the life cycle management planning for the MS/MFIVs.

Compiling, Reviewing And Evaluating The Current Maintenance Plan

The current maintenance activities and parameters for the MS/MFIVs were determined from interviews with the system engineer, maintenance rule coordinator, work scheduler, maintenance crafts, records management, NPRDS and EPIX coordinator and other plant personnel. Applicable procedures were also identified and reviewed. The vendor technical manuals [14, 15] were reviewed to confirm that preventive maintenance procedures had captured the vendor recommended practices. The interviews, procedure and work order reviews were used to determine the individual tasks, frequency of the tasks, level of effort required, type of skill required and materials to be used (parts, consumables). The work order review also confirmed the scope of the MS/MFIV maintenance activities had been appropriately captured. The labor categories established by the plant were used.

A qualified life limitation was established for the electrical and non-metallic mechanical parts of the MSIV and MFIV actuators as part of the plant's Environmental Qualification (EQ) Program [16]. The mechanical seals have the shortest qualified life. Each actuator uses over 300 elastomeric seals, manufactured from Viton (fluorcarbon rubber) and ethylene-propylene rubber. The plant, and industry, practice is to remove the entire actuator assembly and perform all the component replacement / refurbishment activities at the same time in the plant's maintenance shop. Therefore, the qualified life of the mechanical seals dictates the interval between actuator component replacements/refurbishments.

Operating chemistry guidelines for secondary steam generator water are used. These guidelines use EPRI guidelines and Westinghouse chemistry recommendations with actual implementation and control being defined and maintained in plant chemistry procedures. The redundant actuator power trains of each MSIV and MFIV are subjected to closure time and on-line operability testing. The valves are checked for closure time at each refueling. The operability of the actuators is checked periodically, while the MSSS is in operation, by exercising the valve to approximately 90 percent of full open. Inservice inspections of the valve body to piping welds are performed as part of the Inservice Inspection Program.

The main steam and feedwater systems are within the scope of the maintenance rule (MR) and are monitored using performance criteria. The performance criteria were taken from the plant PSA calculations.

The corrective maintenance activities and their labor, material and frequency parameters for the MS/MFIVs were established by reviewing the work orders. The air-oil pump for the MSIVs, and the tubing and fittings for the MFIVs, had the most corrective maintenance activity. The plant listing of forced outages was reviewed to determine if these corrective maintenance activities resulted in an outage or power reduction. The list did not have any outages or power reductions attributed to MS/MFIV technical specification limiting conditions for operation.

A comparison was performed of the MS/MFIV current maintenance activities and the recommendations provided in the vendor manuals [14, 15] and the EPRI PM basis documents [17, 18, 19, 20, 21]. Most of the current activities match favorably with the recommendations. However, some differences were noted. Further investigation of the plant's PM basis is expected to resolve many of these differences. The investigation, and establishing the basis for the noted differences, was captured as an LCM planning activity.

Performing Aging, Obsolescence And Performance Assessment

An integrated plant assessment process (IPA) as defined in NEI 95-10 [22] was applied to the MSIV and MFIV primary pressure boundary components (valve body, bonnet and bolting). The assessment determined that Secondary Chemistry Control Program, Component Wall Thinning Monitoring Program, a new Bolting Integrity Program, and additional external visual inspections are required to adequately manage the effects of aging for the MSIV and MFIV pressure boundary components. However, several enhancements to the Secondary Chemistry Control and Component Wall Thinning Monitoring Programs were found to be necessary. The enhancements and new program/inspections were needed to demonstrate that all the attributes of the NRC's Generic Aging Lessons Learned [23] programs have been addressed.

The technical obsolescence issue was examined for the MS/MFIV components. The valve, actuator and most of the electrical parts and materials are not expected to become obsolete. The availability of EQ replacement parts from the valve vendor is not expected to be an issue. Similarly, the mechanical parts (e.g., the accumulators) are also expected to be readily available. Peripheral components, such as limit switches, instruments, and sensors will be susceptible to technical obsolescence. The plant uses its own craft to rebuild/refurbish the actuators. The individuals involved have become skilled and efficient in the rebuild process. Loosing these individuals would be an impact in terms of training costs and increased rebuild costs and corrective action work orders until the new individuals become proficient.

Identifying Possible Alternative LCM Plans Compatible With Plant Operating Life Strategies

The Wolf Creek operating term strategies are as follows:

- Strategy 1: Operate the plant for its currently licensed period of 40 years.
- Strategy 2: Operate the plant for 60 years under a License Renewal Program

For the MS/MFIVs, four LCM plan alternatives were developed for the first strategy. Each of these alternatives are described below. The same alternatives, with a 20-year life extension, are used for the second strategy.

A. A base case, that assumes continuation of the current maintenance, planned and unplanned, activities.
B. Extend the qualified life of the actuator soft components to 12 years. This would be accomplished through successive service-life evaluations of the elastomeric seals, implementing a comprehensive elastomeric seal service life monitoring program involving components in similar service, and implementing a vendor/industry program to identify seal materials with longer qualified life expectancies.
C. Enhance the current maintenance plan and acquire spare MS/MFIV actuators. The hydraulic actuators that are removed at a sister plant would be acquired. Several of the acquired actuators would be preserved as full assemblies so they can be used as rotating spares. The other actuators would be used for spare parts. The MS/MFIV EQ parts replacement/refurbishment work would be done between outages.
D. Replace the hydraulic operated actuators with system medium operated actuators. The change is expected to significantly reduce the preventive and corrective maintenance activity for the valves.

Assess Performance And Cost Of Alternative LCM Plans

Each of the alternatives was evaluated for 40-year and 60-year strategies. Economic parameters such as, inflation/discount rates and labor rates were provided by the plant. The economic results, in terms of total NPV cost, are provided for comparison in Table 7.

Table 7. LCM Plan Alternative Economic Comparisons

LCM PLAN ALTERNATIVE	OPERATING TERM STRATEGY	NPV COST TOTAL	NPV COST TOTAL
Alternative 1-A, Continue current maintenance plan, as-is (base case)	40 years	**$4,300,000**	
Alternative 2-A, Continue Alternative 1A through the extended operating period	60 years		**$6,500,000**
Alternative 1-B, Extend the qualified life of the actuator components	40 years	**$4,700,000**	
Alternative 2-B, Continue Alternative 1B through the extended operating period	60 years		**$6,800,000**
Alternative 1-C, Enhance the current maintenance plan and acquire spare actuators	40 years	**$5,400,000**	
Alternative 2-C, Continue Alternative 1C through the extended operating period	60 years		**$6,500,000**
Alternative 1-D, Procure and install new valve actuators	40 years	**$4,400,000**	
Alternative 2-D, Continue Alternative 1D through the extended operating period	60 years		**$5,000,000**

Main Steam and Main Feedwater Isolation Valve LCM Planning Recommendations (Optimum LCM Plan)

The economic comparisons showed that Alternative D appears to be the most prudent course of action. The actuator vendor and installation costs need to be formally established and compared with the assumptions used in the economic assessment. It is also recommended that the industry operating experience for these actuators be further investigated to confirm the scope of maintenance activities and corrective action trends. The assessment assumed that the new actuators would be installed in the near-term (2003).

NEXT PHASES OF LCM PLANNING

Now that LCM planning has been demonstrated for twelve types of SSCs at four plants, all operating plants can apply the EPRI process to their plant-specific important SSCs. To facilitate and reduce the cost of extensive applications, EPRI has begun to produce "LCM Sourcebooks." Sourcebooks are information catalogs containing generic information an engineer typically needs to produce plant-specific LCM plans for a particular SSC type. The generic information and guidance in sourcebooks will enable plant engineers to develop plant-specific LCM plans with substantially less effort than if they were to start from scratch.

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