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PRESERVING THE LIFE EXTENSION OPTION FOR WOLSONG NPP UNIT 1 THROUGH PLANT LIFE MANAGEMENT PROGRAM

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Abstract

The first CANDU 6 plants, including Wolsong Unit 1 nuclear power plant (NPP) (which entered service in the early 1980's) are now approaching two thirds of their thirty-year design life. Korea Electric Power Research Institute (KEPRI) and Atomic Energy of Canada Limited (AECL) have worked together since 2000 to develop and implement a comprehensive and integrated CANDU Plant Lifetime Management (PLiM) program for Wolsong Unit 1 NPP. PLiM will see this plant successfully and reliably through to the design life and preserve the option for life extension.

The focus of the initial phase of the program is on the major critical components and structures and any potential aging phenomena that might affect plant safety and availability. In-depth life assessments of Wolsong Unit 1 critical systems, structures, and components (CSSCs) are under going. It is recognized that effective plant practices in inspection, monitoring, maintenance, and operations are the primary means of managing aging through the design life and necessary for preserving the life extension option. Hence, the PLiM assessments identify enhancements to current plant programs to mitigate aging effects and to ensure reliable life attainment and performance.

The KEPRI/AECL co-operation for the PLiM program over the last few years is providing in-depth assessments and promising life prognosis for the key CSSCs of Wolsong Unit 1. The assessments are also identifying those areas for optimized plant inspection, monitoring and maintenance programs to achieve utility targets for safety, reliability and production capacity during extended life. These outcomes are important inputs to decision makings to embark upon a detailed Wolsong Unit 1 life management program. In this paper, the PLiM program assessment methods and techniques tailored to the components, like CANDU 6 steam generators, are described. A typical proactive aging management program for steam generators, aimed to continue current excellent service for long and reliable life, is also outlined. Furthermore, the paper briefly describes the interaction between the PLiM Life Assessment program and Plant Condition Assessments that will collectively form the basis for evaluating refurbishment requirements and for plant life extension planning.

1.0 CANDU CSSCs Life Assessment Methodology

Many critical components in the early CANDU 6 plants have had a very good service record with little or no significant active degradation to date. However, this excellent in-service experience (and hence lack of degradation data) provides a unique challenge for the critical systems, structures, and components (CSSC) life assessments within the Plant Lifetime Management (PLiM) program. In performing the systematic and detailed assessments, a key activity is diagnosis of the operational history for aging indicators, as well as a thorough understanding of applicable degradation behavior. With little degradation data from the plant, the challenge is to provide a reasonably comprehensive and detailed assessment of aging effects for the next 20 to 30 years of operation. To meet this challenge, a thorough understanding of the applicable degradation mechanisms and the associated -“stressors”- is used. This understanding has derived from research and development programs, integrated with knowledge from relevant field data of other plants.

An in-depth understanding of the plant operational history and the current plant programs related to aging are both key inputs to the life assessment process. Involvement of utility staffs in the process is encouraged. This aids them to understand the CSSC history and the current plant programs that manage aging, also to understand the life assessment outcomes, and subsequently to dispose life assessment recommendations. Developing an efficient and effective approach to the interfaces with key utility staffs (such as aging management experts, system engineers, component engineers, reliability engineers and maintenance personnel) has contributed to the success of the PLiM assessment program.

Some of these key steps in the life assessment process and interfaces between the various groups are shown diagrammatically in Figure 1. A key part of the life extension program is to utilize the outcomes of the PLiM assessments and the aging management strategy developed from the work to enhance current plant programs for extended operation. Effective plant practices in inspection, monitoring, maintenance, and operations are the primary means of managing aging through the design life and for the extended life operation. For instance, life assessment work on the CANDU concrete containment has led to an enhanced monitoring program at Point Lepreau NPP.

Details of the CANDU PLiM program, including the CSSCs life assessment methodology, have been documented in previous papers [1, 2]. In this paper, the development of PLiM program diagnostic and assessment methods and techniques for the CANDU 6 steam generators at Wolsong Unit 1 NPP will be described. Examples of a typical proactive aging management strategy of steam generator for the life extension that results from this type of detailed technical assessment are also covered.

2.0 Steam Generator Life Assessment

Detailed and comprehensive life assessment studies of the steam generating equipment have been completed at two CANDU 6 plants in Canada and well processed for Wolsong Unit1. They have assessed the integrity and degradation of sub-components including the pressure boundary, the external support structure, the tubing, and all the key internals of steam generators. CANDU 6 SGs are tubed with Alloy 800M (M means “modified”) and have experienced relatively little tube corrosion to date. For instance, at the Wolsong Unit 1 (that has 19 years of in-service experience), there are only nine SG tubes plugged of which seven were found before in-service operation out of the total population of over 14,000 tubes.

This excellent service record requires a rather novel approach to predicting future performance, such as potential for tubing corrosion degradation. The assessments involve a very thorough review of tubing corrosion mechanisms that can occur in nuclear steam generator [3]. The knowledge from AECL’s R&D studies of SG tubing corrosion behavior in various chemistry environments has been a key element of this methodology. First, a detailed assessment is made of worldwide experience with Alloy 800M, and other steam generator tubing alloys. From this review, all the specific types of corrosion mechanisms, and the chemistry environments that have been instrumental in causing tubing corrosion degradation are systematically identified and the key stressors assessed. Second, each of these tubing corrosion situations is evaluated for relevance to the Wolsong Unit 1 steam generator design and operation. The tolerance of the Alloy 800M tubing to the presence of plausible aggressive secondary side impurities (such as lead & chlorides) in various plausible ranges of chemistry conditions is assessed. Those conditions might exist in steam generator crevices, such as in the tube sheet sludge pile or in the tube-to-support gaps that have become blocked with deposits.

Additionally, other degradation mechanisms are reviewed for their impact on SG condition, operation, and future life. These include analysis of the thermo-hydraulics, vibration and fretting, and potential for fretting of the tubing against the U-bend support structures. Fouling, both of the primary and secondary sides of the SG can also significantly reduce operating efficiency, and the efficiency of the station output.

While SG tubing degradation is considered as the largest single potential source of SG problems, this alone is not the only important factor in determining the prognosis for achieving 50-year life. Steam generator non-tube components also present a challenge in estimating current condition as well as future life. Hence, the Wolsong Unit1 steam generator life assessment also considers the other components in a SG that could compromise life. These include components that are grouped into the following categories:

- Primary side pressure boundary
- Secondary side pressure boundary
- External supports
- Primary side internals
- Secondary side internals

As with the tubing, detailed consideration is given to all potential degradation mechanisms based on the world wide and other CANDU experience. Next, the potential for plausible degradation is assessed with the Wolsong Unit 1 data of design, manufacturing, operation, inspection, and maintenance.

3.0 Proactive Steam Generator Aging Management Strategy

Despite the excellent record at the Wolsong Unit 1, it is well known that steam generators provide challenges for the assurance of continued good health through the design life and particularly for a significant period of extended operation. Many important secondary side internal components are so difficult to inspect that, consequently, little is known about their current condition. Subtle changes to plant operation may have a significant impact on the tubing corrosion potential under deposits that have built up and in crevices between the tubing and support structures. As an outcome of the SG assessment work at a number of CANDU plants, it has been concluded that each plant and its steam generators have unique aspects that could affect life attainment or extended operation.

The life assessment recommendations typically focus on specific aspects of chemistry control, proactive inspection and monitoring, and periodic cleaning. Even the prognosis for the life attainment and extended operation of CANDU 6 steam generators is plausible, it has been found out that the conclusion is very dependent upon the implementation of the recommended program enhancements. The programs are about inspections, effective maintenance, good chemistry control, and trend evaluation of the future field data [3,4]. It is also dependent on assumptions on the condition of not inspected components, particularly those on the secondary side of the SG.

From the studies undertaken to date, a typical proactive SG aging management strategy for life extension would include the following elements.

Enhanced Tube Bundle Inspection/Interpretation

In the recent years, there has been considerable advancement in the tubing eddy current (EC) testing technology, in the knowledge of tubing degradation mechanisms, and EC inspection techniques can be effectively used for detecting defects. In addition, improvements in analysis and interpretation technology of eddy current data and use of these data for predicting early signs of tubing degradation have been developed. A proactive SG aging management program uses the results of the life assessment, couples it with these advanced inspection and interpretation techniques, and let them have developed an enhanced SG tubing inspection program for plausible tubing aging degradation. The objective of development is to have as-early-as-possible identification of any possible tubing degradation by focusing inspection effort on the “age-sensitive” regions of the tube bundle with appropriate techniques capable of detecting the plausible degradation. Typical examples of information not available previously from the EC inspection are the quantification of the depth and extent of deposits on the tubing primary side and detection of tube-to-support gaps for use in vibration and fretting wear assessments.

SG Surveillance Tubes

An important proactive life management technique in many CANDU’s is a program of regular tube removal and subsequent metallurgical evaluation. For instance, examination of removed tubes is a requirement of the Canadian Standards Association (CSA) standard. Such examinations are an important supplement to the NDE inspections and provide confirmation of tube wall condition and an insight into the local operating environment on the tube surface. This is particularly useful for the tube surfaces of secondary side that have been exposed to under-deposit conditions (such as sludge piles on tube sheet).

Secondary Side Internals

It is a typical outcome of the SG life assessment that though internal components are important and key to the successful long-term operation of SGs, information on in-service condition is relatively short. A detailed risk assessment of these non-tube components based on design function and operational experience leads to identification of those specific internals that should be subject to inspection in a proactive and comprehensive aging program for life management. There have been several instances, both in CANDU SGs and PWR ones, of degradation of internals structures resulting from flow assisted corrosion. This experience indicates that the secondary side internals are an area where some inspection for component integrity is essential for assurance of continued operation beyond design life.

Secondary Side Crevice Conditions

Most plants place considerable emphasis on controlling the operational chemistry of the secondary side so that it is consistently within acceptable levels. In steam generators, tubing life is directly related to the local chemistry conditions at the surfaces of tube secondary side. In the crevices at tube supports and in the region of tube sheet sludge, successful long life requires maintaining the crevice chemistry within ranges that minimize tubing corrosion. Subtle changes that can significantly affect tubing life may result from variations in feedwater impurity. If these impurity fluctuations are within the specifications of normal bulk water, their potential to increase tubing corrosion damage, particularly in secondary side SG crevices, could go unnoticed until extensive damage becomes evident.

To assess crevice conditions for corrosion damage potential with given operational chemistry parameters, plant staffs need knowledge of the local chemistry in the steam generator tube bundle crevices, in addition to the bulk chemistry of the water surrounding the tubing. In the past, this was a rather difficult and time intensive task that could only be done by chemistry and corrosion experts not usually found at the plants. However, recently, tools have been developed to provide a CANDU SG crevice chemistry prediction that can be used on-line by the plant operator. The effects of impurity in-flows to the secondary side water, on local crevice chemistry, and fouling in the steam generators are identified as where of concern, and flagged.

This type of on-line monitoring and prediction system gives the plant operator an important life management tool for good health of steam generators by providing early indication of any change in chemistry parameters. Operators’ on-line access to the current and past chemistry conditions enables appropriate responses while on-line monitoring and diagnosis of any change in corrosion susceptibility including chemistry in the critical crevice and planning of shutdown maintenance actions. They can get ideas from the on-line condition monitoring what inspections need to verify local conditions and specific areas to be cleaned.

Proactive SG Cleaning Program

Even with the best control of secondary side water chemistry, corrosion products from the secondary side systems will continue to be carried into the SG tube bundles during its lifetime. A large percentage of these corrosion products come to rest in the steam generator as deposits, mostly on the tube surfaces. Those deposits that end up on horizontal surfaces, particularly the tube sheet, can be difficult or impossible to remove while the steam generator is in service. While considerable effort is made to maintain good chemistry of bulk water in the steam generator, advanced methods of chemistry control are now available to reduce such fouling and deposits. If the fouling and deposits are allowed to accumulate, they will become hard or consolidated at the crevice of tube sheet-to-tube interface as well as at the gaps of the tube-to-support. Feedwater impurities diffuse to these crevices and, as a consequence of boiling in the crevice, can concentrate by factors of up to 10E6. Hence, a proactive aging management program for SGs should include secondary side cleaning (particularly tube sheet flushing or lancing), with regular application, even before the presence of significant SG deposit is detected.

Although there is considerable world experience to support this activity, plant operation and maintenance staffs sometimes question the benefits of cleaning because of the costs involved. To provide some enhanced tools (and the science behind them) that will aid cleaning decisions, AECL is further developing models to predict tubing corrosion damage using a variety of laboratory and field data. It is known that Alloy 800, similarly to all other SG tubing, is not immune to pitting corrosion or stress cracking, particularly under deposits (like tube sheet sludge piles) where aggressive contaminants such as chlorides and Pb may have concentrated. Pitting is likely the highest concern for CANDU SG tubing. Pitting potential modelling is being co-ordinated with the crevice/SG chemistry modelling to provide a qualitative guide for operators to assess the adequacy of current chemistry control and to provide input to plan tube sheet sludge lancing. For further details, see Reference [4].

Implementation of Proactive SG Aging Management

The detailed steam generator life assessment work for Wolsong Unit 1 is expected to lay the foundation for the program enhancements of plant inspection, maintenance (cleaning) and operations (chemistry) that will ensure extended life of this critical equipment. Following completion of the Phase 1 assessment work, implementing the recommendations of inspection, monitoring, and maintenance program that result from the Phase 1 (and other assessments) should be begun.

However, it is recognized that programs that simply increase the plant total inspection, maintenance, and monitoring effort will not be compatible with plant performance goals. Hence, the programs must be “optimized” for aging management effectiveness to preserve the life extension option. This optimization should make use of a proactive aging management approach for SGs involving use of advanced diagnostic and inspection techniques. These techniques can be used to focus the plant programs on those areas-at-risk of potential significant aging in SGs during the operational period in advance. A structured and managed approach to this part of the implementation process has been developed, in co-operation with Canadian CANDU utilities, for implementing before life extension.

4.0 Interaction Between PLiM Life Assessment and Condition Assessment

Typically, the PLiM program for a CANDU plant has an initial focus on a relatively small set of critical systems, components and structures. For critical structures and components, this program uses the CSSC life assessment processes described earlier. In addition to these studies, Canadian utilities that are evaluating PLEx (with an objective to extend plant operation another 20 to 30 years) are also performing a systematic review of the complete plant. This is to determine what other equipment refurbishment or replacement will be required due to aging or obsolescence. From the experiences, it is important to keep the refurbishment outage scope separate from the on-going work for extended operation to ensure that this outage duration is not lengthened or burdened with cost of maintenance work.

This systematic review of the complete plant is being carried out with a process called "Plant Condition Assessment". While Condition Assessment (CA) has been used as part of plant license renewal in the United States, the Canadian utility application (such as for the Point Lepreau project [5]) covered a wider scope. The emphasis in license renewal is on ensuring that adequate programs exist to properly manage aging of the plant so that safety is maintained. In addition, this project must establish the likely timing of replacement of major pieces of equipment so that estimates can be made of the expenditures to be expected during the refurbishment project and during the life of the refurbished plant.

It provides a structured approach by following these main steps:

1. Determination of systems important to nuclear safety or power production,
2. Generation of complete lists of constituent structures, components, and commodities (SCCs) in each system,
3. Determination of those SCCs that are adequately addressed by normal maintenance activities,
4. Condition Assessment of those SCCs where normal maintenance may not sufficiently identify or mitigate aging effects,
5. Assessment to determine items that are obsolete, and
6. Development of recommendations for items that need to be refurbished or replaced and the timing for these activities.

It should be noted that over the past six years, AECL has also been working with Canadian utilities (like NBP and HQ) on a comprehensive CANDU Plant Life Management (PLiM) program, focused on critical systems, structures, and components. Included are in-depth life assessments of critical structures and components, and systematic maintenance optimization assessments of critical systems. While effort continues as the PLiM program advances, many important outcomes have resulted from the work to date. Work methods have been developed to ensure that the life assessment results are fully and effectively utilized and complement those of the plant CA program and planning of the refurbishment outage scope.

5.0 Conclusions

The objective of both KEPRI and AECL is to maintain the Wolsong Unit 1 as a safe, economic, and reliable means of electricity production throughout its design life and to preserve its capability for extended life operation. A comprehensive and integrated program of plant lifetime management (PLiM) has been developed and is in process of being implemented.

The CANDU PLiM program is already helping other reactor owners achieve their goals for effective life attainment and to preserve the option for extended operation. It has provided CANDU utilities with in-depth assessments and promising life prognosis for the key critical SCCs in the plant. This has been an important input into Canadian utility decisions to embark upon a detailed CANDU 6 plant extended operation program (such as in the case of Point Lepreau).

To date, the steam generators in the CANDU 6 Wolsong Unit 1 have had a very good service record with essentially no significant active degradation reported. In performing the systematic and detailed life assessment of this critical equipment, a key activity is diagnosis of the operational history for aging indicators, as well as a thorough understanding of applicable degradation behavior. With little degradation data, a heavy reliance is placed on the thorough understanding of the applicable degradation mechanisms and the associated -"stressors"-. This understanding derives from research and development programs, integrated with knowledge from relevant field data of other plants.

As an outcome of the SG life assessment work, there are unique aspects of the Wolsong Unit 1 steam generators that could impact on maintaining life attainment or preserving condition for extended operation. While the prognosis for life attainment and for extended operation of Wolsong Unit 1 steam generators is good, it has also been found that this conclusion is very dependent upon implementation of the recommendations of the work. A typical proactive strategy of SG age management recommended for other CANDU 6 plants is outlined. This is an example of the PLiM development and assessment considerations of a particularly critical component, which is supporting CANDU plant life management.

To extend the benefits of systematic aging assessments to the rest of the NPP (and hence better determine the scope of the refurbishment outage), a Plant Condition Assessment process has been developed and applied. This process is also available for using in the future at the Wolsong Unit 1, and which, together with PLiM life assessments, provide the technical basis for evaluating refurbishment requirements for plant life extension planning.

6.0 References

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Figure 1 - Life Assessment Process and Interfaces (for Long Life CSSCs)