CANDU PLANT LIFE MANAGEMENT—SAFEGUARDING THE INVESTMENT

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ABSTRACT

With a large number of the CANDU® [1] NPPs getting to the mid-point of their "design life", a number of programs have been initiated by the Utilities and AECL to proactively manage plant aging, hence ensuring a safe and reliable operation for the remaining design life.

An integrated aging management program is being formulated in response to the regulatory authority the Atomic Energy Control Board (AECB). This integrated program will take into account safety, performance and economic requirements. Elements of this program cover a variety of areas; Phase 1 covers life assessment studies of the critical systems, structures and components (SSCs) including a methodology for defining the critical SSCs. Other programs within Phase 2 address the preparation of a unified set of industry guidelines covering maintenance and inspection requirements during early, middle and late years of plant operation. A "technology watch" program has also been initiated. The objective of this program is to identify far in advance potential aging phenomena and failure modes that could affect plant performance along with the inspection and maintenance required to monitor and mitigate such aging effects.

The importance of maintaining the plant within a well-established "licensing basis" envelope is also discussed. Plant licensing is carried out for an initial set of conditions and equipment status which may vary during plant life. Canadian utilities are required by the licensing authority, the AECB, to assess the impact of aging on the licensing case for each plant in operation. So far, the main focus of these assessments has been the impact of aging on key parameters such as fuel thermal margin and containment leak rate.

Ongoing activities covering characterization of aging, maintenance, monitoring, and appropriate refurbishments are examined. Emphasis of R&D performed to characterize degradation mechanisms, support inspection and fitness for service guidelines are also briefly outlined.

1. INTRODUCTION

This decade marks the maturity of the CANDU program with many plants approaching mid-life particularly in Canada. Table 1 shows the age distribution of CANDU NPPs worldwide (in operation or under construction).

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[1] (CANada Deuterium Uranium) is a registered trademark of AECL (Atomic Energy of Canada Limited)

Table 1 CANDU Reactors in Operation or Under Construction

Name	Location	Capacity Mwe (net)	In-Service date	Age(years)
Pickering 1	Canada	515	1971	27
Pickering 2	Canada	515	1971	27
Pickering 3	Canada	515	1972	26
Pickering 4	Canada	515	1973	24
Bruce 1	Canada	848*	1977	21
Bruce 2	Canada	848*	1977	21
Bruce 3	Canada	848*	1978	20
Bruce 4	Canada	848*	1979	19
Point Lepreau	Canada	633	1983	15
Gentilly-2	Canada	638	1983	15
Wolsong 1	Korea	638	1983	15
Embalse	Argentina	600	1984	14
Pickering 5	Canada	516	1983	15
Pickering 6	Canada	516	1984	14
Pickering 7	Canada	516	1984	14
Pickering 8	Canada	516	1986	12
Bruce 5	Canada	860	1985	13
Bruce 6	Canada	860	1984	14
Bruce 7	Canada	860	1984	14
Bruce 8	Canada	860	1987	11
Darlington 1	Canada	881	1990	8
Darlington 2	Canada	881	1989	8
Darlington 3	Canada	881	1991	7
Darlington 4	Canada	881	1992	6
Cernavoda 1	Romania	665	1996	2
Wolsong 2	Korea	668	1997	1
Wolsong 3	Korea	668	1998	-
Wolsong 4	Korea	668	1999	-
Qinshan1&2	China	700 x 2	2003	-

* Electrical equivalent (electricity plus process steam)

Aging processes affect all nuclear power plants presently in operation. Characterisation of these aging processes that occur in nuclear power plant structures, systems and components (SSC) is needed if age-related degradation is to be properly managed. This Plant Life Management (PLIM) program is designed to examine all facets of plant operation, maintenance and inspection with the objective of ensuring that for all systems structures and components critical to plant safety and reliability, effective mitigation of plant aging mechanism is in place. This program assesses the state of health of critical plant systems, structures and components (SSCs) and identifies any potential aging phenomena that might impact on plant safety and availability. The plausibility of aging degradation mechanisms is also addressed and recommendations are made for effective monitoring inspection and/or maintenance required to mitigate these aging effects and ensure reliable performance. These assessments form the basis of a living aging management program. A successful PLIM program provides the plants with the necessary assurances for continued safe, reliable and cost-effective plant operation and also provide the basis for investment decisions to achieve the design life and beyond.

2. PROGRAM OBJECTIVES

The overall objectives of the PLIM program are:

To perform a comprehensive assessment of the critical systems, structures and components and develop or enhance the plant inspection, maintenance and rehabilitation programs to effectively manage the effects of aging degradation. To ensure continuing safe, reliable and cost effective operation of existing CANDU 6 stations in accordance with the following goals:

a) The risk to the public from operation of CANDU 6 units is well within the regulatory requirements throughout the nominal design life of 30 years (life assurance);
b) Plant availability >= 85% capacity factor lifetime contributes to providing electricity at a competitive cost during the nominal design life of 30 years (life assurance);
c) Major unexpected problems are avoided through identification of potential aging issues before its occurrence. Means for monitoring and mitigation to ensure reliable component performance are implemented in a timely fashion.
d) The life extension option beyond the nominal design life of 30 years is preserved.

3. OVERALL APPROACH & METHODOLOGY

The program has been designed to meet the needs of utilities for a structured work program in support of plant life management. Utilities must be in a position to assess the economic viability of the various elements of the program. These elements have been grouped into three major phases illustrated in Figure 1.

The PLIM planning phase provides the methodologies and studies dealing with the identification of critical structures and components which could impact on life attainment or extension. These studies lead to a number of recommendations for implementation of plant specific programs to monitor and mitigate any degradation mechanisms deemed probable given the operating history. Some of these recommendation are incorporated into the plant life attainment phase and consist of inspection and maintenance programs necessary to assure life attainment. Other recommendations associated with life extension are incorporated into the last phase and consist of studies or programs required for life extension. This phased approach provides the information required for utilities to input to their cost model for plant economic assessments. Table II summarises the elements of each phase.

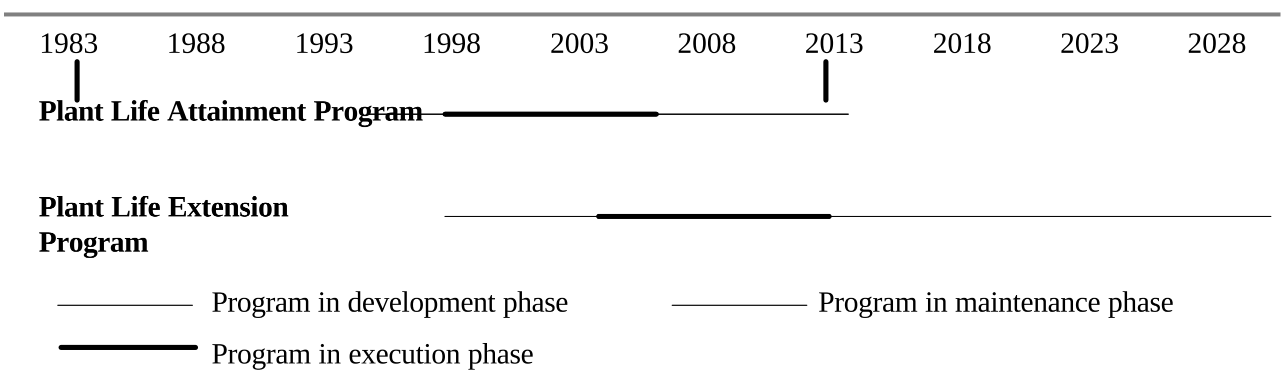

Figure 1 Plant Life Management Program Phases

Table 2 The CANDU 6 PLIM Phased Approach

Phase	***Scope***
PLIM Planning Phase	• Identification of critical SSCs. • Aging assessment studies & R&D of critical components • Technology Watch • Advanced Technology Development
Plant Life Attainment Program	• Fuel Channel Inspection and Maintenance • CANDU 6 plant specific detailed inspection and residual life assessment of key components • Implementation of some life management programs such as plant monitoring and surveillance • Enhancement of plant inspection and maintenance
Plant Life Extension Program	• Fuel Channel replacement strategy and planning • Scoping of regulatory and safety related design changes for life extension • Rehabilitation/Replacement programs for components identified in SSC studies or from inspection in plant life attainment program.

3.1 PLIM Planning Phase

The PLIM planning phase started in 1994. It consisted of the identification of 12 major components based on work done at Ontario Hydro. These components included:

Fuel Channels	Cables
Steam Generators (including internals)	Large Pumps
Reactor Headers, Reactor Coolant Piping	Instrumentation and Control
Reactor Assembly/Calandria Supports	Turbine Generator
Conventional Piping	Cooling Water Intake
Containment Structures	Other Civil Structures
Airlocks	

These components were classified as critical for plant life based on the following criteria:

- Component is non replaceable, or
- Component replacement cost is extremely high, and/or

- Component replacement requires an extensive unit outage.

A number of aging studies were launched on components such as for fuel channels, containment civil structures, reactor assembly/calandria supports. The methodology used for these studies is illustrated in Figure 2. Preliminary results from these studies are discussed in section 4.

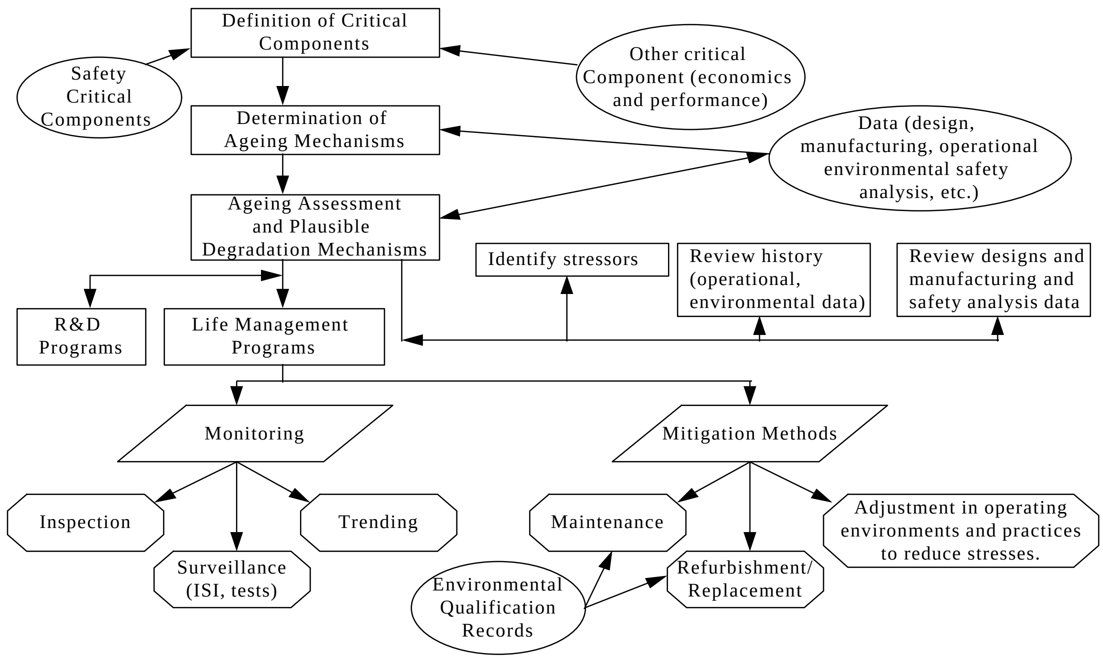

Figure 2 Critical SSC Studies - Key Elements

Recently, unanticipated problems such as feeder pipe flow assisted corrosion and reduced reactor overpower trip margin due to changing flow conditions in the heat transport system suggested that a more comprehensive approach for the identification of potential aging mechanisms is required. While these aging phenomena are not life limiting by themselves, the combined impact of these type of problems on plant capacity factors could be a concern. A two-prong approach is proposed.

1. A technology watch is proposed to anticipate as early as possible problems that could have major implications for the plants in the longer term. The performance of existing plants has been affected on a number of occasions by unexpected technical or licensing problems. The ability of the industry to respond to these issues is dependent on early detection and identification. A technology watch is therefore proposed across the industry to monitor for early signs of system or component degradation in existing plants and initiate timely engineering analysis or research.

2. A comprehensive assessment of critical structures, systems and components will be carried out similar to programs launched by other utilities. The process allows for importance ranking as well as risk ranking thereby providing an overall priority ranking.

The methodology consists of the following steps:

a) For each system important functions to plant safety, environment and reliability will be identified

b) For each function, the failure mechanisms and their impact on plant goals will be identified. In particular, the requirements established in the plant safety analysis and probabilistic safety analysis will be reviewed in detail to ensure that any degradation mechanisms which could invalidate the analysis are identified.

c) Components that could cause these failures will be identified. Both active and passive components will be included.

d) Failure modes and effect analysis for these components will then be completed. For components where the failure modes and effect analysis cannot be completed due to lack of information, then these components will be added to the list for special aging studies.

This approach will provide a more comprehensive list of critical SSCs and ensure that the plant surveillance, inspection and maintenance program are enhanced to cater to aging mechanisms before they impact on plant performance.

4. PLANT LIFE ATTAINMENT PROGRAM

A number of specific programs are underway as a result of the PLIM planning phase work to date. A summary of the major programs follows:

4.1 Fuel Channels

To date, pressure tube aging degradation mechanisms have been fully characterized through extensive R&D and inspection of current reactors. These resulted in the development and application of fitness for service guidelines and methods for mitigating aging in current plants. Table 3 provides a summary of key PT aging mechanisms and life management programs. For CANDU units currently under construction or planned, the fuel channel design and material property improvements that have been developed are expected to result in less degradation and significantly reduced inspection and maintenance requirements to achieve the design lifetime of the tubes

Table 3 Summary of Key Aging Mechanisms of CANDU P/T Life Management Actions

Mechanism	Units Affected	Life Management Actions
Irradiation Enhanced Deformation	Pickering (1-4) Bruce (1&2)	Large Scale Fuel Channel Replacement (LSFCR)
	All other units	• Monitor deformation of operating tubes • Testing at fast flux facilities for end of life properties
DHC due to a hydride blister (PT/CT contact)	Pickering (1-4) Bruce (1-2)	LSFCR LSFCR
	Units with 4 potentially displaced spacers	Spacer Location and Relocation (SLAR)
	All other units	No special program required
DHC due to stress concentration (tube flaw)	Early units	P/T with flaws removed
	Later units	Sources of serious tube flaws eliminated. Reference to FFSG. Generally no action needed

4.2 Steam Generators

Steam generators in CANDU plants have performed relatively well compared to PWR plants. However they have contributed to the incapability of operating plants particularly in Bruce A and Pickering. Experience to date with Incoloy 800 tubing on Darlington and CANDU 6 Steam generators has been good. Strict control of operating conditions (e.g. chemistry) and aggressive remedial actions and careful proactive maintenance activities, backed by significant R&D have led to a decrease in S/G related unavailability of CANDU plants. Canadian CANDU utilities have developed programs for remedial actions to combat degradation of performance (Gentilly 2, Pt Lepreau, Bruce A/B, Pickering A/B) and strategic plans to ensure good future operation. CANDU specific fitness for service guidelines (FFSG) are currently being prepared capturing R&D results, corrosion and mechanical degradation of tube bundles and internals, chemistry, thermal hydraulics, fouling, inspection, etc. Apart from the FFSGs, other aging mitigation programs are being implemented as needed including S/G tube primary and secondary side cleaning and regular water lancing of sludge piles. The combined effects of all proactive measures/ improvements in operating practices and chemistry modifications will ensure S/G design life with minimum impact on capacity factors.

4.3 Containment Civil Structure

The containment civil structure study is complete and is being reviewed by the Gentilly and Point Lepreau plants. The plausible degradation mechanism for the containment structure have been identified for both stations; the most important being minor concrete cracking and a slight increase in permeability of containment. The main aging mechanisms causing these degradations were freeze/thaw cycles, concrete shrinkage and creep and repeated containment leak rate test. A number of specific recommendations for each station are being considered for the plant life attainment program. The maintenance practices at the Canadian CANDU 6 stations (Gentilly-2 and Point Lepreau) are currently a combination of corrective and preventive maintenance practices. A significant fraction of the maintenance activities fall into the corrective maintenance category. As plants age a shift in maintenance strategy is needed to move from a predominantly corrective maintenance program (70:30 corrective:preventive) to a predominantly preventive maintenance (30:70 corrective:preventive) one. Otherwise a declining performance could result.

This PLIM program proposes a modernisation of the CANDU plant maintenance and inspection program using the processes and technology currently available and commonly used in the best utilities within Canada, Europe and in the US. Through the methodology described for the assessment of critical SSCs, components and structures critical to overall plant goals will be identified on a system by system basis. Implementation of this program at a specific plant will involve reviewing the plant maintenance history on a component basis, reviewing the existing maintenance program scope and modifying the program accordingly.

5. PLANT LIFE EXTENSION PROGRAM

For the older CANDU plants, fuel channels are currently the only known limiting component for life extension beyond 30 years based on an 80% capacity factor. While research activities may lead to strategies that could extend life of these original fuel channels beyond 30 years, utilities had prudently made plans for a retubing outage some time between 25 and 30 years of service. The retubing outage is therefore an opportunity to consider rehabilitation of other CANDU 6 systems or components during this outage to ensure a 50 year life is achieved thereby avoiding another major outage after retubing. Up front planning of this rehabilitation is key to maximise its benefit. This Plant Life Management (PLIM) is intended to undertake the up front assessments, analyses and planning sufficiently early to ensure any major outage rehabilitation work required for a 50 year plant life is identified and planned for execution during the retubing outage. The scope of this program is preliminary at this stage and will depend heavily on the remaining work from the PLIM planning phase and the result of inspection programs executed as part of the plant life attainment program. Some of the considerations at this stage include:

- Assessment of emerging regulatory and licensing requirements on plant life extension
- Instrumentation and control equipment obsolescence
- Control computer system upgrades

6. PLIM CONSIDERATIONS FOR FUTURE DESIGNS

The lessons learned over the last decade with plant life management have been incorporated into new designs. AECL has adopted general design philosophies for CANDU 9 aimed at long component life, high reliability, ease of maintenance and fast equipment and component refurbishment or replacement. Figure 4 illustrates some of the key considerations which go into the design.

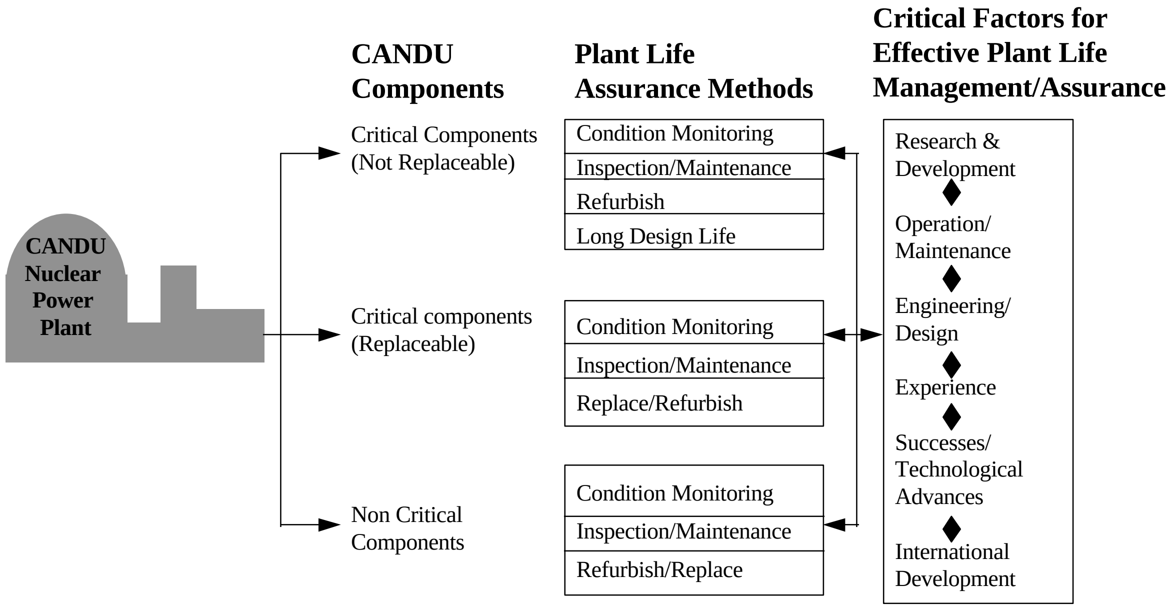

Figure 4 PLIM Considerations During Design

Some of the results are:

1. Detailed studies and assessments were completed on component replacement, single and large-scale fuel channel replacement and steam generator replacement. The findings led to building layouts that are based on improved access for maintenance tasks, with adequate laydown areas and equipment removal paths.
2. Equipment removal paths were assessed by using 3-D Computer Aided Design and Drafting (CADD) "walk through" features. This confirmed the feasibility of fuel channel and other key component replacement.
3. Station and building layouts that locate the balance of nuclear steam plant (BNSP) systems – traditionally referred to as balance of plant (BOP) – in a separate building away from the harsh reactor building environment. This enhances the ability to maintain the BOP and implement plant life management programs. The equipment lasts longer and requires less stringent equipment qualifications, resulting in less frequent equipment maintenance, refurbishment or replacement.
4. The application of modern human factors design practices, including a plant-wide "link analysis". This led to improved plant layout, and operations and maintenance efficiency, while minimising the potential for human error.
5. Outage timing flexibility for plant life management programs.
6. Use of proven components, the provision of redundancies, and extensive availability of on-power maintenance.
7. Use of in-core components that can be replaced quickly; for example, the reactivity control units can be replaced within two to three shifts and single fuel channels can be replaced within four days.
8. Incorporation of design and layout features that promote extended life for cable systems.

7. CONCLUSION

The Canadian nuclear industry objective is to maintain the CANDU NPP as a safe and reliable means of electricity production in recognition of its role in today's global economy. To achieve this standard, the industry has focused on an effective strategy for plant life management and life extension. This program must now be executed on a high priority basis in co-operation with the utilities to assure continued good performance of the CANDU 6 units and preservation of the life extension option. More importantly, through the feedback from these programs, the optimised plant inspection and maintenance and the technology watch, this PLIM will be a living program benefiting existing and future CANDU plant operators.

8. REFERENCES

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