# AGING ASSESSMENT OF CANDU PLANT MAJOR COMPONENTS

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## ABSTARCT

Korea Electric Power Research Institute (KEPRI) had worked a comprehensive Plant Lifetime Management (PLiM) project for a CANDU plant in corporation with Korea Hydro and Nuclear Power (KHNP). The project had been performed to understand the aging status of major components screened from the plant and to address provisions for the continued operation over its design life. A feasibility of the continued operation was reviewed in the aspects of technology, economics, and regulatory environments. This paper introduces general approach of aging assessment, screening of critical components and an experience of aging assessment for an example of fuel channel that is the most critical component in CANDU plant.

**KEY WORDS:** life management, aging management, safety, nuclear power plant, economic assessment, screening, SCCs, PSR, degradation, CANDU, fuel channel, pressure tube, creep, elongation, diametric expansion, deuterium uptake, data collection, database

## INTRODUCTION

A CANDU6 nuclear power plant in Korea has been being operating about 20 years since 1983, which is two-thirds of design life. As time passed, systems, structures, and components (SSCs) can be degraded by various modes of aging phenomena although good operation and maintenance practices have been implemented to the field. Korea Electric Power Research Institute (KEPRI) had worked a comprehensive Plant Lifetime Management (PLiM) project for a CANDU plant in corporation with Korea Hydro and Nuclear Power (KHNP). The project had been performed to understand the aging status of major components screened from the plant and to address provisions for the continued operation over its design life. A feasibility of the continued operation was reviewed in the aspects of technology, economics, and regulatory environments. This paper introduces general approach of aging assessment, screening of critical components and an experience of aging assessment for an example of fuel channel that is the most critical component in CANDU plant.

Figure 1 shows a schematic diagram of the PLiM feasibility study. On and off-shore licensing requirements and current practice for continued operation of CANDU plants beyond design life are reviewed and used for a reference of aging assessments. Prior to assessing aging and life of the SSCs, KEPRI screened the critical SSCs that are passive and long-life components and can limit the continued plant operation. An example of the screened major critical components and groups are listed in the centered box of Figure 1. Collected data of design, manufacturing, test and inspection, maintenance, replacement, drawings, material, and operation history are used as technical fundamental of the assessment. And they are stored into the PLiM database with the results of technical aging and life evaluations. Including PLiM recommendations from assessing aging of each SSC, PLiM cost and investment strategy can be established. Based on the cost and strategy economic evaluation is performed in the way of various economic parameters, like comparison of continued operation cost, generation cost change, and income per kW with alternative power sources that will used instead of the PLiM plant. In this study 1000MWe Korean standard nuclear power plant was assumed as an alternative power source based on the national policy of electricity power resources.

## GENEAL APPROACH OF AGING ASSESSMENT IN PLiM

Nuclear PLiM program is usually consisted of three phases as tabulated in Table 1. In the first phase, a feasibility of the continued operation is evaluated to support top manager's decision making whether continuing to operate the plant. Once the policy is determined to operate the plant beyond design life on the basis of the feasibility study, the second phase program works out to evaluate detailed lives of SSCs and to establish aging management programs together with field walk downs, tests, diagnosis and aging inspections. When the regulator evaluates the results of PSR containing second phase life assessment and endorses, the aging management programs of the PLiM second phase are implemented to the field. This is the PLiM third phase that replaces aged components, install new performance monitoring systems, and change designs to improve obsolescent systems in the following outages as they are scheduled.

Nevertheless the plant safety can be affected by the status of system operating performance that seems to be dependent on the structural integrity and degradations of structures and components (SCs) belong to systems. To solve this issue IAEA has recommended member states to implement PSR as a tool of ensuring a high level of safety throughout plant service life. Reviewing plant safety in every 10 years, PSR can deal with the cumulative effects of the

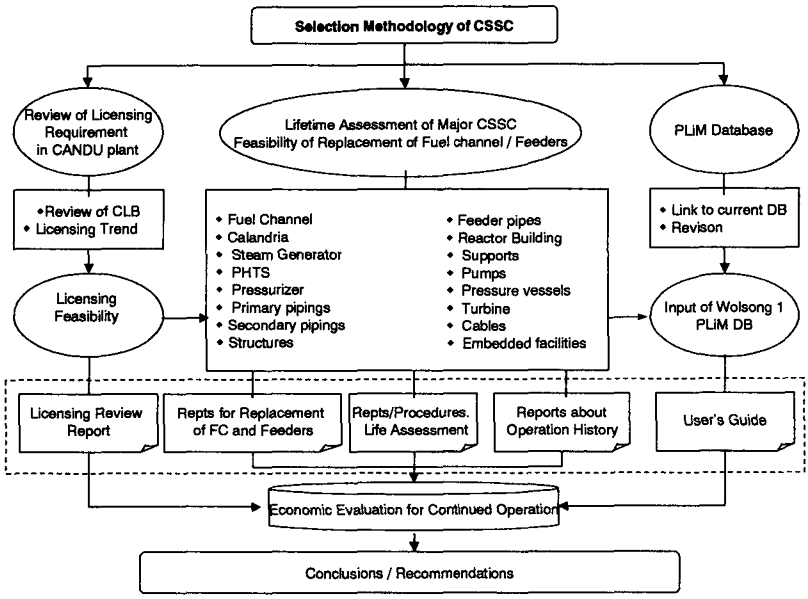


Fig. 1 Schematic diagram of a CANDU PLiM feasibility project

plant aging, modification, operating experience, and technology evolutions.

In spite that all plant SSCs has to be considered in PSR, PLiM basically focuses on the long lived passive components that are relatively hard to replace and refurbish during normal operation. Therefore it can be said that the scope of PSR is wider but depth shallower than that of PLiM, which includes engineering evaluations, such as quantitative time limited aging analysis (TLAA), residual life estimations, field tests and examinations, diagnosis and monitoring, and aging management programs. Figure 2 simultaneously tells the scope and depth of evaluating the SCs of PLiM from PSR.

Short-lived active components excluded from PLiM program are scoped into the aging management of PSR, and the engineering level of life evaluation is not complicate and deep as much as that of PLiM. PSR reviews the current physical status and records of maintenance and inspection done to the components in the past. Comparing the review results with current safety standards and practical experiences on and off-shore in terms of aging and maintenance, utility revises the technical procedures and plans how to improve the system safety and slow down the degradation of SCs for the next 10 years. So the depth of PSR engineering evaluation becomes shallower but the scope wider than that of PLiM.

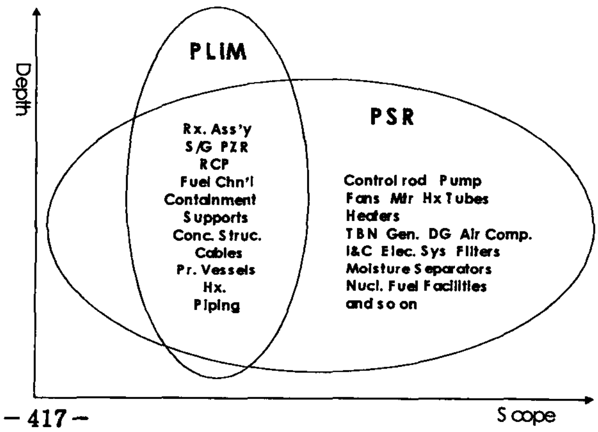

Fig. 2 Technical Depth and Evaluation Scope of PLiM and PSR

The general process of aging assessment for the critical SSCs is shown in. Figure 3. The aging assessment starts with the selection of the critical SSCs among all the plant structures and components. The selection methodology is described in detail next chapter. All possible documents about design, manufacturing, operation, inspection and maintenance should be collected and kept in database. Based on the previous CANDU PLiM experiences and publications, and technical consultations of experts, degradation and aging mechanisms of each SCCs are identified and evaluation methodologies cleared. The aging phenomena can be recognized through reviewing plant data and history of operation, test, inspection and maintenance. Current aging status of the screened CSSCs is evaluated with the design criteria by document review. The next is to find the evaluation methodology for the recognized aging phenomena and/or develop the methodology, when necessary. Finally, remaining lives of CSSCs are evaluated and PLiM cost estimation and work plan for the detailed life evaluation re established.

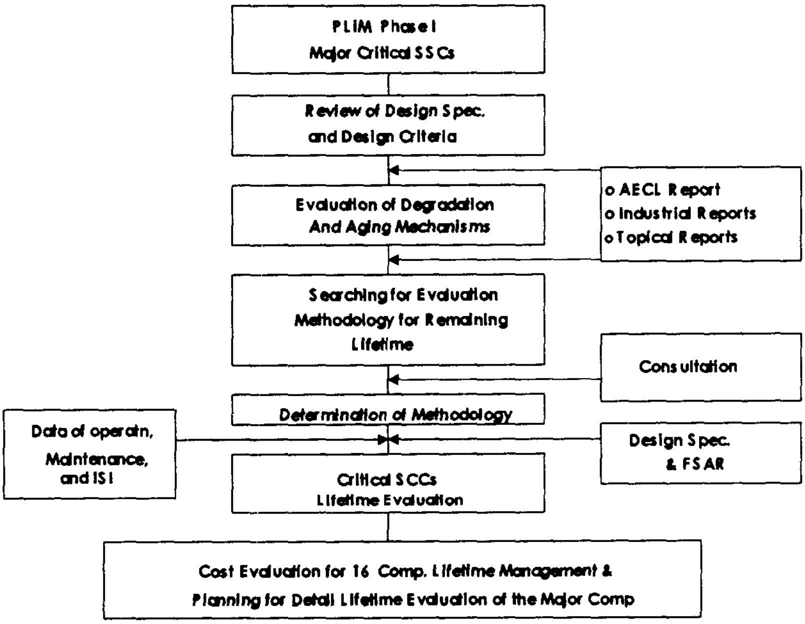


Fig. 3 Process of Aging Assessment

# SCREENING OF CRITICAL SSCs

Screening of systems, structures, and components important to PLiM and identification of critical SSCs for aging assessment is very essential part of the PLiM feasibility project to concentrate the efforts and to properly allocate PLiM resources. They are usually derived from the safety-related, non-safety but can affect plant safety function, and power concerned SSCs. Power concerned criteria showing the importance of SCs in power generation regarding plant availability and other safety requirements are also applied in the screening process. After screening critical SCs, they are to be identified and prioritized to determine their relative importance in PLiM program. Critical components were prioritized using eight attributes as shown in Tale 1.

Most of screened SCs would be long-lived passive ones that are costly, technically difficult to resolve degradation, and limit the continued plant operation because of hard and expensive replacement or no precedent experiences. Other long-lived passive components discriminated from the PLiM and active ones of the plant that are relatively easy to replace or refurbish are maintained in preventive maintenance and PSR. It is necessary to develop a methodology to rank plant structures and system components according to their relative importance based on failure risk assessment. Once relative ranking exercise is completed, a threshold is established above which the components are considered critical for formal assessment. For such critical SSCs, life assessment studies should be performed an in-depth understanding of the degradation mechanisms and the development of an aging management plan to address them. Factors applied to prioritize the CSSCs are as follows: effect of failure on public safety, effect of failure on plant environment, effect of failure on plant production capability, component failure and repair implications on worker safety, cost of replacement or repair, likelihood of failure, etc.

Table 1 Weighting factors and values

| No. of Items | Weighting factors | Maximum estimating value | Absolute weighing value | Maximum weighed value | Relative weight value |
|---|---|---|---|---|---|
| A1 | Safety impact | 10 | 10 | 100 | 0.15 |
| A2 | Failure category (expectancy) | 10 | 5 | 50 | 0.08 |
| A3 | Impact on environment | 10 | 8 | 80 | 0.12 |
| B1 | Worker safety impact | 10 | 5 | 50 | 0.08 |
| B2 | Repair cost | 10 | 9 | 90 | 0.14 |
| B3 | Production impact | 10 | 10 | 100 | 0.15 |
| B4 | Repair difficulties | 10 | 4 | 40 | 0.06 |
| C | Likelihood of failure | 10 | 15 | 150 | 0.23 |
| | total | - | 66 | 660 | 1.00 |

Typical CSSCs can be screened in CANDU PLiM through the above screening process are as follows: Fuel channels, feeder pipes, reactor assembly, steam generator, pressurizer, primary heat transfer system piping, primary system pipes, secondary system pipes, pumps, pressure vessels, reactor building, supports, turbine, cables, structures, embedded facilities. Primary system pipes, secondary system pipes, pumps, pressure vessels, supports, cables are grouped and re-categorized according to their materials, operating condition and other characteristics. A few representative components are selected among the group components and assessed of their aging. Phase I study covers the representative components and structures to understand the aging phenomena.

## AGING ASSESSMENT OF FUEL CHANNEL

As of an example of aging assessment of CANDU CSSCs, detail procedure and methodology applied to the aging assessment of fuel channel are presented. Although aging status depends on the design condition and O&M history of each plant, fuel channel is usually the most highlighted component in aged CANDU plants in terms of safety, integrity, performance, and maintenance. To assess aging of fuel channel they reviewed lots of plan information and evaluated its aging in respect to the degradation mechanisms

**Design Requirements**

Design requirements and performance expectations/criteria along with degradation allowances covering the service life of the pressure tube are review first. This includes design temperature and pressure, design mechanical loads, pressure tube initial dimensions, corrosion and wear allowances, pressure tube deformation allowances, fracture toughness, pressure tube material, end fitting material, etc. Design documents such as FSAR, design manual, technical specification are reviewed to understand the design requirements. The fuel channel assemblies are designed to satisfy its functional requirements for 210,000 effective full power hours (EFPH) of CANDU6 reactor operation (i.e., 30 years at a capacity factor of 80%). Table 2 shows the allowance OF corrosion/wear and deformation of a pressure tube.

Table 2 Dimension and allowances of a pressure tube

| Dimension or Allowance | Value |
|---|---|
| Diametric creep strain, % | 4.117 |
| Reduction in wall thickness, mm | 0.279 |
| Inside wear and corrosion, mm | 0.165 |
| Outside corrosion, mm | 0.038 |
| Reserve, mm | 0.051 |
| Maximum inside diameter (per drawing), mm | 104.09 |
| Minimum wall thickness (per drawing), mm | 4.191 |

**Configurations**

Plant configuration data of design, materials, manufacture and assembly of the fuel channel is basically reviewed to see the conditions that can have a significant influence on fuel channel aging. This includes pressure tube to end fitting zero clearance and low clearance rolled joints, calandria tube design criteria, annulus spacer design criteria, and end fitting design criteria. History docket is to be reviewed to understand any design changes and modifications during manufacturing and construction. Sometimes it could be found that there has been deviation disposition requests and their mitigation of the deviation from the requirements on technical specifications during manufacturing of fuel channel.

### Operation, Inspection and Maintenance Activities

Operations, tests, inspections and maintenance activities to date on the fuel channels are reviewed. They are to be inaugural fuel channel inspections, examination of pressure tube archive samples, fuel channel elongation measurements, pressure tube diameter measurements, pressure tube wall thickness measurements, fuel channel sag measurements, gap between calandria tubes and horizontal reactivity mechanisms, pressure tube deuterium concentration sampling, pressure tube volumetric inspections for flaws, examination results of tubes removed from operation, garter spring repositioning by SLAR, and chemistry data of primary heat transport system, etc. Table 3 shows an example of the inspection and maintenance history of operating fuel channels.

### Assessment of Degradation Mechanisms

Active and plausible degradation mechanisms are identified and their impacts on future performance and life expectancy of the fuel channel components and in particular the pressure tube are assessed. These assessments are based on the information generated from previous sections mentioned above, operational/chemistry data are obtained from the plant documents and engineering evaluations, as required, using as-known knowledge and expertise. The degradation mechanisms to be addressed include irradiation induced deformation, deuterium ingress, susceptibility to delayed hydride cracking, fracture toughness reduction, service induced damage, high operating loads, and fatigue loads, etc. The deformation is found as dimensional changes and classified as axial elongation, diametric expansion, wall thinning, pressure tube sag between channel annulus spacers, and fuel channel sag. Fig.4 shows the typical aging assessment process of fuel channel.

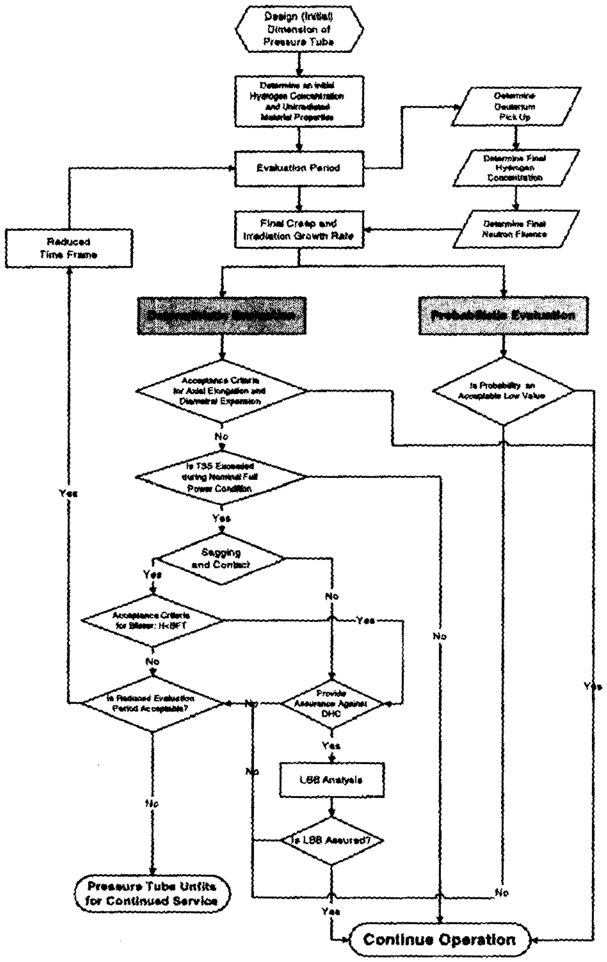

Fig. 4 Aging assessment process of fuel channel

Table 3 An example of inspection and maintenance activities for a fuel channel

| Activity | Outage Start | Time, EFPH |
|---|---|---|
| Criticality | 1982 November 21 | 0 |
| In-service | 1983 April 22 | NA |
| Baseline inspection | 1990 April 9 | 51,261 |
| Periodic inspection | 1992 September 26 | 70,729 |
| Baseline measurement of D2O concent. | 1992 September 26 | 70,729 |
| Periodic inspection | 1994 January 24 | 81,161 |
| Replacement of fuel channels | 1994 January 24 | 81,161 |
| SLAR (spacer location and repositioning) | 1995 May 17 | 90,000 |
| Re-configuration | 1996 October 1 | 101,304 |
| SLAR | 1996 October 1 | 101,304 |
| SLAR | 1998 January 1 | 110,500 |
| Periodic measurement of D2O concent. | 1998 January 1 | 110,500 |
| SLAR | 1999 February 20 | 118,632 |
| SLAR | 2000 March | 126,600 |
| Meas. of gap between LIN and cal. tubes | 2000 March | 126,600 |
| SLAR | 2001 September | 137,200 |
| Periodic inspection | 2001 September | 137,200 |
| Periodic measurement of D2O concent. | 2001 September | 137,200 |

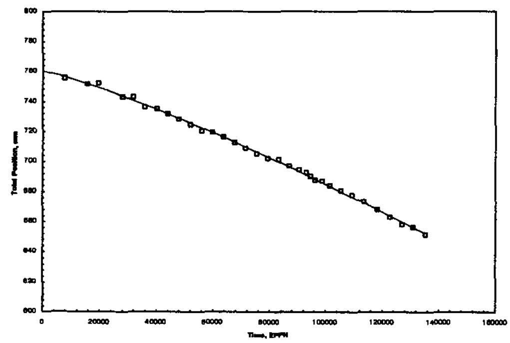


Fig. 5 Axial elongation of a channel

Ageing assessment is performed for the known degradation mechanisms of fuel channels and the most life limiting degradation mechanism would be channel elongation. Fuel channels of the first generation of CANDU6 reactors are expected to reach its limit of elongation before plant design life. So it might be necessary to be replaced the aged fuel channels for continued operation. A several assessment results of fuel channel ageing are introduced in Fig. 5 to 8. Fig.5 rends the axial elongation of a channel and shows non-linear behavior with operating time. Fig.6 and Fig.7 show the inspection results and trend of diametric expansion and thickness of fuel channels, respectively. Fig.8 indicates the trend of deuterium uptake rate at a location of fuel channels. The remaining life is evaluated by analyzing those trends, their design limits, and applying appropriate conservatism.

*Recommendations*

After assessing remaining life of a component, recommendations are to be developed for more detailed life evaluations and in-depth analyses of fuel channel for identified areas, then the recommendations to be performed as a part of Phase II PLiM program. The followings can be issued for the recommendations of life management of fuel channels: stress analysis for nip-up condition and feeder coupling load, bearing chamfer operation, for channel shift work, preparation for large scale fuel channel replacement, revision of in-service inspection program, and etc.

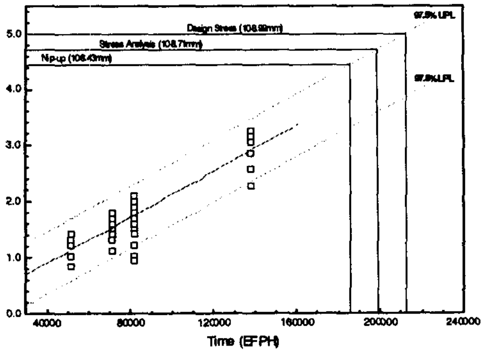


Fig. 6 Diametric expansion of fuel channel

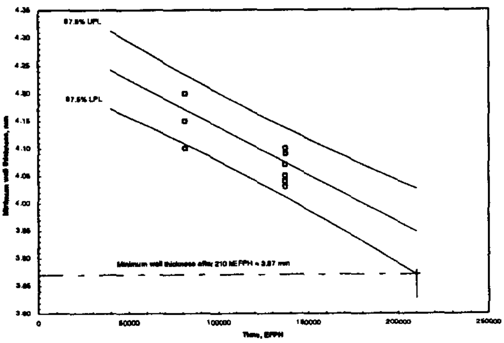

Fig. 7 Thickness of fuel channel

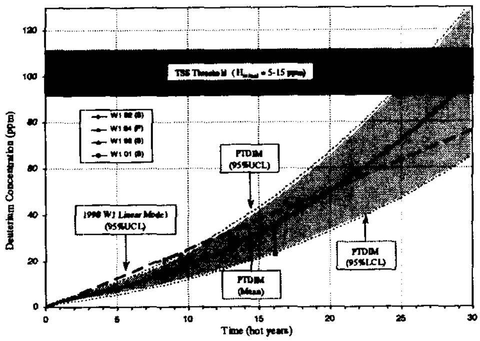


Fig. 8 Deuterium uptake of a pressure tube

# CONCLUSION

The methodology for aging assessment of CANDU6 plant was introduced by showing the experience of plant lifetime management (PLiM) feasibility project. The life evaluation of major critical systems, structures, and components (CSSCs), and embedded commodities has been performed. Those CSSCs were selected by screening and prioritized methodology developed by KEPRI. General approach of aging assessment, relation of PLiM and periodic safety review (PSR), detail screening method used were explained with an actual experience in technical evaluations.

As an example of aging assessment of CSSCs, the results of fuel channels evaluations were introduced that it will come to design limit before 210,000EFPH and need remedial actions. All the products of this project will be used as a background information to make managerial decision on the continued operation beyond the design life of plant.

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