CANADIAN REGULATORY OVERSIGHT OF AGEING MANAGEMENT FOR NUCLEAR POWER PLANTS

K. Kirkhope, A. Blahoianu and G. Frappier
Canadian Nuclear Safety Commission, Ottawa, Ontario, Canada

Abstract

This paper describes Canadian Nuclear Safety Commission (CNSC) staff perspectives on managing the safety aspects of ageing of structures, systems, and components (SSC) of nuclear power plants (NPP). Managing the safety aspects of NPP ageing requires a proactive, systematic, and integrated ageing management approach for the coordination of all activities relating to the understanding, control, monitoring, and mitigation of ageing degradation of SSC. A proposed new CNSC regulatory document on ageing management based on modern international guidelines is described. The regulatory document will provide CNSC guidance for NPP ageing management during design, manufacturing, construction, commissioning, operation, life extension and decommissioning.

1. Introduction

Nuclear Power Plants have been supplying electricity to the Ontario power grid since 1962 and to the New Brunswick and Quebec power grids since 1983. At present, there are 20 CANDU reactor units in Ontario, and one unit each in New Brunswick and Quebec holding power reactor operating licences issued by the CNSC. Most of the operating NPP are now approaching or past 20 years operation. The original planned design life for these reactors was typically 30 or 40 years. The experience has been that the reactors require refurbishment after about 25 effective full power years to replace all of the pressure tubes, and possibly other major components such as feeders or steam generators, due to ageing related degradation [1].

Ageing effects can reduce the ability of an SSC to perform its design functions and to meet its performance requirements over time. Ageing effects may also increase the probability of common cause failures, for example, the simultaneous degradation of physical barriers and redundant components that leads to a reduction of defence in depth. The effect of ageing on overall system or plant safety and performance can be compounded by synergetic effects of multiple ageing mechanisms and component degradations. For example, some utilities are applying an integrated approach to manage the combined effects of different ageing mechanisms for the fuel channels, feeders, steam generators and other components of the primary heat transport system [2]. Therefore, it is important to manage ageing effectively to maintain plant safety, i.e. to detect ageing effects of SSC and to take corrective actions before loss of SSC integrity or functional capability occurs.

With the current NPP fleet approaching or past 20 years operation, and with life extension or long term operation (LTO) planned for some plants, ensuring the continued safety and reliability of ageing plants has become one of the most important tasks facing both the nuclear industry and the CNSC. As well, considering new reactor builds are being contemplated in Canada, experience has shown that a proactive approach that begins early in the design phase is most effective in preventing and managing ageing. This proactive approach should continue through construction and commissioning, operation, possibly extended long term operation, and finally through decommissioning.

CNSC staff is therefore implementing measures to strengthen the role and consistency of implementation of proactive ageing management programs through the life cycle of a NPP. Several aspects of the Canadian regulatory approach to ageing management have been described in previous papers, for example [1, 3-5]. These aspects include the licensee's in-service and periodic inspection programs, component life-cycle management programs, processes to report and investigate newly identified degradation mechanisms, the development of fitness-for-service guidelines, maintenance and environmental qualification programs, the use of probabilistic methods for condition monitoring and operational assessment, and risk-informed in-service inspections. This paper focuses on the current and planned initiatives to improve the Canadian regulatory framework for ageing management programs, including development of a new proposed Regulatory Document, RD-334. This regulatory document will provide guidance for a recommended approach to the ageing management of structures, systems, and components of nuclear power plants to ensure that safety and performance remain within acceptable limits throughout the life cycle of the NPP.

2. Development of CNSC guidelines on ageing management

The CNSC has been a long time proponent of early identification, proactive assessment and strategic safety management of ageing components and systems at NPP [1]. Licensees have developed, on their own or in conjunction with the plant designer, generic procedures for evaluating component and system ageing. These have typically been based on IAEA [6] or industry guidelines [7, 8]. Ageing management and ageing-related program reviews (e.g. periodic inspection, component life cycle management, maintenance, and environmental qualification) have been performed as part of CNSC evaluation of licensee's safety programs [9] and Integrated Safety Reviews for plant life extension in accordance with RD-360 [10]. These assessments evaluated the feasibility, from a safety standpoint, of continued use of the components. However, the reviews have also indicated the current regulatory approach to ageing management lacks consistency by focusing on individual cases. Without common benchmarks it is difficult to ensure consistency and uniformity of compliance assessments of ageing management programs at different licensee sites.

A review of international practice as well of current domestic approaches identified the need to further enhance the current Canadian regulatory framework with respect to ageing management [1]. CNSC staff is also aware that the current level of ageing management effort may need to be further augmented to ensure plant safety as Canada's NPP continue to age, with some plants undergoing life extensions, other units being placed in lay-up prior to

decommissioning, and with the possibility of new builds. Therefore, CNSC staff is implementing measures to strengthen the role and consistency of implementation of proactive ageing management programs, including development of a Regulatory Document. The proposed regulatory document, designated RD-334, will provide guidance for a recommended approach towards ageing management program for nuclear power plants. This document is not intended to override the requirements of other codes and standards, but rather to provide the expected framework within which the codes and standards are applied to ensure that the ageing degradation of SSC is being both effectively monitored and managed. The proposed regulatory document will represent the CNSC's adoption and adaptation, consistent with the Canadian regulatory framework, of the guidance established by the International Atomic Energy Agency (IAEA) in draft safety guide DS382 [12], at which staff also participated in drafting. Key principles and elements used in developing this guide are therefore consistent with modern international safety guidelines and practices, for example [6, 7, 8, 11, and 12], as described in the following sections.

3. Proactive life-cycle strategy for ageing management

An effective NPP AMP follows an approach utilizing the systematic ageing management process that provides a framework for the coordination of all programs and activities relating to the understanding, control, monitoring, and mitigation of ageing of a specific SSC throughout its service life. The CNSC (following IAEA recommendations) have adopted Deming's Plan-Do-Check-Act cycle (see Figure 1) as a model to establish guidelines and to evaluate the extent by which an NPP has systematic processes in place to manage ageing. The systematic ageing management process, which is a key concept of effective ageing management, is divided into five distinct areas, as described below:

1. Understand (Box 1): In order to be effective, the systematic ageing management approach requires a comprehensive understanding of a component, its ageing degradation and the effects of this degradation on the component's ability to perform as per design. The 'Understand' activity is central to this approach, surrounded by other interactive activities.

2. Plan (Box 2): The 'Plan' activity in the figure is aimed at maximizing the effectiveness of ageing management through the co-ordination of all programs and activities that relate to managing the ageing of a component.

3. Do (Box 3): The 'Do' activity is aimed at minimizing expected component degradation through the 'gentle operation/use' of the component in accordance with operating procedures and limits.

4. Check (Box 4): The goal of the 'Check' activity is the timely detection and characterization of any significant degradation through component inspection and monitoring and the assessment of observed degradation to determine the type and timing of any corrective actions.

5. Act (Box 5): The 'Act' activity provides timely mitigation/correction of component degradation through appropriate maintenance and design modifications, including component repair and replacement.

The process indicates the need for continuous improvement of an ageing management program, based on the current understanding of component ageing and on the results of self-assessment and peer reviews. The information obtained through this approach provides important inputs to existing plant programs, such as maintenance and operation.

The CNSC regulatory document emphasises the need for early and pro-active consideration of ageing management for all stages of a plant's life cycle: design, fabrication, construction, and commissioning, operation, life extension, decommissioning as described in the following subsections.

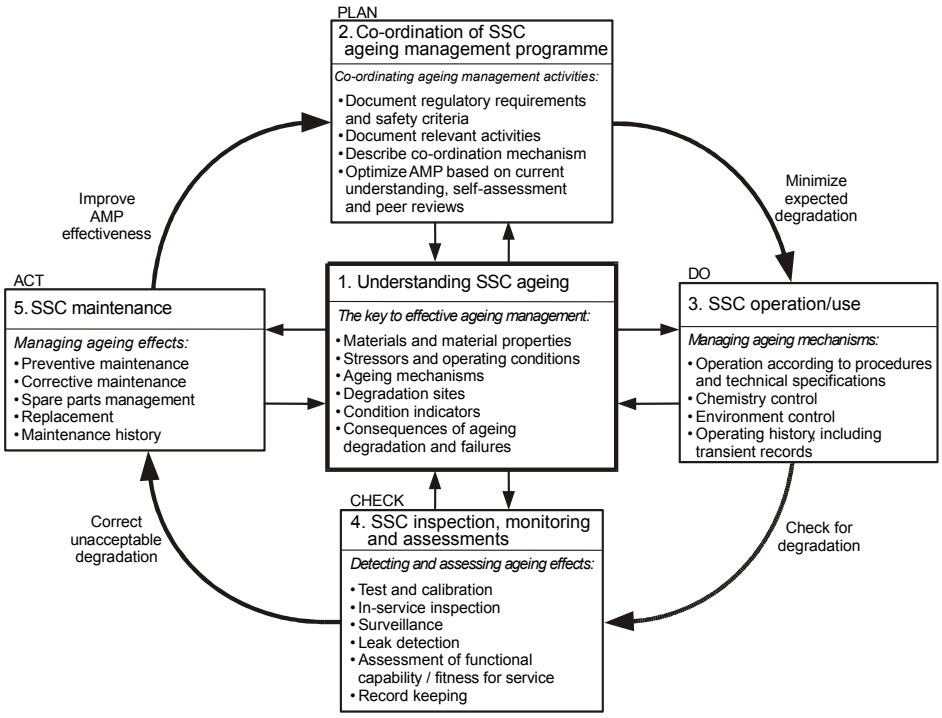

Figure 1 Systematic ageing management process [6]

3.1 Design

A proactive approach to ageing management begins with the design phase during which important decisions having significant impact for preventing and managing ageing effects are made. Ageing was considered in the original CANDU NPP design with knowledge of materials degradation from research and development (R&D) and industry operating experience (OPEX) from early CANDU designs. However, over time the operating performance at some plants declined due to unanticipated ageing effects on certain components which resulted in extended outages to allow for inspections and repairs to address safety concerns. The importance of design features to facilitate ageing management,

inspections and maintenance is much better recognized now than when the plants were originally designed.

The CNSC expects the next generation of NPP will be designed to be much more resistant to ageing and to include features to specifically facilitate ageing management, inspections and maintenance. Provisions should be made in the design for SSC monitoring, testing, sampling, inspection, and surveillance to assess predicted ageing mechanisms and degradation, and to identify unanticipated behaviour or degradation that may occur during operation. The plant layout and SSC design should facilitate inspectability, maintainability and easy access for inspection, testing, monitoring, maintenance, repair and replacement, and which will also minimise occupational exposure during these activities.

The use of advanced materials with greater ageing resistant properties should be considered, along with the need for material surveillance and testing programs to monitor ageing degradations. The need to incorporate on-line monitoring should be considered, particularly where this technology would provide forewarning of degradation leading to failure of SSC and where the consequences of failure could be safety significant.

Appropriate margins should be provided in the design of SSC important to safety taking into account:

- all known relevant ageing mechanisms, potential age related degradation, their interaction and synergistic effects;
- ageing degradation of SSCs in all service conditions, including SSC duty cycles, environmental, process, maintenance and testing conditions, and postulated accident and post-accident conditions;
- impact of ageing degradation on SSC safety functions;
- SSC replacement and refurbishment plans.

In addition to known phenomena, the design should include safety margins and contingencies to cope with “the unexpected” including new load types and previously unidentified ageing mechanisms [13].

It is also considered that ageing management should be addressed in a separate, dedicated section in the Safety Analysis Report (SAR) and should be taken into account in establishing operational limits and conditions (OLC). The SAR should outline the overall strategy for ageing management and prerequisites for its implementation, including identifying all safety significant SSC of the plant that could be affected by ageing; design inputs for equipment qualification of the SSC important to safety, necessary equipment functions to be qualified for normal operation and postulated initiating event service conditions; and specific ageing assumptions (e.g. ageing mechanisms, rates, end of life conditions) used in establishing OLC.

Procurement documents for new NPP and for SSC should specify requirements to facilitate ageing management, including information to be provided by the NPP supplier and other contractors.

3.2 Fabrication, construction and commissioning

Fabrication and construction practices can have a significant effect on the ageing resistance of SSC, often which only become apparent much later in the operating life. Provisions to monitor, manage, and control ageing degradation of SSC should therefore be established and implemented to ensure that the manufacturing, construction, and commissioning processes do not adversely affect ageing degradation of SSC. These provisions should take account of current ageing management knowledge and experience, and other relevant factors affecting ageing and ageing management of an SSC. Key considerations include ensuring:

- Relevant information on the factors affecting ageing management is provided to manufacturers and is sufficiently taken into account in manufacturing and construction;
- Manufacturing takes into account current knowledge about relevant ageing mechanisms and effects/degradations and possible mitigation measures; and
- Reference (baseline) data are collected and documented during manufacturing, construction and commissioning, and documented in a records management system.

3.3 Operation

Operation and maintenance decisions can have huge impacts on plant ageing and potential for long term operation. An effective ageing management program for SSC important to safety should be implemented to help ensure that the intended safety functions and performance are maintained and the risk to the public, worker safety, and the environment from operation of the NPP remains within the licensing basis. The AMP should provide for the timely detection and mitigation of ageing effects in SSC, including detection and evaluation of unexpected service conditions and behaviour of SSC in order to identify new or unforeseen ageing phenomena.

In NPP operations, effective ageing management can be implemented by coordinating within an overall plant AMP existing programs, including operations, in-service inspection, maintenance, as well as technical support and external programs such as research and development. The AMP should provide an integrated framework to coordinate and facilitate feedback between all programs and activities relating to the understanding, control, monitoring, and mitigation of ageing. A systematic approach (including appropriate organizational arrangements, data collection and record keeping, and SSC screening) should be used to provide for the development, implementation and continuous improvement of SSC-specific AMP. The information from the AMP should be incorporated as appropriate into the SAR and other operational programs to ensure the adequacy of OLC. This is discussed in greater detail in Section 4.

3.4 Life extension / long term operation

NPP life extension, or long term operation (LTO), is operation beyond an established timeframe (e.g. by design, standards, licence, and/or regulations etc.) which has been justified by safety assessment, considering life limiting processes and features for SSC. Life extension

depends, among other things, on the material condition of the plant which is influenced significantly by how well ageing has been controlled or managed.

The CNSC Regulatory Document RD-360 [9] provides information on the key elements to be considered when a licensee undertakes a project to extend the life of a nuclear power plant. One of the major elements to assess the safety operation of the plant for the extended period is the Integrated Safety Review (ISR). The ISR is a comprehensive assessment of plant safety for the extended life performed by the licensee in accordance with IAEA Safety Guide on Periodic Safety Review (PSR) of Nuclear Power Plants [10]. The scope of the ISR includes a number review areas (termed "Safety Factors") that are relate specifically with plant material condition and ageing including "Ageing Management", as well as "Plant Design", "Actual Condition of SSC", and "Equipment Qualification". Within the framework of the ISR per RD-360, the licensee therefore evaluates the effects of ageing on NPP safety, as well as the effectiveness of ageing management programs for future long term operation, in order to identify corrective actions and areas for improvement.

3.5 Extended lay-up and decommissioning

During extended lay-up prior to decommissioning, and where required to facilitate decommissioning, appropriate ageing management arrangements need to be continued to ensure that required SSC remain available and functional. This may require implementing relatively long term ageing management provisions for containment system, cooling equipment, and fire protection, lifting equipment and monitoring equipment consistent with licensing requirements.

4. Ageing management program implementation in NPP operation

This section provides additional description of a systematic approach to develop, implement and provide for continuous improvement of SSC-specific ageing management programs for in a NPP operating phase. Alternative approaches are acceptable if it can be shown that they are effective in managing ageing degradation.

4.1 Organizational arrangements

Appropriate organizational arrangements should be established to facilitate effective implementation of an NPP AMP. The following should be considered:

- NPP senior management should establish the policy and objectives of the AMP, allocate the necessary resources (such as human, financial, training, tools, and equipment), and monitor the program to ensure that it is meeting its objectives;
- Responsibility should be assigned to an AMP Coordinator for the AMP implementation, including the co-ordination of relevant supporting programs, periodic review of the AMP effectiveness and continuous AMP improvement;
- Responsibility should be assigned to appropriate organizational units of the NPP (e.g. operations, maintenance, engineering) for the implementation of SSC-specific AMP; and

- Interfaces should be defined and controlled between the AMP Coordinator and other organizational units.

An illustration of the organizational arrangements including participating organizations and their roles and interfaces is shown in Figure 2.

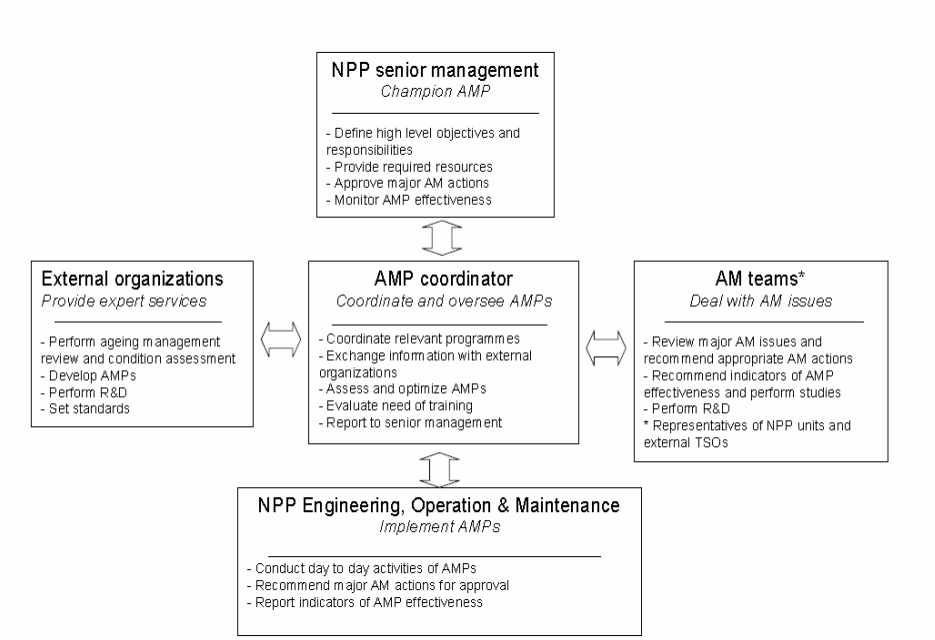

Figure 2 Illustration of organizational ageing management arrangements [12]

4.2 Data collection and record keeping system to support ageing management

A data collection and record keeping system should be established early in the life of an NPP to support the ageing management program. Data and records relevant to the AMP include, but are not limited to, design and design change documentation, manufacturers data, commissioning data, operating history, maintenance history, inspection, surveillance results, and OPEX. Data entered into the system should be auditable, to demonstrate an adequate verification of the data entered, detailed description of the basis for any conclusion, and to trace all applicable sources of information.

4.3 SSC selection and screening for the AMP

A systematic screening/selection process should be used to identify SSC to be included in the scope of the AMP, i.e. those SSC that can have a negative impact on the safe operation of the plant and which are susceptible to ageing degradation. All systems that have been identified as important to safety should be reviewed systematically for their susceptibility to ageing degradation. For SSC that are not selected for AMP, appropriate provisions should be implemented to ensure that their safety significance does not change throughout the plant life due to ageing degradation.

The selection process, including the selection and screening criteria, the information sources used to determine whether the SSC are susceptible to ageing degradation, and the selected SSC, should be documented and justified. This process should establish clear criteria as to which SSC at the facility can be excluded from the scope of AMP, and should include reviewing and using relevant operating experience (OPEX) and research findings.

4.4 SSC ageing evaluations

SSC selected for the AMP should be subject to ageing evaluation to obtain information on the understanding, monitoring, and mitigation of SSC ageing. Existing ageing management reviews (e.g. generic reviews prepared by an owners group, plant supplier or technical support organizations) may be used to minimize duplication of effort. Information from relevant NPP programs (such as the chemistry, periodic inspection, maintenance, and environmental qualification programs) should be taken into account in the ageing evaluation. The SSC ageing evaluation should identify and assess:

- potential ageing mechanisms and their effects for specific SSC or SSC groupings;
- the impact of ageing degradation on SSC functionality / integrity;
- gaps of knowledge in understanding the aging mechanism and in managing degradations;
- effective means to detect and monitor the extent and rate of SSC degradation for the specific ageing mechanisms;
- condition indicators and related acceptance criteria to ensure that the required integrity and functional capabilities of the SSC are maintained;
- effective means to mitigate ageing mechanisms and their effects; and
- appropriate intervals for performing condition assessments.

The methodology and results of the ageing evaluations should be documented and justified. This information should be stored as permanent records in the records management system.

4.5 Condition Assessments

Using the results of the above ageing evaluation as a starting point, the licensee should perform an assessment of the actual condition of an SSC or a component group to:

- Determine the current performance and condition of the SSC, including the assessment of any age-related failures or indications of significant material degradation;
- Compare the current performance and condition against predictions for the identified ageing mechanisms and acceptance criteria;
- Based on current performance and conditions, predict the future performance, ageing degradation, and, if possible, the residual service life of the SSC (i.e., the length of time the SSC is likely to meet its function and performance requirements); and,
- Determine whether the ageing degradation assumptions for the SSC made in the design remain valid and, as appropriate recommend follow-up corrective actions and preventive measures for the SSC-specific AMP.

The condition assessment of an SSC should be derived from relevant ageing management review reports, operation and maintenance and engineering data, and inspection and assessment results, including special inspections and tests, if necessary. Recommendations based on condition assessments should be implemented in a timely manner to monitor performance, prevent unacceptable degradation, and restore function and performance.

4.6 Development and Implementation of SSC-specific AMP Recommendations

Based on the outcomes of the assessments described in subsections 4.4 and 4.5, recommendations for SSC-specific AMP activities should be compiled, documented, and dispositioned. The AMP should provide all information for understanding and managing ageing, including materials, degradation sites, ageing stressors and environment, ageing mechanisms and effects, condition indicators, inspection and monitoring requirements and methods, mitigation methods, regulatory requirements and acceptance criteria. The AMP should include the following attributes [12]:

- Scope of the AMP
- Understanding / predictability of SSC aging
- Preventive actions to minimize and control ageing degradation
- Monitoring and detection of ageing
- Mitigating ageing effects
- Operating experience feedback
- Quality management

Ageing management recommendations that affect other plant programs (such as plant operations, chemistry control, equipment qualification, inspection, maintenance, and major component or plant life management programs) should be made available to those programs. The AMP Coordinator (see 4.1) should ensure such communication. A confirmation process should be established to ensure that adequate corrective actions and preventive measures have been completed and are effective.

4.7 AMP Review and Continuous Improvement

A process for performance review and continuous improvement of the AMP should be established for:

- Identification of deficiencies and opportunities for improvement;
- Optimization of operating conditions, practices, and remedial actions that would reduce ageing degradation rates; and
- Decisions on programs to adjust gaps and to develop improvements in the understanding and managing of ageing.

Both the overall AMP of the operating organization (including policy, scope, organizational arrangements, and resources) and SSC specific AMP should be evaluated in light of current knowledge and adjusted, as appropriate. The SSC-specific AMP may be reviewed against the generic attributes of an effective AMP presented in Section 4.7.

Performance indicators by which the effectiveness of the AMP can be measured should also be developed and trended. Examples of indicators include failure and degradation rates, and comparison of preventive and corrective maintenance efforts.

Whenever an AMP deficiency is identified the significance should be assessed and, where appropriate, a root cause determined and corrective actions taken. Corrective actions should be implemented in a timely manner to prevent recurrences. A confirmation process should be established to ensure that corrective actions have been completed and are effective.

5. Path Forward

The drafting of Regulatory Document RD-334 on ageing management for NPP is completed and it is expected the document will be published for public consultation this year. The guideline will reflect the key ageing management approaches outlined in the preceding sections, and emphasize the adoption of a life-cycle approach to ageing management as well as the establishment of a systematic ageing management program. Once published, the CNSC will initiate compliance program activities to assess licensee programs using these guidelines as a basis for rating safety performance in the area of ageing management.

6. Conclusion

CNSC staff is implementing measures to strengthen the role and consistency of implementation of proactive ageing management programs, including development of a Regulatory Document. Although currently programs are in place to address ageing at each of the Canadian nuclear power facilities, additional regulatory guidance is required to provide a common set of benchmarks to which these programs may be evaluated and to facilitate CNSC staff evaluations of industry performance in this area. The publication of a regulatory document, along with other initiatives that CNSC staff are undertaking at both the national and international level, is expected to serve to provide adequate assurances that the ageing degradation of Canadian NPP is being effectively managed such that sufficient safety margins remain, thus minimizing risks to workers, the public and the environment.

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