AGING MANAGEMENT AND LONG TERM OPERATION IN CANADA – REGULATORY PERSPECTIVE

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ABSTRACT

The nuclear power plants (NPP) in Canada began operation in the early 1970's to the early 1990s, with an intended service life of 30 to 40 years. Almost all of the NPP are now considering or undergoing projects to extend operation beyond the original intended life; this is referred to as for Long Term Operation (LTO). For some plants, the service life is being extended for a relatively short period (a few years) beyond the original design life of the life-limiting components. In other cases, major plant refurbishment projects are required to replace life limiting components in order to extend the operating life 25 years. In either case, LTO of these plants depends very much on how well the actual condition and the aging of the structures and components is understood, controlled and managed. Effective aging management is considered to be a joint responsibility of industry and regulators to ensure the continued safe-long term operation of these facilities. This paper will describe the expectations for long term operation and aging management of NPPs from the Canadian regulatory perspective. Canadian regulatory documents for long term operation and aging management, which are based on modern international guidelines, are described. CNSC participation in a number of aging management and structural integrity initiatives with industry and other national regulatory agencies both, within Canada and at international level is also presented.

INTRODUCTION

There are currently twenty CANDU reactors operating at six NPP locations in Canada. Construction on the earliest operating units, at Pickering A and Bruce A, began in the late 1960's while the most recent reactor units at Darlington entered service in 1993. Several NPP have been, or in the process of being refurbished for continued operation up to 60 years. Longer term operation of these plants depends on by how well aging of their structures and components are being controlled and managed. Based on Canadian and international refurbishment or extended operation experiences, it became evident that at the outset specific safety areas related to the design, operation, and aging management of a nuclear reactor have to be considered for potential refurbishment and upgrade, or for extended and continued operation after the assumed design life of the reactor is reached [1, 2].

THE NUCLEAR REGULATORY FRAMEWORK IN CANADA

The CNSC is an independent Canadian federal government agency whose mission is to regulate the use of nuclear energy and material to protect the health and safety of the public and the environment and to respect Canada's international commitments on the peaceful use of nuclear energy. The CNSC governs the entire life cycle of NPP and every aspect of their operation through the Nuclear Safety and Control Act and its associated regulations.

The CNSC licensing process for NPP follows the stages laid out in the Class I Nuclear Facilities Regulations for site preparation, construction, commissioning, operating, decommissioning, and abandonment phases. At each licensing stage, CNSC determines whether the licence applicant is qualified and has made adequate provisions for the protection of the environment, the health and safety of persons, and the maintenance of national security. If satisfied with the application, the Commission Tribunal of CNSC may issue a Licence that contains conditions that are appropriate for the facility. Power Reactor Operating Licences (PROLs) are issued for closed-term periods, typically not longer than 5 years. The PROL is subject to renewal on the basis of compliance with the licence terms. Compliance verification criteria for the PROL are described in the associated Licence Conditions Handbook (LCH).

The detailed regulatory requirements are described in CNSC Regulatory Documents and industry standards such as those published by the Canadian Standards Association (CSA). The requirements for Long Term Operation (LTO) of NPP are described in CNSC Regulatory Document RD-360 "Life Extension of nuclear Power Plants" [3]. More recently in June 2011, CNSC Regulatory Document, RD-334 on "Aging Management of Nuclear Power

Plants" [4] has been published. As well, licensees have been requested to include in their submissions to CNSC with regard to current operation and life extension lessons learned from Fukushima event.

The regulatory framework and perspectives on LTO and integrated aging management in these two Regulatory Documents are discussed in more detail and in the following sections.

LONG TERM OPERATION

The Canadian Nuclear Safety Commission (CNSC) issued in 2008 a Regulatory Document RD-360 "*Life Extension of Nuclear Power Plants*" [3] which requires a licensee to conduct an Integrated Safety Review (ISR) for a single-unit or multiple-unit nuclear power plant (NPP) approaching the end of its assumed design life. The ISR process as a systematic and comprehensive approach [1, 2, 5] to determine the:

- Actual state of plant's structures, systems and components (SSCs);
- Adequacy and quality of plant design, licensing and operational documentation;
- Presence of established and effectively implemented management and operation programs; and
- Reasonable and practical modifications to improve or maintain plant safety in line with modern national and international codes, standards and practices.

In addition to RD-360, the conduct of the ISR by the licensee and the corresponding regulatory oversight utilize the guiding process of the International Atomic Energy Agency (IAEA) Standard Guide NS-G-2.10 *"Periodic Safety Review of Nuclear Power Plants"* [6]. The scope of the ISR includes a number of review safety areas (termed "Safety Factors") that are relate specifically with plant material condition and aging including "Aging 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 aging on NPP safety, as well as the effectiveness of aging management programs for future long term operation, in order to identify corrective actions and areas for improvement.

In the last few years, RD-360 has been applied refurbishment and extension-of-operation projects, not only for NPPs, but also for a research reactor. The cumulative CNSC experience is documented in a Staff Review Guide [7] which is consistently and routinely used by the CNSC staff as guidance on how to assess licensee's documents resulting from an ISR. However, CNSC staff also determined that updates to the RD-360 document were needed.

In July 2011 CNSC staff released, for public consultation, draft regulatory document RD-360 version 2 [8], which was re-titled as "*Life Management of Nuclear Power Plants*". A draft guidance document GD-360 "*Guidance for Life Management of Nuclear Power Plants*" [9] has also been issued for comment. RD-360 version 2 sets out the requirements of the CNSC regarding activities a licensee must undertake in support of a project for long-term operation or to prepare for the end of operation of an NPP leading up to its decommissioning. It reflects CNSC and industry cumulative experience and lessons learned from ongoing life-extension projects. It also takes into account updates in associated national and international guides such as IAEA Safety Reports Series No. 57, "*Safe Long Term Operation of Nuclear Power Plants"* [10].

For the purposes of RD-360, version 2, long-term operation of an NPP denotes operation beyond the assumed design life of the plant. The end of operation is the final, permanent shutdown of reactor operation of an NPP. The NPP remains subject to its power reactor operating licence that authorizes activities during the transition period from reactor unit shutdown and safe state of storage until decommissioning. LTO may require the repair or refurbishment of major components, or substantial modifications to the plant, or both. The need for refurbishment will be largely dictated by the proposed period of LTO.

The activities the licensee must undertake for LTO include:

- conducting the ISR
- developing the Integrated Implementation Plan (IIP)
- developing and implementing the Continued Operation Plan
- developing and implementing the refurbishment and project execution plan

An important lesson learned from earlier refurbishment projects and ISR was the need, at the outset, to establish an appropriate protocol between the licensee and the CNSC. This protocol should facilitate meeting the requirements of all applicable regulations and RD-360, and should address the following four key items:

- identification of points of contact for communication
- specific schedules or timeframes for planned activities
- mechanism for dispute resolution
- process for controlling changes to the agreed protocol

The protocol facilitates adherence to schedules and ensures timely submissions of complete and comprehensive information, and applies to the entire project.

Once the ISR is completed, modifications and upgrades are described in the IIP for the safe operation of the facility and are commensurate to the scope of the review performed and the proposed period of LTO. The licensee submits either a Continued Operation Plan or a detailed refurbishment project execution plan, including return to commercial operation considerations. In multi-unit stations, different plans may be applied to each unit. For example, if the licensee decides to refurbish a multi-unit station it may plan for a staggered refurbishment of each unit instead of a single continuous outage of all units at once. In this case, the plan would require considerations for both continued operation and refurbishment.

The scope of RD-360 version 2 was also broadened to include requirements for activities related to the end of operation of a nuclear power plant (NPP). It was recognized that the licensee may, in some case, decide to end operation of the NPP. The end of operation is the final, permanent shutdown of an NPP's reactor operation (or a unit of a multi-unit NPP facility); the NPP facility remains subject to its power reactor operating licence that authorizes activities during the transition period from reactor unit shutdown and safe state of storage until it enters the decommissioning phase. The licensee must implement an end of operation plan, including a sustainable operations plan for the safe operation of the NPP until the final permanent shutdown of each reactor. Depending upon the strategy chosen, the end of operation plan must also include either a detailed decommissioning plan or a safe state of storage plan for the transition period until decommissioning the NPP.

RD-360 version 2 will supersede RD-360, *Life Extension of Nuclear Power Plants*, after it receives final approval by the Commission Tribunal and is published. Publication of RD-360 version 2 is planned for February 2012.

INTEGRATED AGING MANAGEMENT

Aging management is the engineering, operational, inspection, and maintenance actions that control, within acceptable limits, the effects of physical aging and obsolescence of SSCs occurring over time or with use. An aging management program (AMP) is a set of policies, processes, procedures, arrangements, and activities for managing the aging of the SSCs for an NPP. The CNSC regulatory document RD-334 [4] sets out the requirements of the CNSC for managing the aging of SSCs of an NPP.

RD-334 represents the CNSC's adoption and adaptation, consistent with the Canadian regulatory framework, of the guidance established by the International Atomic Energy Agency (IAEA) in Safety Guide NS-G-2.12 [11], at which CNSC staff also participated in drafting. Key principles and elements used in developing RD-334 are therefore consistent with modern international safety guidelines and practices.

CNSC RD-334 requires that appropriate measures and features are introduced in the design stage to facilitate effective aging management throughout the lifetime of the NPP. The designer of a new NPP should therefore take into consideration the requirement for implementing an effective integrated aging management program for addressing both physical aging of SSCs, resulting in degradation of their performance characteristics, and obsolescence of SSCs. Aging management applies to SSCs that can, directly or indirectly, have an adverse effect on the safe operation of the NPP.

Licensees are expected to apply a systematic and integrated approach to establish, implement, and improve appropriate programs to manage aging and obsolescence of SSCs. NPP management processes are to include requirements to ensure there is a documented overall integrated AMP framework for the NPP that addresses the following elements:

- organizational arrangements
- data collection and record keeping
- screening and selection process for aging management
- evaluations for aging management
- condition assessments
- SSC-specific AMPs
- management of obsolescence
- interfaces with other supporting plant programs
- implementation of AMPs
- review and improvement of AMPs

SSC-specific AMPs are implemented in accordance with the overall integrated AMP framework. The SSC-specific AMPs must address the attributes of an effective AMP as presented in Appendix A of RD-334.

Note: Currently, CNSC is writing a guideline document on Aging Management (GD-334) which will provide guidance how the aging management requirements set-up in RD-334 could be met. GD-334 is scheduled to be released for public consultation by March 2012.

Interfaces with Other Supporting Programs

In practice, effective aging management requires the involvement and support of many internal and external organizations, and essential plant programs and processes. For example, in the CNSC Regulatory Framework this includes:

- Safety Analysis (RD-310, S-294)
- Design, Engineering Change Control (CSA N285, CSA N286, CSA N293, etc)
- Equipment Reliability (S-98)
- Periodic & In-Service Inspection Programs (CSA N285.4, CSA N287.7)
- Maintenance Programs (S-210)
- Environnemental Qualification (EQ) programs (CSA N290.13)
- Operating procedures, Chemistry programs (CSA N286)
- Operating experience (OPEX), significant events analysis (S-99), and research programs

Each of these plant programs and process are important, but none in itself provides a complete program or process for managing aging of SSCs. For example:

- Reliability and maintenance programs typically focus on active and short-lived (replaceable) passive components (e.g. Batteries, Cooling Fans, Diesel / Gas Turbine Generators, Motors, Snubbers, Switches, Shut Off /Control Rod Drives, Transistors, Valves (except bodies), etc.).
- Maintenance is usually not planned during the service life for long-lived passive components and structures (e.g. Fuel Channels, HTS Feeders, Steam Generators, Primary / Secondary Piping, Containment Structures, Cables, Component Supports, Heat Exchangers, Pressure Vessels, Valve Bodies / Casings, etc.).
- Inspection programs provide information / confirmation of condition of passive SSC (or a specific location of a SSC), but this is only part of the picture.

There is a need to effectively coordinate existing programs that contribute to AM of SSCs. This requires a systematic approach providing an integrated framework for coordinating all supporting programs and activities associated with the understanding, control, monitoring, and mitigation of aging effects at the facility. As mentioned earlier, aging management is defined in RD-334 as the engineering, operational, inspection, and maintenance actions that control the effects of physical aging. Integrated Aging Management does not replace existing programs but, on the basis of evaluation, modifies them (reduce/enhance/eliminate/supplement) and provides the framework to achieve a systematic and integrated program for effective AM. This key concept is illustrated in Figure 1 which shows the associated technical documents which concur to the effective regulation of AM of SSCs in Canadian nuclear power plants.

Interdependency Effects of Aging on SSC

A key aspect of the concept of an "integrated" AMP is the fact that component and systems are not maintained in isolation. The aggregate effect of several age-degraded components or elements on the safety performance of the overall system or structure, and on the overall NPP safety performance and risk, must be managed. Engineering, operation, inspection and maintenance activities considered for one system are analyzed to ensure there will be no adverse effects on interrelated or neighbouring systems to the extent possible. One example of this would be the implementation of chemistry controls for the feedwater system. Chemistry controls utilized to protect against Aging Related Degradation Mechanisms (ARDMs) for materials used in the construction of a component, such as a condenser, dearator, etc., should not result in degradation of steam generator internals or steam generator tubes. Of course this also leads back to the concept of considering aging management requirements in the design stage to ensure the compatibility of materials. Where material compatibility is not possible, provisions should be incorporated into the design to permit the plant operator to carry out replacement or refurbishment activities for SSCs which may be impacted adversely.

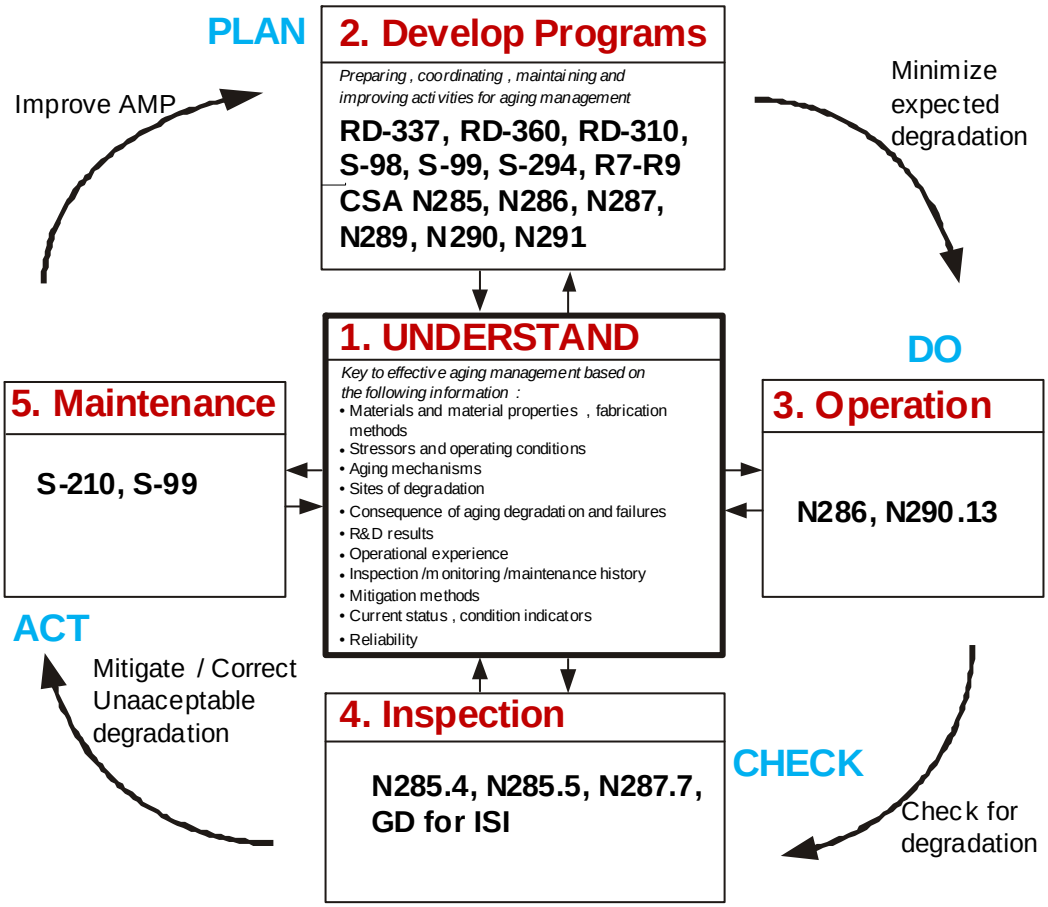

Figure 1: Integrated Aging Management – Interfaces With Supporting Programs

Relation between Safety Case and Aging of SSCs

Another key aspect of an "integrated" AMP mandated by RD-334 is maintaining the close relation between Safety Analysis and aging management. The safety analysis for the NPP is to be based on complete and accurate design and operational information and is to account for the cumulative effects of aging degradation of SSCs on overall systems and plant safety performance. Significant uncertainties in analysis or data relevant to aging assumptions, including those associated with NPP performance, operational measurements, and modeling parameters, are to be identified and considered.

An example of aging issues that affect safety analysis results for the CANDU systems is the critical channel power (CCP) calculations under accident conditions. Aging adversely affects the protective systems' performance due to aging-related changes in the primary heat transport system (PHTS). All of the individual components of the PHTS may be fit-for-service, but may have aged to the extent that additional safety measures may be needed for continued safe operation. For example, steam generator tubes may be found fit-for-service but may not be safe for continued operation unless certain precautions pertaining to safety analysis are taken into account (e.g., increase in the inlet header temperature and increased pressure drop). Similarly, certain reactor outlet feeders are known to experience wall thinning of the pipes due to flow assisted corrosion (FAC), and yet wall thinning is not considered as being a safety analysis issue - the feeders are maintained fit-for-service by using component (feeders in this case) aging management program/component life cycle management program– as long as appropriate aging (thermalhydraulic) models are used to capture the impact on the safety analysis results (e.g., changes in the frictional loss coefficients; pressure drop and two-phase flow characteristics as well as the physical phenomena that are related

to the material behaviour of the SSCs that have the potential to impact safety have to be accounted for in the safety analyses) [12].

CO-OPERATION AND RESEARCH AND DEVELOPMENT

CNSC staff is participating in a number of initiatives closely related to LTO and aging management of NPP through international organizations (IAEA, OECD/NEA) as well as cooperative projects with other nuclear regulatory agencies. CNSC participation in these activities provides an opportunity to harmonize our regulatory guidance approach and documents with international best practices and recommendations.

CNSC and Canadian Industry are participating in the recently launched IAEA International Generic Aging lessons Learned (IGALL) programme, part of which will involve documenting recommendations and best practices for aging management of CCS and other structures important to safety of Canadian NPP. There is a need and practical consolidated international approach to AMP and LTO. For example CNSC RD-334 [4] is adapted from the IAEA Safety Guide NS-G-2.12 [11], and CNSC RD-360 version 2 [7] accounts for IAEA Safety Guide NS-G-2.10 [6] and Safety Report No. 57[10]. The USNRC, in order to address the aging in connection with license renewal for extending operation of their NPP from 40 to 60 years, has published a comprehensive compilation of "generic aging lessons learned" [13], which has been effectively used both by the regulator as well as by the plant operators in the United States. In response, the IAEA initiated a 3 year Extrabudgetary Programme (Programme) on 'International Generic Aging Lessons Learned' (IGALL). The objective of the IGALL Programme is to develop the IGALL Document, which will provide:

- A roadmap to aging mechanisms and effects based on research results and operational experience accumulated to date, and,
- A common internationally agreed basis on what constitutes an acceptable aging management programme for typical plant's components, structures, material, and environments.

The scope of the IGALL includes CANDU as well as other reactor technologies such as Boiling Water Reactors (BWR), Pressurized Water Reactors (PWR), other Pressurized Heavy Water Reactors (PHWR), and Russian PWR (denoted WWER). The aim is to compile state of the art international practices and experience in aging management of SSC for various NPP technologies. It is expected the output of the IGALL programme will facilitate exchange of experience accumulated in IAEA Member States operating nuclear power plants, on identification, establishment, and implementation of AMP. In Canada, this will support industry implementation of and compliance with RD-334 and RD-360 version 2. Also, while the IGALL programme is aimed to address aging management issues of the operating nuclear power plants, it will also provide a knowledge base on aging management for design of new plants, design reviews, etc.

The CNSC also monitors R&D activities of licensees, as coordinated through the CANDU Owner Group (COG). COG is an organization essentially made up of members from the CANDU industry which consists of representatives from the licensees, suppliers, manufacturers, etc. The main mandate of COG is to provide research and development (R&D) activities to support the advancement of the CANDU industry. Current examples of COG R&D project in the area of aging management and long term operation of fuel channel pressure tubes, inspection and/or testing of bonded pre-stressing systems in the concrete containment, and cable aging.

SUMMARY AND CONCLUSION

Many NPP in Canada are approaching the end of their originally planned design life. Several licensees are moving forward with projects to extend the operating life, which depends on by how well aging of their structures and components are being controlled and managed. CNSC staff are undertaking initiatives at both the national and international level, to provide adequate assurances that the materials degradation due to aging of Canadian NPP is being effectively managed such that sufficient safety margins remain for long term operation, thus minimizing risks to workers, the public and the environment.

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