REGULATION AND PROACTIVE MANAGEMENT OF AGEING STEAM GENERATORS IN CANADA

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Abstract

Effective ageing management programs of key safety-related structures, systems, and components (SSCs) are an efficient means for ensuring the long-term safe and reliable operation of nuclear power plants. In the early days of design of nuclear power plants, it was assumed that the operational life-cycle of steam generators would be the same or similar to that of other key components in the reactor primary-heat-transport-system. However, widespread degradation of the steam generator tubing that has occurred at a number of plants has shown that this original assumption was incorrect or at least too optimistic. Observed degradations can be attributed to a number of factors ranging from shortcomings in the design codes, manufacturing processes, or water chemistry, and unanticipated mechanisms of material and component degradation resulting from high temperature, high fluid flow, cycling loads and presence of corrosive species. The licensees have responded to this challenge with extensive inspection and maintenance programs, supported by research and development in the areas of corrosion and mechanical degradation of tubes and internals, chemistry, thermal hydraulics, fouling, inspection and cleaning, and specialized inspection tools.

This paper discusses the Canadian Nuclear Safety Commission approach towards ensuring that licensees operate and maintain their plants in a safe operational condition. It briefly describes elements of the CNSC requirements and the overall regulatory oversight process to achieve these goals. The paper also discusses the known degradation mechanisms in Canadian steam generators and describes the requirements in place to ensure licensees sufficiently monitor the condition of their SSCs and appropriately disposition the results of inspections. Particularly, the tube degradation is a major driving force for development of CANDU specific fitness-for-service guidelines, and for specialized inspection and monitoring technology. The regulatory approach ensures that the licensees demonstrate that no tubes degrade to the point where their integrity could be impaired and that any leakage due to degradations would not exceed the regulatory limits.

CNSC staff recognize the importance of cooperation and information exchange and is actively involved with a number of ageing-management and structural integrity initiatives with industry and other national regulatory agencies both, within Canada and at international level. To strengthen the role of proactive ageing management at Canadian nuclear power plants, CNSC is continuously maintaining and improving as well as developing new regulatory documents, standards and compliance program activities, and is encouraging further research on ageing degradation of SSC's important to safety. On a final note, the paper describes the current and planned initiatives to improve the Canadian regulatory requirements for ageing management programs, as well as the oversight for the surveillance of critical SSCs, including the use of probabilistic methods for condition monitoring and operational assessment, and risk-informed in-service inspections.

INTRODUCTION

CANDU Nuclear Power Plants (NPP) have been supplying electricity to the Ontario power grid since 1962 and to New Brunswick and Quebec power grids since 1983. At present, there are 16 operational CANDU units in Ontario, representing 40% of the installed electricity generating capacity, and one unit each in New Brunswick and Quebec. Canadian CANDU NPPs had an excellent safety and reliability track record in their early (typically 12) years of operation but performance at some plants declined due to cumulative effects of ageing degradation. At the design phase, the known ageing mechanisms were considered and their predicted rates were accounted for to the best of the knowledge available at that time. Theoretically this would have allowed the plants to operate to their end of design life without the need to replace the many long-lived components.

In the early days of design of nuclear power plants, it was assumed that the operational life-cycle of steam generators would be the same or similar to that of the other key components in the reactor primary-heat-transport-system (calandria, fuel channels, piping, primary coolant pumps, etc.). However, widespread degradation of the steam generator tubing that has occurred at a number of plants has shown this original assumption was incorrect or at least too optimistic. Observed degradations can be attributed to a number of factors ranging from shortcomings in the design codes, manufacturing processes, or water chemistry, and unanticipated mechanisms of material and component degradation resulting from high temperature, high fluid flow, cycling loads and presence of corrosive species. As a result, the extent of the damage to steam generator tubes in both, CANDU and PWR, power plants has resulted in significant losses in efficiency and abandonment or replacement of steam generators well before their design lifetime was reached. Furthermore, steam generator problems have ranked only behind fuel outages as the most significant contributor to lost power generation. Steam generators have therefore represented one of the largest problems in terms of reliability, availability and unanticipated cost that the nuclear industry has had to face.

The early high level of performance of CANDU NPPs resulted from solid design and construction, efficient operation by well trained and experienced staff and expert technical support. Ageing of safety critical structures, systems, and components (SSCs) was being addressed proactively through a number of programs, such as a ‘durability program’ for major SSCs initiated at NPD nuclear generating station in 1970’s and the Nuclear Plant Life Assurance program of the Nuclear Generation Division of Ontario Hydro initiated in 1980’s.

This paper discusses ageing management of Canadian CANDU NPPs from the regulatory perspective. The paper briefly reviews the main safety related ageing concerns and mitigation strategies for steam generators as one of the key SSCs. It then describes the Canadian regulatory approach to ageing management and the licensees’ ageing management programs. Finally, the paper describes the current and planned initiatives to improve the Canadian regulatory requirements for ageing management programs, as well as the oversight for the surveillance of critical SSCs, including the use of probabilistic methods for condition monitoring and operational assessment and risk-informed in-service inspections.

CANADIAN REGULATORY APPROACH TO AGEING MANAGEMENT

In Canada, the CNSC has been a long time proponent of early identification, proactive assessment and strategic safety management of ageing components and systems at NPP.

In response to early signs of NPP ageing, CNSC implemented a "regulation-by-feedback" process (Fig.1). This process ensured that when component degradation was

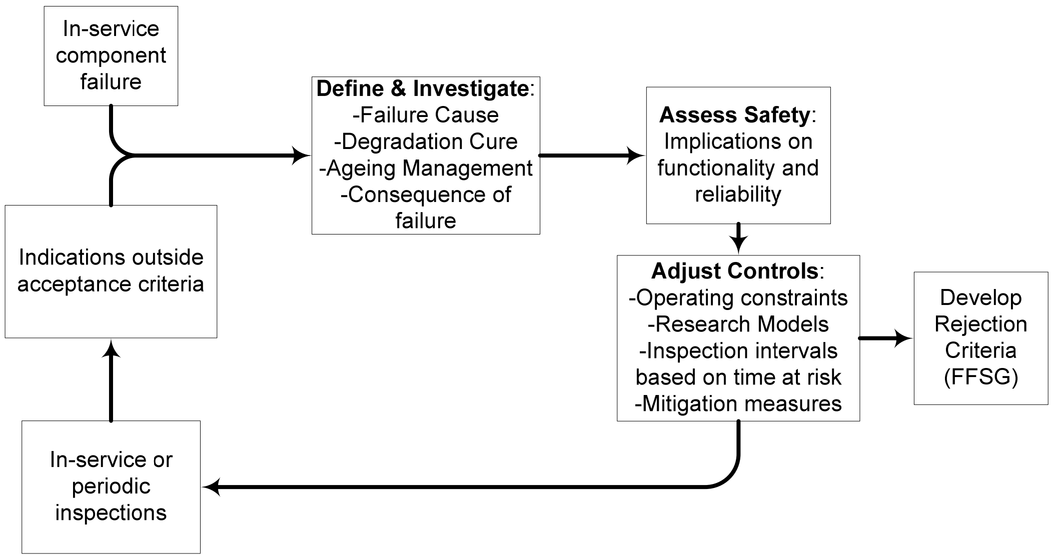

Figure 1: Regulation by feedback process for managing component degradation

discovered, either through inspection results or component in-service failures, licensees investigated the degradation, assessed its safety impact, and adjusted controls to minimize further degradation. Subsequent inspections verified the adequacy of these measures. This process was applied on a case-by-case basis, as new degradation mechanisms were identified.

In general, new forms of material degradation have been discovered through in-service inspections, and occasionally through in-service failures, such as flow-assisted corrosion (FAC) of steam generator tube-support plates (TSP), pressure tube delayed-hydride cracking (DHC) or feeder stress-corrosion cracking (SCC). Through operating licences, the CNSC requires licensees to comply with in-service inspection standards, which provide extensive inspection requirements for nuclear-safety-related systems. In-service inspections have served to identify, at an early stage, degradation of safety-critical SSCs. When discovered through leak-detection and system-monitoring activities, CNSC staff was notified of these events as required in regulatory standard S-99 (formerly R-99) [1] which requires the licensees to report pressure-boundary failures. Failed components, having been removed from service, were examined, repaired or replaced, and extensive research investigations were undertaken to determine the cause of the failure and to develop mitigation strategies. In addition, through requirements for in-service inspections, licensees must report all in-service inspection indications that do not meet defined acceptance criteria. These reports allow the CNSC to remain abreast of the overall plant condition at our licensees' sites.

Having identified a previously unknown material degradation, CNSC require licensees to investigate extensively the cause of the failure, and to assess the implications of this failure on overall plant safety and on the existing safety case. Similar systems, which may be subject to this form of degradation, must also be inspected. Both licensees and CNSC use the information from these investigations to make a risk-informed decision whether to continue/ to allow operation of the plant. This information is also shared with other operators to ensure that they also remain abreast of recent developments in reactor ageing. The approval to restart is granted only when the CNSC staff are satisfied that the licensee has a clear understanding of the causes of the degradation and that appropriate measures to mitigate further failures have been implemented.

Taking into account the information gained from the studies described above, rejection criteria for future inspection indications are also developed. These criteria are specified in Fitness-for-Service-Guidelines (FFSG). For example for steam generator tubes, FFSGs include the maximum allowable size for flaws based on the predicted inspection interval. This maximum size is based on the predicted growth rate of the flaw and ensures that the flaw will not propagate to failure prior to its next inspection.

The knowledge gained through these studies is used in the development of ageing models and modelling methodologies to predict component lifetimes. The operating histories of failed components also aided in determining the projected service life of similar components. As new failures occurred, it was recognized that a more preventive approach towards component ageing was also needed.

At the end of the 1980's, CNSC recognized that although NPP licensees had programs in place related to ageing, they had not yet adequately integrated them into a comprehensive and systematic ageing management strategy. As a result, in 1990, CNSC raised a *Generic Action Item "Assurance of Continuing Nuclear Station Safety"*, which required licensees to demonstrate that:

- potentially detrimental changes in the plant condition are being identified and dealt with before challenging the defense-in-depth philosophy;
- ageing related programs are being effectively integrated to result in a disciplined overall review of safety;
- steady state and dynamic analyses are, and will remain, valid;
- a review of component degradation mechanisms is being conducted;
- reliability assessments remain valid in light of operating experience; and
- planned maintenance programs are adequate to ensure the safe operation of the plant.

The scope of work and of the associated ageing management programs covered SSCs important to safety, including such systems as: special-safety and safety-related systems; SSCs whose failure could prevent a safety-related or a special-safety system from fulfilling its function or cause a safety-system actuation; SSCs used in emergency-operating procedures; and SSCs relied upon for protection from fire and seismic events.

In response to the above Generic Action Item (GAI), licensees' submissions listed and described a number of ageing related surveillance and maintenance activities that they were carrying out to ensure continuing nuclear safety. However, licensees did not demonstrate that they had a systematic and integrated approach to ageing management. CNSC recommended that the licensees use the International Atomic Energy Agency (IAEA) guideline "Implementation and Review of a Nuclear Power Plant Ageing Management Programme" [2] as an appropriate framework for such a program.

Licensees have since developed or modified existing programs based on this guideline that cover ageing management of the above systems. In 2003, letters were sent to each power reactor licensees informing them of CNSC staff's decision to close the GAI on the basis of the submissions provided and to monitor licensee program performance through the CNSC's ongoing compliance program.

In order to address ageing, the licensees are required to inspect and perform material surveillance according to the technical requirements of CSA standards N285.4 on Periodic inspection of CANDU nuclear power plant components [3], N285.5 on Periodic inspection of CANDU nuclear power plant containment components [4], and N287.7 on In-service examination and testing requirements for concrete containment structures for CANDU nuclear power plants [5]. These requirements include inspection techniques, procedures, frequency of inspection, evaluation of inspection results, disposition, and repair.

Maintenance programs are required for the purpose of limiting the risks related to the failure or unavailability of any significant SSC. For so-called "destiny components" (pressure tubes, feeder piping, and steam generator tubes), in addition to the standards' minimum requirements, the CNSC requires NPP licensees to develop fitness-for-service guidelines and life-cycle management plans/programs.

Currently CNSC is finalizing for internal review the draft Regulatory Standard S-334 [6] which sets out requirements for an ageing-management program (AMP) that a licensee who constructs or operates a Nuclear Power Plant (NPP) shall implement to ensure structures, systems or components (SSC) important to safety will continue to meet their design and performance specifications throughout the lifetime of the facility. The requirements cover the full span of the plant life-cycle, from design to decommissioning. The objectives of this regulatory standard are to:

- describe the organizational characteristics of an effective ageing-management program;
- describe the general attributes of an effective ageing-management program for managing specific ageing mechanisms and their effects on particular SSCs or types of SSCs;
- inform NPP licensees of CNSC expectations and recommendations relating to ageing management of SSCs important to safety; and to,
- facilitate CNSC evaluations of the effectiveness of NPP ageing-management programs within the framework of CNSC's compliance program.

The regulatory standard includes, as part of licensees' overall ageing management programs, such requirements as:

Plant Reviews: involving a systematic review of the plant to identify all the SSCs which must be addressed by the program and the potentially detrimental effects of ageing on the ability of each of the SSCs to meet its design requirements;
Gap Analyses: involving an assessment of the adequacy and effectiveness of existing activities already in place to manage each SSC's ageing, and to identify enhancements or additions to these activities; and,
Documentation: including the governing ageing-management programs procedures and the requirements for continuous improvement of the program, as well as the procedures for all supporting programs and activities.

An effective AMP should follow a systematic approach to the co-coordination of all programs and activities relating to the understanding, control, monitoring and mitigation of ageing of an SSC. Such an approach is illustrated in Figure 2 [2, 6].

The circular structure of this approach 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. To illustrate key activities in a systematic approach to ageing-management, Figure 2 is divided into five distinct areas, as described below:

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.

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.

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.

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.

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

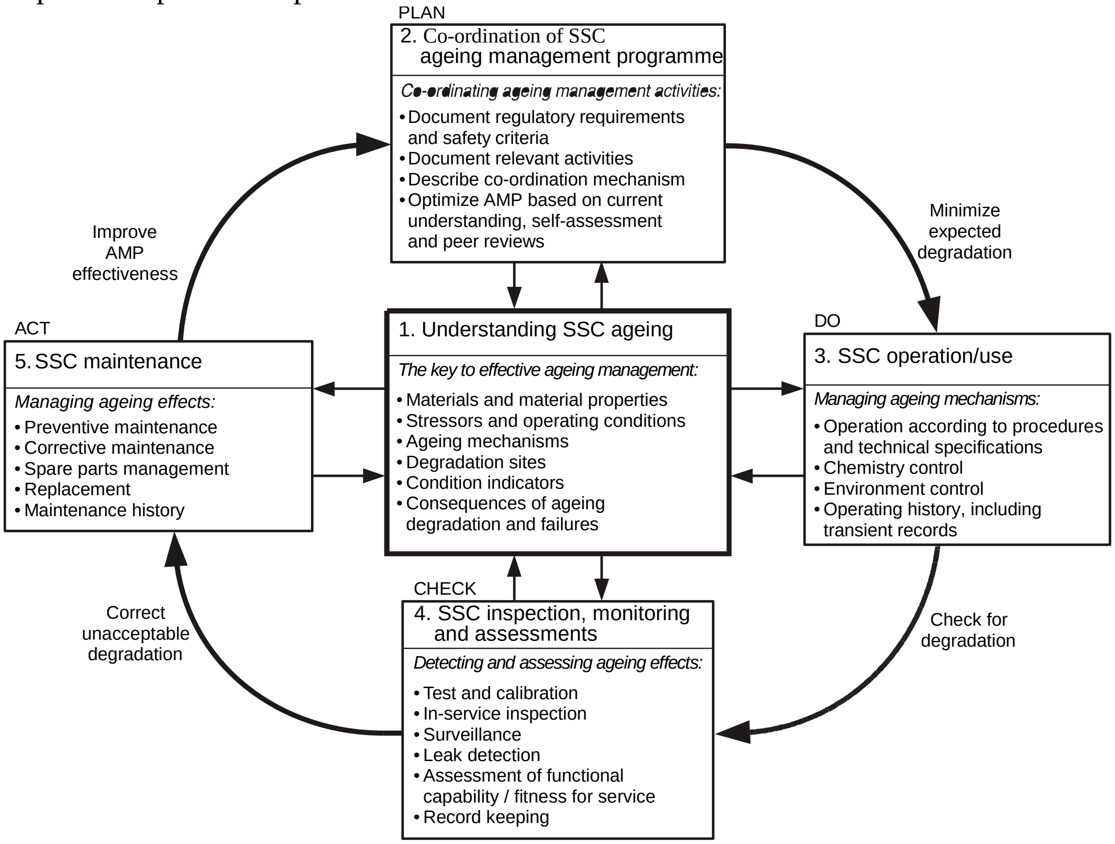

Figure 2. Systematic approach to ageing-management [2, 6]

Regulatory Standard S-334 requires that NPP licensees shall ensure that the effects of ageing on systems, structures and components (SSCs) important to safety are being managed, such that their required safety functions are maintained during their service life, and that effective AMPs are in place to mitigate their effects for future NPP operation. The standard describes the following steps for the development, implementation and continuous improvement of the AMP:

- Establishing organizational arrangements for effective ageing-management
- Establishing a data collection and record keeping system to support ageing-management
- Screening SSCs for focused ageing-management
- Ageing-management evaluation of the selected SSCs
- Condition assessment of major SSCs
- Development and implementation of SSC-specific recommendations and ageing-management programs
- Continuous improvement and AMP review

AGEING CONCERNS IN CANDU STEAM GENERATORS

CANDU steam generators (SGs) are similar in construction to PWR steam generators and suffer from similar ageing degradation mechanisms and effects, such as corrosion (SCC, IGA, pitting, wastage), fretting, denting, and erosion of SG tubes. The twenty-two CANDU power reactors licensed in Canada are equipped with a total of 184 steam generators of different designs, and tubing material, ranging from Monel 400, to Alloy 600 and Incoloy 800. Regulatory controls and ageing-management actions comparable to those for PWRs are being used in Canada, however to date, no SGs have been replaced. Bruce Units 1 and 2 are to be the first Canadian power plants with replacement steam generators when life extension of these units is completed.

The various degradation mechanisms [7-11] and the locations at which they have been observed in steam generators are summarized here and shown schematically in figure 3:

Stress Corrosion Cracking and *Intergranular Attack* (IGA): Primary water SCC occurs at certain locations on the inside surfaces of SG tubing with high residual-stresses. These locations include the U-bend regions of the tubing in the inner rows (i.e., tubes with a small bend radius), the roll-transition regions in the tube sheets, and at dent locations. PWSCC generally occurs on the hot leg side of the steam generators, however, cold leg PWSCC has been observed elsewhere on PWR plants. Intergranular SCC is stress-oriented grain-boundary degradation, and IGA is characterized by attack of the grain boundaries with no stress orientation. Both these degradations occur on the outside surfaces of SG tubes primarily in the hot leg tube-to-tubesheet crevice and sludge pile regions and the tube-to-tube support plate annuli.
Pitting: Local corrosion, caused by the formation of local cells in the sludge pile or where scale containing copper deposits are found, has caused pits on the outside surfaces of SG tubes.
Wastage (Thinning): This general type of corrosion of the outside surfaces of tubing has occurred primarily in relatively stagnant regions where phosphate solutions become concentrated (tube-to-tubesheet crevices, the sludge pile, and the tube-to-tube support plate annuli.
Denting: Denting is the plastic deformation of the tubes from build-up of carbon steel support plate corrosion products (magnetite) in the top-of-tube support plate annuli. Denting has occurred at all the various tube support plate locations on the hot leg sides with carbon steel support plates.
Fretting (Wear): Fretting, wear, and thinning are SG degradation types broadly characterized as mechanically-induced or aided degradation mechanisms. In general, these degradations occur at SG tube-to-tube support structure interactions as a result of secondary-side flow-induced vibrations.
Erosion-Corrosion: Mechanical damage can be caused by a corrosive environment and the impingement of liquid or solid particles.

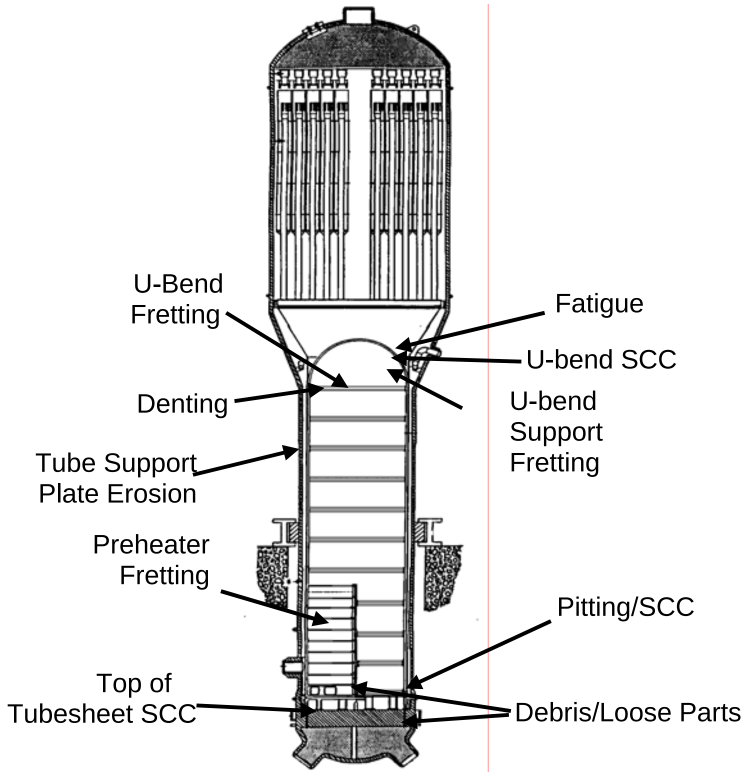

Figure 3: Illustration of steam generator typical degradations

Steam generator tube leaks result in primary to secondary side leakage, contaminating the steam/feed water with irradiated coolant (containing tritium, activation products and possible fission products from failed fuel). This leak may result in a release of radioactive materials to the environment through the secondary side relief valves.

The SG FFSG [12], revised in 2005, make use of probabilistic tools for performing Leak-Before-Break (LBB) simulations for the determination of flaw stability within the entire tube population and for determining flaw size distributions for condition monitoring and operational assessments. The SG FFSG considers the probabilistic approach as an alternative to deterministic methods. Shortcomings of current probabilistic methods and SG FFSG include:

- the use of “pattern-based” variables, which do not make use of mechanistic or physics of degradation tools;
- the lack of a clear basis for probabilities and distribution parameters;
- the tools are primarily reactive, rather than proactive; and,
- FFSG does not address inspection scoping.

Probabilistic methods for safety assessment and operational evaluations of key SSCs, i.e. analysis methods that determine the distributed output of engineering analyses based on probabilistic representations of distributed input parameters, are an important and powerful tool. Prior to making full use of probabilistic tools, however, CNSC staff foresee the need for further refining these methods, including the completion and/or further verification of probabilistic representations of distributed input parameters and further justification of the proposed probability acceptance levels for the results of a probabilistic analysis.

PATH FORWARD

The regulatory standard S-334 is intended for both CNSC and licensees: NPP licensees will use the document as a benchmark for self-assessments of their ageing-management programs, and CNSC staff will use the document as a regulatory basis for ongoing compliance inspection of ageing-management programs and for comprehensive licensing assessments of licensee long-term operation applications. CNSC staff expect that this standard will result in an increased effectiveness of licensee ageing-management programs and an increased reliability of SSCs important to safety, thus improving NPP safety.

To strengthen the role of proactive ageing-management at Canadian NPPs, CNSC will continue maintaining and improving regulatory documents, standards and compliance program activities, and encourage further research on ageing degradation of SSCs important to safety, as needed.

In parallel with finalizing S-334, CNSC is working on draft version of the Regulatory Standard S-335 on Requirements for Pressure Retaining Components [13]. The purposes of this Regulatory Standard are:

- Outline requirements that assure the integrity of pressure retaining components at nuclear power plants, research reactors, waste management facilities, uranium refineries, and other nuclear facilities, and
- Facilitate CNSC evaluations of the appropriateness, completeness and timeliness of information reported to the CNSC by the operators of nuclear power plants.

The Regulatory Standard S-335 will provide administrative requirements with respect to the design, installation, modification, repair, testing, examination, inspection, and performance of work related to pressure vessels, boilers, systems, piping, fittings, parts, and supports. It will outline the applicable technical codes and standards, the responsibilities and accountabilities of licensees, and the role of inspection agencies with respect to these pressure retaining components.

In recent years, Canadian NPP licensees have completed several life-extension projects, notably the return to service of the Pickering A Units 1 and 4, and Bruce A Units 3 and 4.

New Brunswick Power Nuclear Corporation also announced a decision to proceed with the Point Lepreau life extension project with on-site refurbishment planned to start in 2008. Bruce Power has announced plans for the life extension of Units 1 and 2 [14]. Life extension involves the replacement or refurbishment of major components or substantial modification to the plant. The CNSC considers it to be in the public interest that the facilities meet modern high-level safety goals and applicable regulatory requirements for safe and secure operation over their life-cycles. To this end, NPP licences are amended to introduce specific licence conditions for the regulatory control of life extension projects. In addition, CNSC issued for public consultation a regulatory guide G-360 on Life Extension of Nuclear Power Plants [15]. In keeping with its regulatory mandate, CNSC expects the licensee to demonstrate that the following requirements are met for any life extension project:

- Perform an Environmental Assessment (EA);
- Carry out an Integrated Safety Review (ISR) which calls for review of ageing-management programs; and
- Develop an Safety Improvement Plan, based on the results of the EA and ISR

Recently, CNSC identified the need to further augment inspection requirements for high-energy non-nuclear safety important systems. Failure of these systems would not have significant radiological consequences, and therefore had not been included in nuclear in-service inspection standard; however these systems have the potential to affect conventional worker health and safety. CNSC staff is now evaluating the available means to incorporate additional inspection requirements in order to ensure that licensees are effectively monitoring the condition of high-energy conventional SSCs. CNSC staff is working closely with the industry to develop a separate CSA N285.7 Standard on Inspection of Secondary Side Systems Important to Safety. In addition, CNSC staff is actively involved in development of another addition to CSA N285 family of Standards, one on risk-informed in-service inspection of safety-related components.

The CNSC also foresees the need to further develop and improve probabilistic tools for condition assessments and condition monitoring of critical SSCs. Some specific uses of these tools are described in previous sections, and will result in a more risk-informed approach towards managing the ageing of Canadian NPPs. In addition, the CNSC is moving towards the use of process-based approvals (PBA) for dispositions of certain well-understood ageing phenomena. PBAs will allow licensees to self-disposition low-risk inspection indications provided the disposition is performed in accordance with accepted FFSGs and with a pre-approved and audited procedure. CNSC staff foresee that an increased use of PBAs will result in improved regulatory effectiveness and efficiency, while reinforcing the CNSC’s policy that licensees bear primary responsibility for ensuring the safe operation of NPPs.

COOPERATION WITH NUCLEAR INDUSTRY

As the nuclear industry matured it became obvious that cooperation on the national and international level is a necessity. CNSC staff is actively involved in discussions with the nuclear industry on a number of research and development programs that industry supports through the CANDU Owners Group (COG). The Canadian nuclear industry is actively involved with the Electric Power Research Institute (EPRI) and Institute of Nuclear Power Operations (INPO) to share experience and best practices in operation of nuclear power plants. In addition, CNSC staff is participating or cooperating with industry on a number of initiatives through international organizations (IAEA, OECD/NEA) as well as cooperative projects with other nuclear regulatory agencies. Some of programs include:

International Steam Generator Tube Integrity Program (ISG-TIP) - The International Steam Generator Tube Integrity Research Program is directed to the development of experimental data and predictive correlations and models required for the independent evaluation of the integrity of steam generator tubes as plants age and degradation proceeds, as new forms of degradation appear, and as new defect-specific management schemes are implemented. The present program, in its third phase, is divided into four technical areas: Assessment of Inspection Reliability; Research on ISI Technology; Research on Tube Integrity and Integrity Predictions, and Research on Degradation Modes.

Risk-informed In-service Inspection Methodologies (RISMET) – The RISMET program is an international program coordinated by OECD Nuclear Energy Agency (NEA). The overall objective of the project is to apply various methodologies of Risk-Informed In-Service Inspection to the selected cases in one nuclear power plant: The project will provide a comparative study aimed at identifying the impact of such methodologies on reactor safety and how the main differences influence the final result (i.e. the definition of the risk-informed inspection program); Compare the risk rankings obtained by different methodologies and evaluate the significance of differences in the results; Compare qualitative and quantitative Risk-Informed In-Service Inspection methodologies with traditional (deterministic) programs that are based on established classification of components; and the impact of the optimized In-Service Inspection Program on the reductions in radiation dose to workers performing (NDE) Non-Destructive Examination.

Stress Corrosion Cracking and Cable Aging (SCAP): The SCAP Project was initiated earlier this year by OECD NEA with the aim of producing a database and knowledge base on ageing issues, with focus on stress-corrosion cracking and cable ageing, as well as commendable practices for ageing-management. Two subjects, i.e., stress-corrosion cracking and degradation of cable insulation were selected as the focus of this project, because of their relevance for plant-ageing assessments and implication on inspection practices. They also represent two areas where the states of knowledge as well as the inspection methods are quite different. Considerable information has been generated on SCC related events, including piping and component failure, and methodologies exist for SCC inspections and some mitigating measures. However, there is still a need to consolidate the acquired knowledge and experience into commendable practices. For cable ageing, the information on degradation-induced "events" or failures is limited and the inspection methodology is not yet well established. These differences will necessitate that the two subjects of this project be addressed using separate approaches. Nevertheless, the overall project goals will be similar for both parts of the project and will ultimately consist of producing a database on operating experience, a knowledge-base on background information, requirements and methods, and a basis for commendable practices for ageing-management founded on an assessment of the available information.

The OECD Pipe Failure Data Exchange project (OPDE): The Nuclear Energy Agency (NEA) and the Organization for Economic Cooperation and Development (OECD) established the Piping Failure Data Exchange (OPDE) Project. The objectives of the OPDE Project include the establishment of a framework for multi-national cooperation in piping reliability. Initially a three-year program, the primary activities of the OPDE Project are to: Collect and analyze pipe failure data in order to promote a better understanding of underlying causes of failure, observed and potential impacts on plant operation, safety and prevention; Project participants that provide validated pipe failure data will gain full access to the OPDE database; Generate qualitative insights about the root causes of pipe failures; Establish a mechanism for efficient feedback of experience gained in connection with pipe failure and development of defenses against pipe failure; and Collect information on piping reliability attributes and influence factors to facilitate estimation of pipe failure frequencies.

The OECD Pipe Failure Data Exchange project has received a considerable amount of international interest and now counts twelve members. Although the project is only in its early stages of development, the improvements that have been implemented over the last year are numerous. Data from the database has already been used for practical applications on nuclear power plants in support of risk-informed in-service inspections or for estimating LOCA frequencies from piping defects. As the collaborative project evolves into a fully functional and continuously maintained database, its benefits and ensuing success will be a stepping stone for multi-lateral cooperation on new research and information sharing projects. Such projects provide excellent framework for the growth and improvement in the nuclear industry. However, the project will only be successful with the continuing support from all licensees. The project provides an effective tool and technical basis in support of the development of such items as risk-informed in-service inspection programs for Canadian licensees, probabilistic safety assessment (PSA) initiating event frequencies associated with piping-system failures, degradation-mechanism evaluation, reliability assessment of instrumentation systems as well as several other examples [16,17].

Maximizing Enhancements in Risk-Informed Technology (MERIT): As the technology associated with commercial nuclear power generation has matured, risk management has become one of the cornerstones behind the maintenance and operation of these plants. Over the years a number of risk-management tools have evolved to the point that they are now frequently used in the decision making process. On the other side, probabilistic risk/safety assessment (PRA/PSA) analyses are used by both the industry and regulatory staff. Risk-informed in-service inspection protocols are being incorporated into inspection criteria embodied in ASME Pressure Vessel and Boiler Code. Probabilistic fracture mechanics (PFM) codes, such as PRAISE and PRODIGAL, and databases of in-service operating experience are being used more to access potential risks associated with the operation of nuclear power plants. In order to further enhance some of these risk-management tools, Battelle launched an international research program, known as MERIT which is structured to build upon earlier highly successful programs, like IPIRG (International Piping Integrity Research Group) and BINP (Battelle Integrity of Nuclear Piping). MERIT program concentrates on addressing three focused disciplines with associated specific objectives: Continued development of a probabilistic fracture mechanics code PRO-LOCA for estimating the frequencies of various size loss-of-coolant accidents (LOCA); Assessment of weld residual-stresses and their impact on stress-corrosion cracking; and Continued development of a flaw evaluation criteria for Class 2, 3 and balance of plant (BOP) piping.

The OECD NEA Committee on Safety of Nuclear Installations (CSNI) performs an important function today and it will continue to have a prominent role in the nuclear safety arena in the future. Seen in the perspective of a shrinking nuclear infrastructure, increased public expectations on safety, industry globalization and initiatives to improve economics, all of which characterize the nuclear industry today, there will be an increased need for a body like CSNI. This is necessary to lead internationally coordinated efforts in developing the nuclear safety knowledge and seeking consensus on safety approaches. This will also be essential for maintaining a solid technical basis in support of member countries. The CNSC staff in cooperation with industry is present and strongly supports activities of NEA through participation in CSNI. Particularly, of interest to steam generators is the CSNI Working Group on Integrity of Components and Structures (IAGE). The mandate of this working group is to advance the current understanding of the relevant aspects related to the maintenance of the integrity of components, systems and structures, and to propose general principles on the optimal ways of dealing with challenges to the integrity - in particular those from ageing of operating as well as new nuclear power plants. IAGE is currently preparing a survey on the state of the art and best practices in Steam Generator Life-Cycle Management which will be distributed to all utilities and regulatory agencies in member countries. CNSC staff hopes for strong support and participation from licensees in this timely information and experience exchange exercise.

CONCLUSIONS

After a period of good performance in their early life, steam generator tubes at several CANDU nuclear power plants are showing signs of degradation. Tube leaks have occurred due to pitting, fretting, and cracking. In addition to tube degradation, Canadian steam generators experienced problems with extensive degradation of tube support plates, divider plate leakage and excessive magnetite deposition along the primary side of SG tubing. Observed degradations can be attributed to a number of factors ranging from shortcomings in the design codes and manufacturing processes, water chemistry, and unanticipated mechanisms of material and component degradation resulting from high temperature, high fluid flow, cycling loads and presence of corrosive species. The licensees have responded to this challenge with extensive inspection and maintenance programs, supported by research and development in the areas of corrosion and mechanical degradation of tubes and internals, chemistry, thermal hydraulics, fouling, inspection and cleaning, and specialized inspection tools. No steam generators in any of Canadian nuclear power plants have been replaced yet.

The CNSC has been a long time proponent of early identification, proactive assessment and strategic safety management of ageing components and systems at NPP. In response to early signs of NPP ageing, the CNSC implemented a "regulation-by-feedback" process to ensure that when component degradation was discovered, either through inspection results or component in-service failures, licensees investigated the degradation, assessed its safety impact, and adjusted controls to minimize further degradation. Subsequent inspections verified the adequacy of these measures. This process was applied on a case-by-case basis, as new degradation mechanisms were identified.

CNSC recognizes that the current level of ageing-management effort may need to be increased to ensure plant safety as Canada's NPPs continue to age. CNSC staff is implementing measures to strengthen the role of proactive ageing-management by focusing on important SSCs susceptible to ageing degradation and the greater application of systematic ageing-management processes.

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