Canadian Practices on Fatigue Management on Major Pressure Retaining Components

IAEA/Areva International Technical Meeting on Fatigue Assessment in Light Water Reactors for Long Term Operation: Good Practices and Lessons Learned

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The views expressed herein are those of the authors and do not represent official positions of the Canadian Nuclear Safety Commission
Presentation Outline

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- Introduction to Canadian Nuclear Safety Commission (CNSC) and CNSC Regulatory Framework
  - Overview of Regulatory Framework
  - CNSC Safety Control Areas (SCAs)
- Aging Management
  - Overview of CNSC Regulatory Document, REGDOG-2.6.3
  - Integrated Approach
  - 9 Key Attributes in CNSC REGDOC-2.6.3
- Overview of Canadian Practices for Fatigue
- CSA N285.4: Periodic Inspection of CANDU nuclear power plant components
- CSA N289.3: Design Procedures for Seismic Qualification of Nuclear Power Plant
- Configurations of Major Components
- Fatigue Management for Major Components
  - Primary Heat Transport (PHT) Piping
  - Feeder Piping
  - Fuel Channels (FCs)
  - Steam Generators (SGs)
- Concluding Remarks
Status of Fatigue Management in Canadian Nuclear Plants

- Power Reactor Operating License (PROL) requires that licensees have programs to ensure fitness for service of Structures, Systems and Components (SSCs).
- Licence Conditions Handbook (LCH) identifies and clarifies the regulatory requirements and other relevant parts of the licensing basis for each licence condition in accordance with referenced Canadian Nuclear Safety Commission (CNSC) regulatory documents and Canadian Standards Association (CSA) standards in order to ensure that the licensee maintains facility operation in accordance with the licensing basis for the facility and the intent of the nuclear power reactor operating licence (PROL)
- CNSC REGDOG-2.6.3 on aging management is currently available.
- CSA N285.4 provides requirements on scope of inspection, inspection interval, acceptance criteria, and reporting together with inspection for environmentally assisted cracking (EAC)
- A new informative annex is being added to N285.4-14 to provide an alternate approach to identify locations that are potentially susceptible to fatigue cracking and EAC
- Monitoring and recording of transient cycles is mandatory requirement as per aging management program. Thus, Canadian utilities are developing transient monitoring programs as per aging management program
- This presentation focuses on fatigue management plans for major components (i.e., Primary Heat Transport (PHT) piping, feeder pipes, fuel channels, and steam generators)
- Fitness For Service Guidelines (FFSG) for feeder pipe, FCs and SGs provide evaluation procedure for fatigue
- No fatigue failure has been reported in major components, PHT piping, feeder pipes, fuel channels excepting tube failures in steam generator prior to the installation of Anti-Vibration Bars (AVBs)
Canadian Nuclear Safety Commission (CNSC) - Overview

- Canada’s nuclear watchdog
- Quasi-judicial body
- Independent of, but not isolated from, government

**Our Mission**

- Regulate the use of nuclear energy and materials to protect the **health, safety and security of persons** and the **environment**
- Respect Canada’s **international commitments** on the peaceful use of nuclear energy
- Disseminate objective scientific, technical and regulatory information to the public.
Overview of Regulatory Framework

- Regulatory Framework
  - Safety & Control Areas (SCAs), Licence Conditions
- Regulatory Requirements & Guidance
  - CNSC Regulatory Documents (REGDOCs) & Canadian Standards Association (CSA) Standards
## CNSC Safety and Control Areas (SCAs)

14 SCAs used by CNSC staff across all regulated facilities and activities in a comprehensive framework to assess, evaluate, review, verify and report on performance of regulatory requirements.

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<th>Functional Area</th>
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<td>13. Safeguards and Non-Proliferation</td>
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<td>14. Packaging and Transport</td>
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There are SCAs particularly relevant to Aging Management.
CNSC’s adoption and adaptation of IAEA NS-G-2.12 Aging Management of Nuclear Power Plants (2009)

Covers all stages of NPP lifetime, including design, construction, operation, Long Term Operation (LTO), safe storage and decommissioning

Requirements for:
- Integrated Aging Management Program (Plant Level framework / governance)
- Aging / Life Cycle Management Plans for specific SSCs or specific aging degradation mechanisms
- Safety Analysis and Risk Assessments to account for cumulative effects of aging
- Data and information collection for aging management and to confirm safety analysis assumptions and acceptance criteria continue to be met
Aging Management – Related REGDOC and Standards

1. UNDERSTAND
Key to effective aging management based on the following information:
• Materials and material properties, fabrication methods
• Stressors and operating conditions
• Aging mechanisms
• Sites of degradation
• Consequence of aging degradation and failures
• R&D results

2. Develop Programs
Preparation, coordinating, maintaining and improving activities for aging management
REGDOC-2.5.2, REGDOC-2.6.3, REGDOC-2.4.1, REGDOC-3.1.1

3. Operation
N286, N290.13

4. Inspection
N285.4, N285.5, N287.7, GD for ISI

5. Maintenance
RD/GD-210, REGDOC-3.1.1

PLAN
ACT
CHECK

Improve AMP
Mitigate / Correct degradation
Check for degradation
Minimize expected degradation

Direct the system to action according to the feedback to the system.

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Aging Management Plans (AMPs) (i.e., Life Cycle Management Plans (LCMPs)) must comply with the requirements of CNSC REGDOC-2.6.3
- Must be implemented in accordance with the overall Integrated aging management program framework, and
- Must address the 9 attributes of an effective aging management program (same attributes as in IAEA NS-G-2.12 and International Generic Ageing Lessons Learned (IGALL))

9 Attributes of an effective aging management program (e.g., monitoring/detection/acceptance criteria, etc.)

Provide sample methodology* for aging evaluation in REGDOG-2.6.3
Aging Management – 9 Key Attributes in REGDOG-2.6.3 – 2/2

- **Attribute #1:** Scope of the Aging Management Program based on understanding aging
- **Attribute #2:** Preventive actions to minimize & control aging degradation
- **Attribute #3:** Detection of aging effects
- **Attribute #4:** Monitoring and trending of aging effects
- **Attribute #5:** Mitigating aging effects
- **Attribute #6:** Acceptance criteria
- **Attribute #7:** Corrective actions
- **Attribute #8:** Operating Experience (OPEX) feedback & feedback of R&D results
- **Attribute #9:** Quality management
Overview of Canadian Practices for Fatigue

- Fatigue management plan is implemented in Life Cycle Management Plan (LCMP) as part of Aging Management Plan (AMP) for major components with the overall Integrated Aging Management Program framework addressed in CNSC regulatory document, REGDOC-2.6.3
- There are two CNSC Regulatory Documents providing requirements for Monitoring Transient Cycles
  - REGDOC-2.5.2 for Design New Plant
  - REGDOC-2.6.3 for Aging Management
- There are two CSA standards related to inspection and acceptance criteria for fatigue
  - CSA N285.4 on periodic inspection requirements for pressure boundary systems
  - CSA N289.3 on design procedure for seismic qualification for nuclear power plants
- In Canada, flaw tolerance approach is provided in Fitness For Service Guidelines (FFSG) for feeder pipe, FCs and SGs to demonstrate fitness for continued service.
CSA N285.4 addresses periodic inspection requirements for pressure boundary systems. CSA N285.4 provides scope of inspection, inspection interval, acceptance criteria, type of inspection, and reporting. Clause 7.1.3 provides requirements for the calculation of Fatigue Usage Factors (FUF) used in establishing inspection categories. Three levels of fatigue usage factor classifications: 1. Low, 2. Medium, and 3. High. Two main parameters (i.e., FUF and stress ratio (i.e., stress/allowable)) are required to determine locations which would be susceptible to fatigue crack initiation.
CSA N285.4: Periodic Inspection of CANDU Nuclear Power Plant Components – Overview 2/3

- Inspection locations based on FUF only encompass design basis fatigue assumptions
- A new informative annex is being included in the amendment to CSA N285.4-14 to provide an alternate approach to cover locations that are susceptible to fatigue mechanisms that were not addressed in the design report
  - Assessing fatigue susceptibility based upon the degradation assessment methods defined for the EPRI Risk Informed In-Service Inspection (RI-ISI) methodology,
  - However, CSA N285.4-14 has not yet been applied by licensees
- Similar requirements have been implemented in CSA N285.7: Periodic Inspection of CANDU nuclear power plant balance of plant pressure boundary systems and components
- CSA N285.7 incorporates the RI-ISI concept
Clause 7.4.8 of CSA N285.4-09 provides requirement on inspection for Environmentally Assisted Cracking (EAC).

This Clause requires licensees to assess the potential for EAC in all Stress Corrosion Cracks (SSCs) governed by CSA N285.4 by consideration of the following aspects:

- Historical system chemistry
- Component design; material, configuration, applied loads, and residual stresses
- Industry Operating Experiences (OPEX)
CSA N289.3: Design Procedures for Seismic Qualification of Nuclear Power Plant

- This standard is developed to provide the following design requirements and methods:
  - for determining response spectra for use in the design and seismic qualification of SSCs; and
  - for performing seismic qualification of specified SSCs by analytical methods

- Clause 6 of CSA N289.3 provides the following analytical methods for seismic qualification:
  - Methods of analysis (e.g., time history, response spectrum, etc.)
  - Mathematical model, damping, seismic fatigue, etc.

- Clause 7.3.3 of CSA N289.3 provides the following requirements on seismic fatigue:
  - 3 Sm screening criterion
  - Approach essentially follows ASME* BPVC**, Section III, Division 1
  - The minimum number of seismic cycles shall be 25 of Design Basis Earthquake (DBE)
  - Load combination and acceptance criteria

*: American Society of Mechanical Engineers (ASME)
**: Boiler and Pressure Vessel Code (BPVC)
Configurations of Major Components - 1/2

Fig. 1 Configuration of Typical CANDU 6 PHT System

Fig. 2 Feeders and FCs on Reactor Face
Fig. 3 Reactor Assembly

Fig. 4 Schematic Picture of Fuel Channel (FC)
Fatigue Management for Primary Heat Transport (PHT) Piping -1/2

- Inspection results and Operating Experience (OPEX) indicate that no PHT pipe fatigue failure (i.e., leak or rupture) has been reported to date

- Types of plausible fatigue crack mechanisms:
  - Fatigue due to high localized stress
  - Fatigue due to dynamic loads (e.g., vibration or seismic loads, etc.)

- Types of fatigue analysis
  - Evaluation of Cumulative Usage Factor (CUF)
  - Implementing fatigue transient monitoring programs
  - Alternate approach to cover locations that are susceptible to fatigue
    e.g., non-design basis thermal fatigue such as thermal mixing or thermal stratification
Fatigue Management for Primary Heat Transport (PHT) Piping -2/2

- Inspection methods as per CSA N285.4
  - Volumetric inspection using ultrasound
  - Surface inspection and visual inspection
- Requirements on the scope of inspection and inspection interval
  - CSA N285.4
- Acceptance criteria for fatigue
  - CSA N285.4 and CSA N289.3 provide acceptance criteria for fatigue
Fatigue Management for Feeder Piping – 1/2

- Inspection results and Operating Experience (OPEX) indicate that no feeder pipe fatigue failure (i.e., leak or rupture) has been reported to date for the CANDU plants.
- Susceptibility of fatigue crack mechanisms have been assessed through a Failure Modes and Effects Analysis (FMEA) based on OPEX, inspection results, and research activities.
- Susceptible locations and types of plausible fatigue crack mechanisms have been identified as follows:
  - Fatigue at wall thinned region due to high localized stress.
  - Fatigue crack initiation due to vibration at a feeder attached on a defueled channel.
- Three different types of fatigue analysis have been conducted for a degraded feeder pipe:
  - Evaluation of Cumulative Usage Factor (CUF). Feeder Bend Test Program (FBTP) was conducted to demonstrate conservatism in usage factor approach.
  - Flaw tolerance approach.
  - Vibration analysis using similar rules in part 3 of American Society Mechanical Engineers (ASME) OM-S/G*:

* Standards and Guides for Operation and Maintenance of Nuclear Power Plant
Fatigue Management for Feeder Piping – 2/2

- Inspection methods as per CSA N285.4
  - Volumetric inspection using ultrasound
  - Surface inspection and visual inspection

- The scope of inspection and inspection interval
  - CSA N285.4
  - Feeder Life Cycle Management Plan (LCMP)

- Feeder Fitness For Service Guidelines (FFSG) provide evaluation procedure and acceptance criteria for fatigue at the thin wall locations (i.e., volumetric flaw)
Inspection results and Operating Experience (OPEX) indicate that no PT fatigue failure (i.e., leak or rupture) has been reported to date.

Susceptible locations and types of plausible fatigue mechanisms in FC:

- Fatigue crack initiation at the tip of surface flaw in a **Pressure Tube (PT)** due to changes of stress level during reactor operation (i.e., low-cycle fatigue).
- Fatigue crack initiation at **Calandria Tube (CT)** due to interaction between the PT, Annulus spacer, and CT during reactor operation (i.e., high-cycle fatigue).
- Fatigue crack initiation at **PT-CT annulus spacers** associated with thermal expansion of the PT during reactor operation.

Types of analysis for fatigue for three susceptible components to fatigue in FC:

- Pressure tube: The risk of crack initiation using crack initiation curves.
- PT-CT annulus spacers: Endurance tests are conducted using removed spacers.
Inspection methods as per CSA N285.4
- Volumetric inspection using ultrasound (PT*)
- Surface inspection and visual inspection (PT-CT** annulus spacers)

Requirements on the scope of inspection and inspection interval
- CSA N285.4
- Draft CSA requirements for PT-CT annulus spacers

Acceptance criteria for Fatigue
- CSA N285.8 provides acceptance criteria for fatigue (PT)
- No failure of removed spacers during endurance tests (PT-CT annulus spacers)
- Very low probability of fatigue crack initiation on CT
Inspection results and Operating Experience (OPEX) indicate that no more SG tube fatigue failure (i.e., leak or rupture) has been reported as of now after the installation of Anti-Vibration Bars (AVBs).

Susceptible locations and types of fatigue mechanisms in SG:
- Fatigue crack initiation at the U-bend region
- Fatigue crack initiation at the feedwater nozzle

Mitigation of fatigue mechanisms in SG
- The U-bend region: the installation of Anti-Vibration Bars (AVBs)
- The feedwater nozzle: Installed thermal sleeves

Types of fatigue analysis in SG
- Flaw tolerance approach when prevention of crack initiation is not demonstrated
Fatigue Management for Steam Generators (SGs) -2/2

- Inspection methods as per CSA N285.4
  - Volumetric inspection using ultrasound and eddy-current
  - Visual inspection

- Requirements on the scope of inspection and inspection interval
  - CSA N285.4
  - Steam Generator Life Cycle Management Plan (LCMP)

- Steam Generator (SG) Fitness For Service Guidelines (FFGS) provide evaluation procedures and acceptance criteria for fatigue
Closing Remarks

- No fatigue failure has been reported in major components, PHT piping, Feeder pipes, fuel channels excepting tube failures in steam generator prior to the installation of Anti-Vibration Bars (AVBs)
- CNSC Requires that licensees have programs to ensure Fitness for Service of Structures, Systems and Components (SSCs) in accordance with Power Reactor Operating License (PROL)
- CSA N285.4 provides requirements on scope of inspection, inspection interval, and acceptance criteria together with inspection for environmentally assisted cracking (EAC)
- A new informative annex is being added to N285.4-14 to provide an alternate approach to identify locations that are potentially susceptible to fatigue cracking and EAC
- All licensees are developing transient monitoring programs as per aging management activities
- Fatigue management plan is implemented in Life Cycle Management Plan (LCMP) as part of Aging Management Plan (AMP) for major components with the overall Integrated Aging Management Program framework addressed in CNSC regulatory document, REGDOC-2.6.3
- Fitness For Service Guidelines (FFSG) for feeder pipe, FCs and SGs provide evaluation procedure for fatigue
Acknowledgements

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