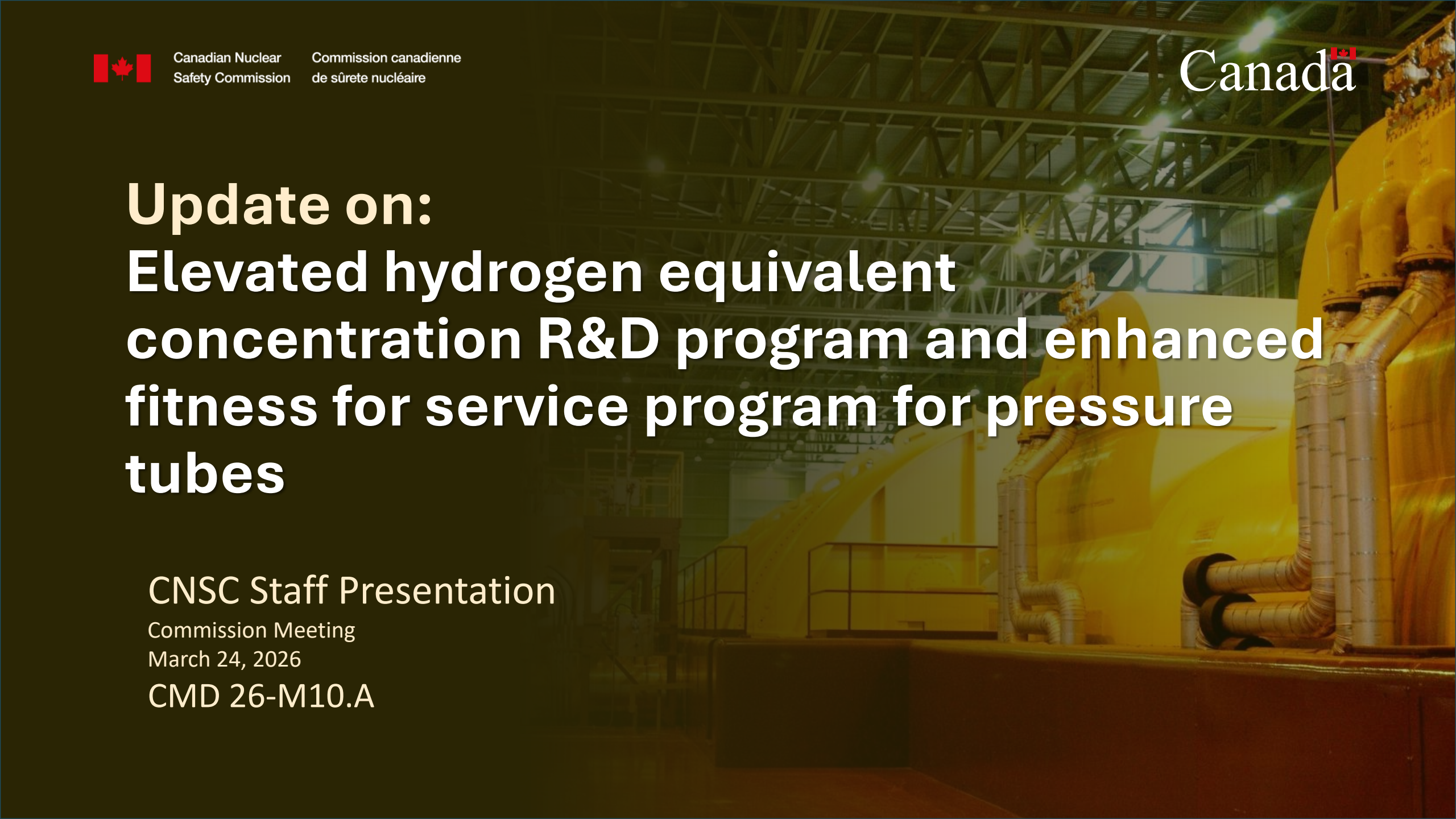
Canadian Nuclear Safety Commission | Commission canadienne de sûrete nucléaire

Canada

Update on: Elevated hydrogen equivalent concentration R&D program and enhanced fitness for service program for pressure tubes



CNSC Staff Presentation

Commission Meeting

March 24, 2026

CMD 26-M10.A

Purpose

To update the Commission on:

- The status of the elevated hydrogen equivalent concentration (Heq) research and development (R&D) activities
- The status of the enhanced fitness for service program for reactors in extended operation

This CMD is provided for information only. CNSC staff is not requesting a decision by the Commission.

Outline

- Introduction
- Status of the Heq R&D Activities
- Assessing Pressure Tube Fitness for Service
- Conclusions

Introduction

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Elevated Heq Findings

- In 2021, elevated Heq was discovered in pressure tubes in extended operation
- Elevated Heq was discovered near the inlet and outlet rolled joint burnish marks
- The Heq values exceeded the administrative limit of 120 ppm

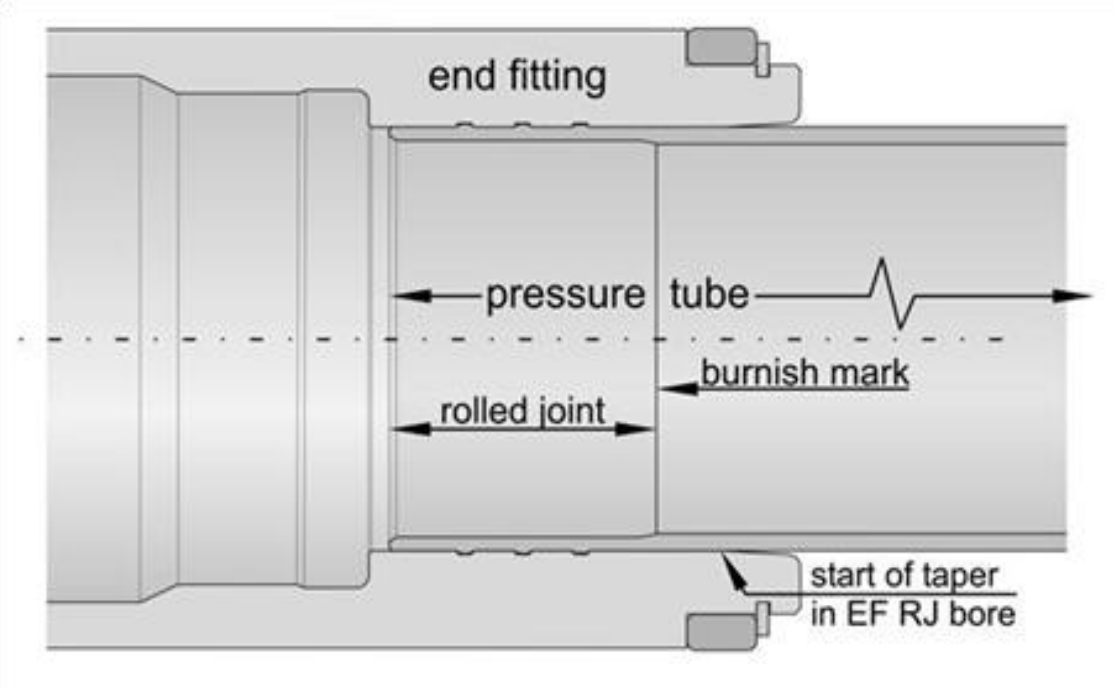

Image credit: Bruce Power

Units Remaining in Extended Operation

Licensee	Station	Unit	Planned to Shutdown*
Bruce Power	Bruce B	5	2026
		7	2028
		8	2030
Ontario Power Generation	Pickering B	5	2026
		6	
		7	
		8	

*Bruce Unis will be shutdown for refurbishment
Pickering Units will be shutdown for proposed refurbishment (pending authorization)

Licence Condition 6.1

LC 6.1 - The licensees shall implement and maintain a fitness for service program

Heq is a key parameter for the models used to assess pressure tube fitness for service

Overview of fitness for service evaluations for flaws in pressure tubes

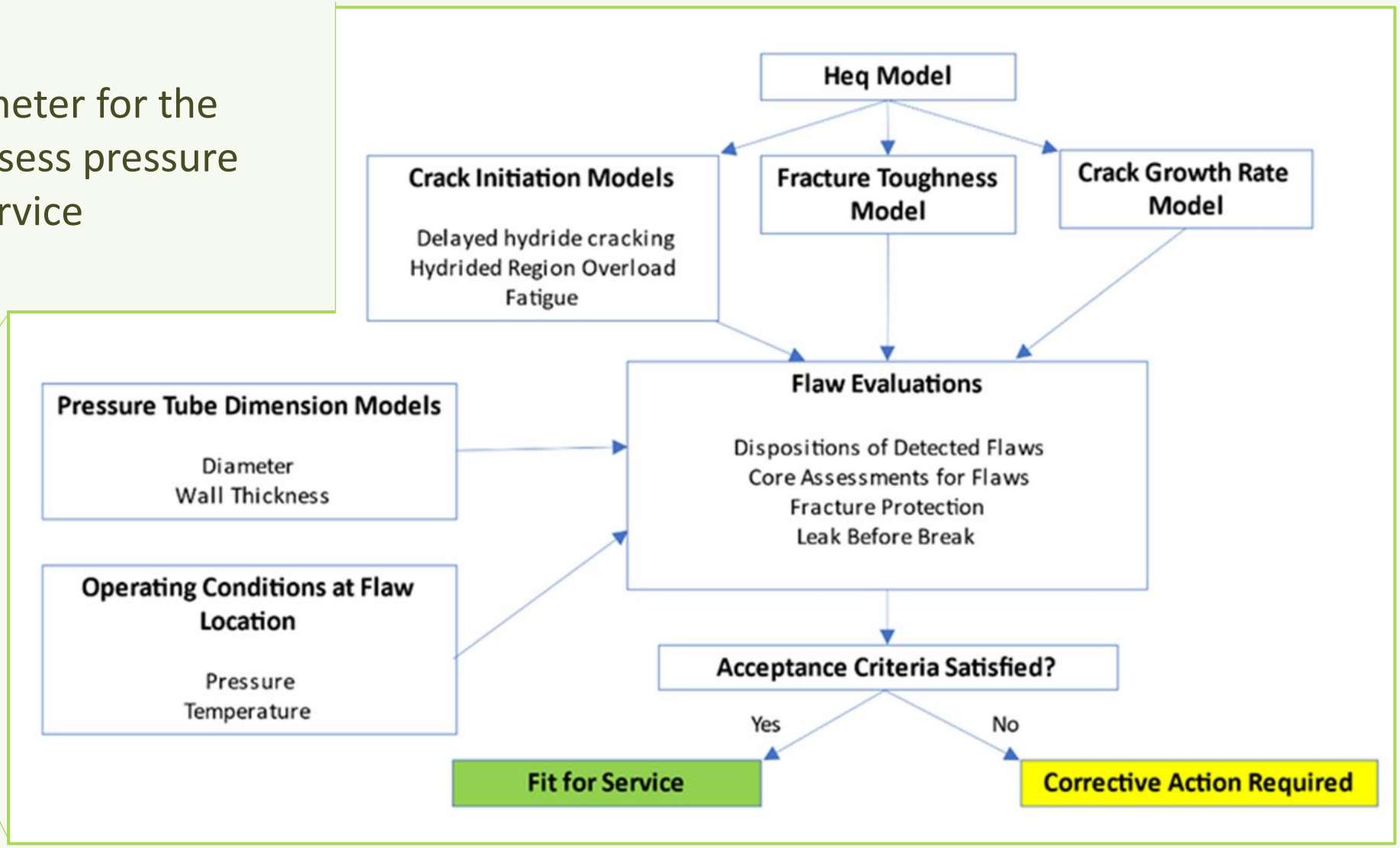

Image credit: CNSC staff

Licence Condition 6.2

In 2018, **Licence Condition (LC) 15.3** was included in **the Pickering and Bruce NGS power reactor operating licences (PROLs)**

LC 15.3 - "*Before hydrogen equivalent concentrations exceed 120 ppm, the licensee shall demonstrate that pressure tube fracture toughness will be sufficient for safe operation beyond 120 ppm*"

After the discovery of Heq levels exceeding 120 ppm in some pressure tubes, **LC 15.3 no longer served its intended purpose**

Commission amended licences to remove LC 15.3 and replaced it with LC 6.2

LC 6.2 - "*The licensees shall implement and maintain an enhanced fitness for service program for fuel channels in extended operation*"

Alternative CVC* for LC 6.2 (1/2)

- Heq research program established to confirm/modify models required for flaw evaluations per LC 6.1 compliance verification criteria
- LC 6.2 introduced temporary alternate criteria based on
  - Low likelihood of service-induced flaws in outlet region for all reactors
  - Low likelihood of service-induced flaws in inlet region of Pickering B reactors
  - Risk-informed decision making evaluation to assess to safe operation with service-induced flaws in the inlet region of Bruce reactors
- Considered time-at-risk for the scheduled duration of the research program

* Compliance Verification Criteria

Alternative CVC for LC 6.2 (2/2)

On December 31, 2025:

- Interim approaches to assess safe operability of pressure tubes expired
- CNSC staff's risk assessment expired
- OPG and Bruce Power should be able to return to assessing pressure tube fitness for service using the CVC in LC 6.1

Status of R&D Activities

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CNSC Staff Actions

CNSC staff raised action items for OPG and Bruce Power to:

- Complete all activities described in the R&D plans
- Respond to all comments arising from CNSC staff reviews of the R&D activities
- Submit progress reports on a semi-annual frequency
- Disposition comments from public interventions

Status of Heq R&D activities

CNSC staff confirm:

- All R&D activities with target completion dates by the end of 2025 have been completed
- There remains one activity to develop the final comprehensive Heq model by Spring 2026
  - Action items remain open to track the completion of the remaining activity

CNSC Staff Review of R&D Program Deliverables

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Heq Modeling

Heq model **predicts the movement of hydrogen** in the material

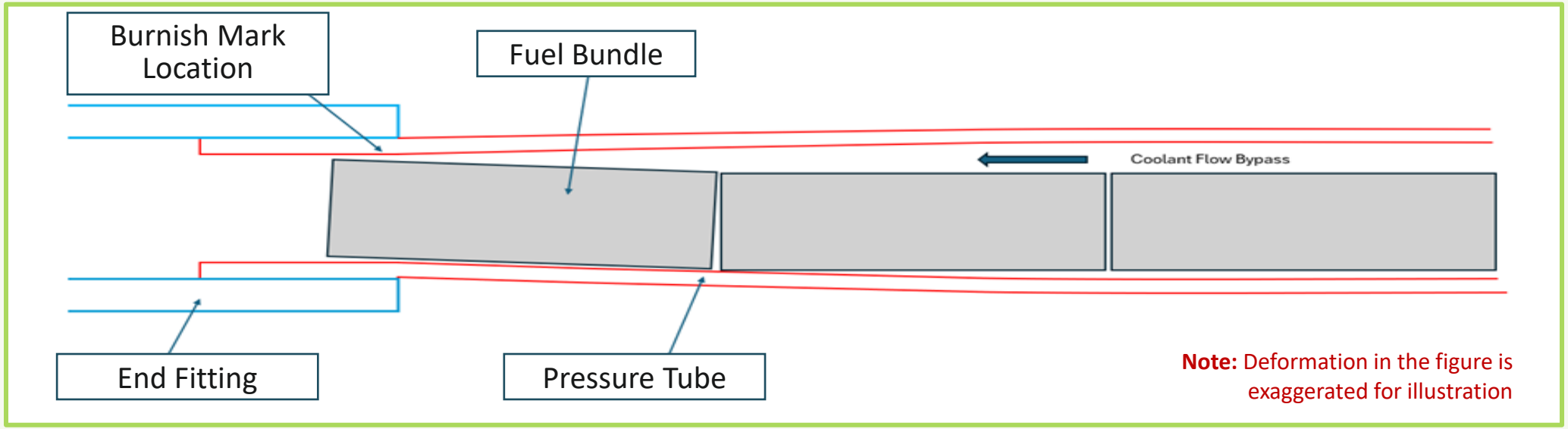
Soluble hydrogen **diffuses to cooler regions**

R&D program results **confirm that there is sufficient hydrogen inventory available** to produce regions of elevated Heq near the burnish marks from established ingress sources

Heq Modeling at the Outlet Rolled Joint

- Thermal and irradiation induced creep **increases the gap** between the top of the fuel bundle and the pressure tube creating coolant flow bypass
- A **20ºC circumferential temperature difference** can exist near the outlet rolled joint due to coolant flow bypass above fuel bundles
- R&D program results demonstrate that Elevated Heq near the outlet rolled joint can be **explained by temperature variation due to flow bypass**

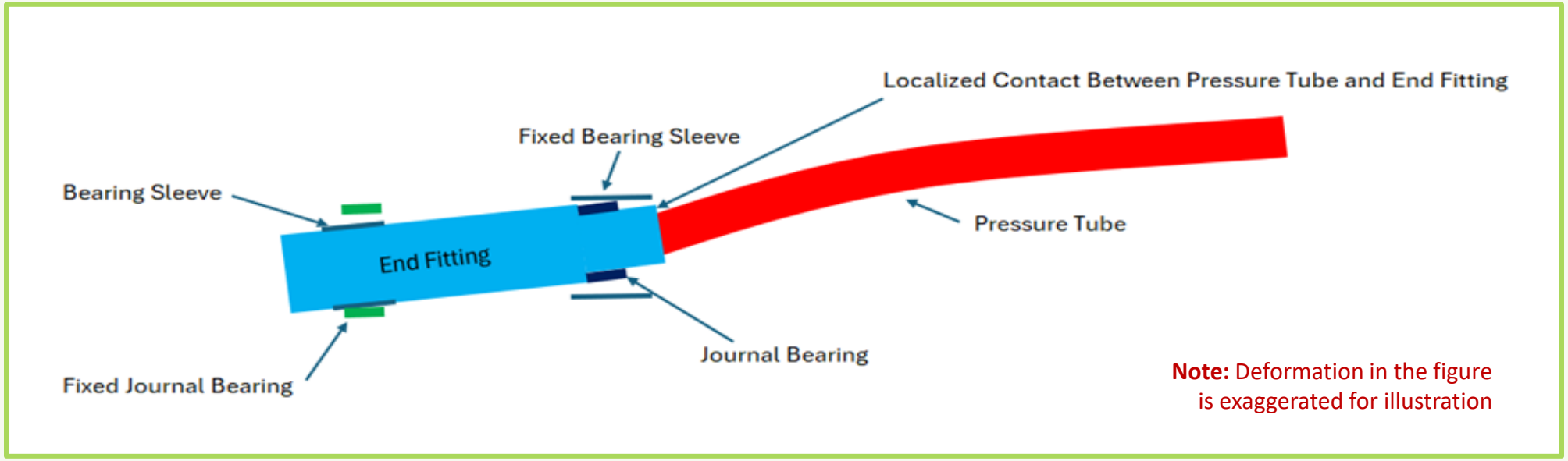
Image credit: CNSC staff



Heq Modeling at the Inlet Rolled Joint

- Pressure tube material can come into localized contact with the end fitting near the burnish mark due to bending
- This creates a cool spot at the outer diameter surface of the pressure tube due to a thermal conductance pathway
- R&D program results demonstrate that localized redistribution of hydrogen to the cool spot forms a Heq “blip”

Image credit: CNSC staff



Models for Flaw Evaluation

Material testing indicated:

- A modification is required for the fracture toughness model for material at the front end of a pressure tube
- A modification is required for the crack initiation model for delayed hydride cracking for material with elevated Heq
- No modifications are required for the crack initiation models for hydride region overload and fatigue for material with elevated Heq
- No modifications are required to the delayed hydride cracking growth rate model for material with elevated Heq

LC 6.1 Compliance Verification – OPG

R&D program demonstrated that the compliance verification for LC 6.1 can be used to assess Pickering Units 5-8 pressure tube fitness for service for the inlet and outlet regions of elevated Heq:

- The shield plugs at each end of the pressure tubes cover the regions
- Bounding analysis indicates that both regions will not extend to locations where flaws may exist before the units are shutdown by the end of 2026

LC 6.1 Compliance Verification – Bruce Power

R&D program demonstrated that the compliance verification for LC 6.1 can be used to assess Bruce A and B pressure tube fitness for service for the regions of elevated Heq:

- The bounding analysis demonstrates that the outlet region will not extend to locations where flaws may exist
- It is possible for flaws to exist within the same axial extent as the inlet region:
  - Service induced flaws only present on the inner diameter surface
  - Elevated Heq on the outer diameter surface of the pressure tube has been demonstrated to have no adverse effect on an inner diameter surface flaw

LC 6.1 Compliance Verification – Going Forward

Pickering B units are scheduled to be shut down by the end of 2026

- Results of R&D program have no impact on current fitness for service evaluations for pressure tube flaws

Three Bruce B units remain in extended operation

- Unit 5 scheduled to be shut down for refurbishment in 2026, Unit 7 in 2028 and Unit 8 in 2030
- No impact on fitness for service evaluations expected for Unit 5 prior to shut down
- Unit 7 and Unit 8 pressure tubes will require further flaw evaluations to demonstrate fitness for service up to proposed shut down

Continued Elevated Heq R&D

Licensees intend to continue R&D activities:

- Further refinement of Heq models
- Likely focus on reducing excess conservatism in the analytical toolset
- Incorporated into existing R&D activities for fuel channels
- CNSC staff will evaluate the results of the continued R&D activities

LC 6.2 Compliance Verification Criteria Update

- Enhanced fitness for service requirements for fuel channels in extended operation remain beneficial
- Focus of compliance verification criteria will be changed from pressure tube integrity assessment to enhanced Heq monitoring activities
  - Integrity assessments will be competed in accordance with CVC for LC 6.1

Conclusions

- Licensees have completed all R&D activities scheduled for completion by the end of 2025
- Licensees have demonstrated that an appropriate analytical toolset is available to perform the evaluations required for LC 6.1
- Further R&D on a variety of elevated Heq subjects will continue
- The compliance verification criteria for LC 6.2 will be revised to reflect the updated requirements for an enhanced fitness for service program for fuel channels in extended operation
- CNSC staff will continue to assess licensee pressure tube fitness for service programs against the CVC for LC 6.1 and LC 6.2
- CNSC staff request the Commission to consider closing the action to provide regular updates on the elevated Heq R&D activities through the status update on power reactors

Thank you

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