Impact on NPPs of Bruce Units 3 and 6 Licence Limit Exceedance of Hydrogen Equivalent Concentration in Pressure Tubes

CNSC Staff Presentation

Commission Meeting
September 3, 2021

CMD 21-M37

Purpose

This CMD provides:

- Details of and an update to the July 16, 2021 Event Initial Report (EIR): Bruce A Unit 3 and Bruce B Unit 6 Hydrogen Equivalent Concentration in Pressure Tubes Licence Limit Exceedance (CMD 21-M39)
- CNSC staff assessments of the licensees responses to the requests made pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations* (GNSCR)
- Next steps following the review by the Commission of the Orders issued to Bruce Power and OPG

This CMD is provided for information only

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BACKGROUND

Chronology of Event at Bruce A & B and Subsequent Actions

All references are publicly available

Discovery Heq issue reported by Bruce Power
via REGDOC-3.1.1 Event Reports
July 5, 2021 (Unit 6) [1]
July 8, 2021 (Unit 3) [2]

GNSCR Subsection 12(2) requests sent to all NPP licensees
July 13, 2021 [5, 6, 7]

GNSCR Subsection 12(2) responses received from all NPP licensees
July 30, 2021 [16, 19, 21]

CNSC letters sent to Bruce Power
requesting additional information
July 8, 2021 (Unit 6) [3]
July 9, 2021 (Unit 3) [4]

Orders issued
to Bruce Power [8] July 26, 2021
and to OPG [9] [10] July 27, 2021

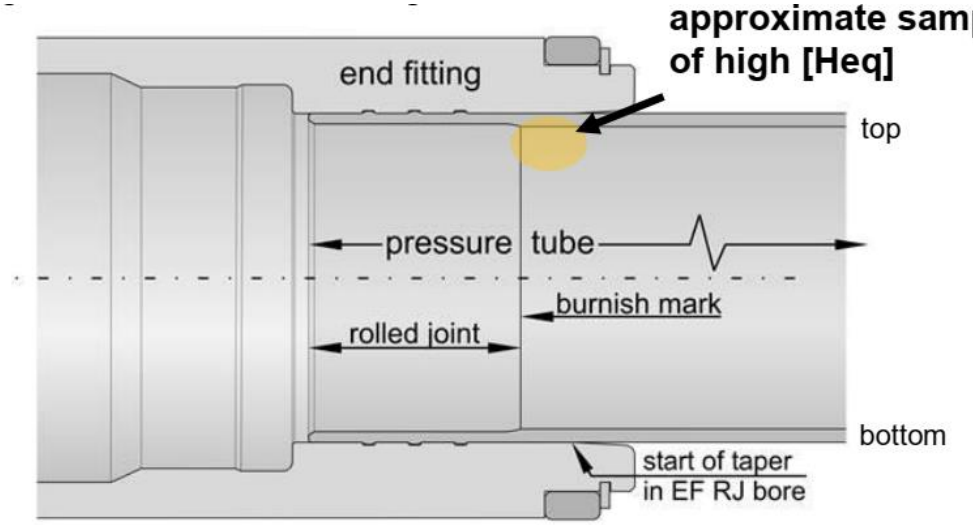
Discovery Reported at Bruce Units 3 and 6

- Pressure tube Hydrogen equivalent concentration (Heq) measurements in Unit 3 and Unit 6 exceeded levels predicted by current Heq models; the Heq limit in the licensing basis approved by the Commission is 120 ppm
  - Unit 6 burnish mark measurement: Heq: 211 ppm
    Predicted value from the model: 100 ppm
  - Unit 3 inspection campaign ongoing – values to be submitted
  - Elevated Heq localized to a region near the outlet end fitting in pressure tubes from both units
- The root cause of the elevated Heq at these locations has not been determined
- Safe operating margins established in the licensing basis were not compromised
- Licensees must demonstrate that pressure tubes remain fit for continued service

Region of Interest in Pressure Tubes

- For a description of the CANDU fuel channel configuration, please refer to **CMD 21-M4**
- The region of elevated hydrogen equivalent concentration (Heq) (“region of interest”) identified in the Bruce Power Unit 3 and Unit 6 pressure tubes is located close to the outlet end fitting

Length of pressure tube between end fittings: Approximately 5500 mm



Region of interest extends less than 75 mm from the outlet end fitting

Potential Impact on Pressure Tube Fitness for Service

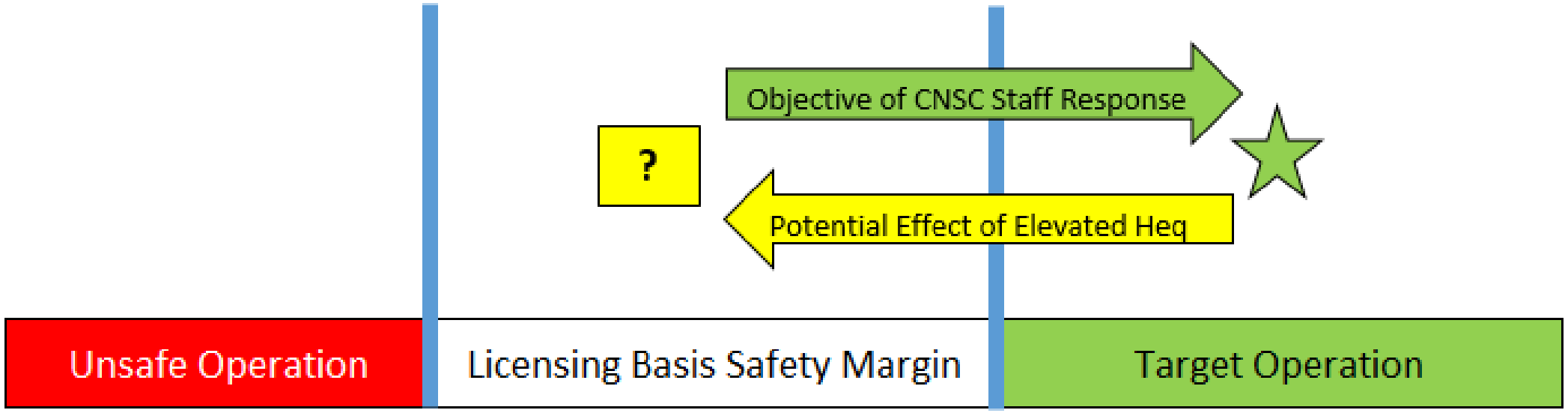
- For a detailed description of factors that can impact pressure tube fitness for service please refer to **CMD 21-M4**
- Elevated Heq can lead to a reduction in fracture toughness
  - Material's ability to resist failure if a crack is present
- Currently accepted fracture toughness model only validated for Heq up to 120 ppm, which constitutes the licensing basis
  - Current fracture toughness model not validated for Heq above 120 ppm
  - If a flaw is present, the elevated Heq may also increase the potential for crack initiation and growth from a flaw
- Licensees must assess the impact of the elevated Heq on fitness for service assessments

Evaluation for Pressure Tube Cracking

Degradation Process	Fitness for Service Program	Requires Knowledge of Heq?
Flaw formation due to interaction with fuel bundle	Inspections for flaws	No
Crack initiation from flaw	Models for crack initiation	Yes
Crack grows through wall	Models for crack growth	Yes
Pressure tube fails	Model for fracture toughness	Yes

Presence of flaws in the region of interest is one of the conditions for pressure tubes crack initiation

Impact on Current Safety Margins



Extended Operation

- Extended operation refers to operation beyond 210,000 equivalent full power hours (EFPH)
- Safe operation is not limited to 210,000 EFPH
  - intended to ensure that reactors were economical to build and operate
  - based on conservative estimates for pressure tube deformation rates
- Safe operating life of pressure tubes based on design and fitness for service safety margins

Safe operation is not limited to 210,000 EFPH

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BRUCE A & B - EIR UPDATE

Status of Bruce Units 3 and 6 (Units in planned outages)

- **Licence Condition 15.3** states: "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". The Licence Conditions Handbook also states that licensees "shall obtain approval of the Commission before operating any pressure tube with a measured [Heq] greater than 120 ppm…"
- **Bruce A Unit 3 and Bruce B Unit 6** unknowingly operated outside of the licensing basis prior to shutdown since their measured Heq was greater than 120 ppm. Both units currently in planned outages
- Modeling predictions underestimated measured Heq values in Bruce Units 3 and 6

Unit 3

- Bruce Power performed additional Heq scrape inspections on 26 channels
- Flaws were not identified in the channels assessed as part of the outage inspection campaign
- Detailed assessment of inspection results will be submitted to CNSC staff

Unit 6

has been in an extended Major Component Replacement outage since January 2020 and will have all pressure tubes replaced

Bruce Power's Submission Regarding Safe Continued Operation

Bruce Power completed **Technical Operability Evaluations** for the operating units (Units 1, 2, 4, 5, 7, and 8)

Bruce Power **reported that Units 1 and 2 are unconditionally operable** as their pressure tubes have been replaced and they have not operated long enough to generate elevated Heq in the pressure tubes

Bruce Power **asserted that pressure tubes in Units 4, 5, 7 and 8 are operable**

Bruce Power performed additional evaluations to demonstrate that continued full power operation of these units is safe

Since Heq cannot be measured during reactor operation, Bruce Power based their conclusion on an assessment of:

- Inspection results performed to date
- Lack of flaws observed in the region of interest that would lead to crack initiation
- Material behaviour at full power operating temperatures
- The concurrence between predictive and measured Heq values outside the region of interest where flaws are known to exist

CNSC Staff Assessment of Bruce A and B Safe Continued Operation

CNSC staff assessment of safe continued operation of Bruce A and B operating units (Units 1, 2, 4, 5, 7 and 8):

- Units 1 and 2 are are currently unaffected by the findings of the discovery event, as their pressure tubes have been replaced and they have not operated long enough to generate elevated Heq
- Elevated Heq will not impact safe operation of pressure tubes unless flaws exist in that region of interest and likelihood of such a flaw is considered low in Units 4, 5, 7, and 8
- CNSC staff conclude that short, medium and longer-term actions should be undertaken by Licensees to account for the elevated Heq discovery event

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GNSCR SUBSECTION 12(2) REQUESTS

GNSCR Subsection 12(2) Request Letter to Bruce Power

CNSC staff made the following requests to Bruce Power:

1. Analyze the impact of this information on the demonstration of pressure tube fitness for service
2. Conduct necessary tests and analysis to verify that operation of all reactors at Bruce Power remains within their licensing basis
3. Inform CNSC of any other measures taken in response to this information
4. Assess the impact of this information on the plan for Unit 3 restart post-A2131 outage
5. Analysis of the hydrogen uptake model validity, reflecting new information

GNSCR Subsection 12(2) Request Letters to OPG and NBP

The Bruce finding of elevated Heq has raised concerns regarding uncertainty in Heq modelling. This issue affects all NPP licensees since they all use similar models.

CNSC made the following requests to other NPP Licensees:

1. Confirm receipt of the information from Bruce Power related to this discovery
2. Analyze the impact of the information on the demonstration of pressure tube fitness for service
3. Conduct necessary tests and analysis to verify that operation of the reactor at [Licensee] Nuclear Generating Station[s] remains within its licensing basis
4. Inform CNSC of any other measures taken in response to this information

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CNSC STAFF ASSESSMENT OF NPP LICENSEES' GNSCR SUBSECTION 12(2) RESPONSES

Reactors in Extended Operation

The following Canadian NPP reactors are currently in extended operation:

- Bruce NGS A and B Units 4, 5, 7 and 8
- Pickering NGS B Units 5, 6, 7 and 8
- Darlington NGS Units 1 and 4

Reactors Not in Extended Operation

The following units have recently been refurbished and therefore have not operated long enough to generate elevated Heq levels in the region of interest and thus can be operated for the remainder of the current licensing periods:

- Bruce NGS A Units 1 and 2
- Darlington NGS Unit 2
- Point Lepreau NGS

Additionally, CNSC staff has not received notification from OPG that Pickering Units 1 and 4 pressure tubes will be operated beyond 210,000 equivalent full power hours (beyond 2024); Heq is expected to remain within licensing limits

Units in a Planned Outage

The remaining units are in planned outages:

- Bruce Units 3 and 6
- Darlington Unit 3

Bruce Unit 6 and Darlington Unit 3 are in extended refurbishment outages and will have all of their pressure tubes replaced; therefore, CNSC staff do not deem any concern with these units and they can be restarted without any concern over elevated Heq or the presence of flaws

Pursuant to the Order, Commission approval will be required to restart Bruce Unit 3

Safe Operation Until Next Outage

Continued reactor's operation is considered safe until the next outage for operating reactors based on the following considerations:

- Pressure tubes retain adequate fracture toughness at full power temperatures
- Low population of flaws in the region of interest of inspected pressure tubes
- Safety Analysis remains valid, and
- Defence in Depth provisions (which ensure safe shutdown) are maintained

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IMPACT OF THE BRUCE DISCOVERY EVENT ON SAFE OPERATION

Assessment of the Safety Case

Defence in Depth

- 5 levels
- Protection of barrier

Fundamental Safety Functions

- Control
- Cool
- Contain

Defence in Depth

Level	Objective	Means
1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation
2	Control of abnormal operation and detection of failures	Control, limiting and protection systems and other surveillance features
3	Control of accidents within the design basis	Engineered safety features and accident procedures
4	Control of severe plant conditions	Complementary measures and accident management
5	Mitigation of radiological consequences	Off-site emergency response

Safety Analysis

- Rupture of a single pressure tube considered a Design Basis Accident for CANDU safety analysis
- Safety Analysis is the performed to confirm safety system effectiveness
  - Bounding initiating events/failures are assumed
  - Accident sequences are determined
  - The plant and safety system responses are modeled
  - Consequences are analyzed

Safety Analysis - Accident Sequence

In the case of a hypothetical pressure tube failure the accident sequence would be as follows:

- Pressure tube (PT) failure and Calandria tube (CT) consequential failure conservatively assumed
  - OPEX indicates that the CT does not always fail
- Failure causes pipe whip which damages adjacent internal reactor components
  - No damage to adjacent PT/CT expected
- Primary Heat Transport water discharges into calandria
  - Calandria overfills and spills out into containment
- Reactor trip, containment Isolated, and Emergency Coolant Injection (ECI) initiated

Safety Analysis – Fundamental Safety Functions

Control

Finding will not impact ability to shutdown

- Reactor trips remain effective
- Shutdown systems capable of shutting down and keeping the reactor subcritical

Cool

Finding will not impact ability to cool the core

- Small break size in case of PT rupture
- Effective ECI

Contain

Finding will not impact containment

- No impact on predicted releases

Impact of Bruce Discovery Event on Deterministic Safety Analysis

The findings of elevated Heq in Bruce Units 3 and 6 do not impact:

- accident sequence
- key analysis sensitivities (amount of sub-criticality and fuel temperature)
- ability to perform the fundamental safety functions
- accident consequences (public dose)

Conclusion: No impact on the plant's ability to meet safety analysis objectives

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DESIGNATED OFFICER ORDERS

Designated Officer Orders issued to Bruce Power and OPG

- The Order requires Bruce Power to obtain authorization from the Commission prior to the restart of any of Units 3, 4, 5, 7 or 8 following any outage that results in the cooldown of the heat transport system
- Similar Orders were sent to OPG for Darlington Units 1 and 4 and Pickering Units 1, 4, 5, 6, 7 and 8
- An Order was not issued to NB Power because Point Lepreau NGS is not in extended operation.
- Pursuant to the NSCA, the the Orders must be reviewed by the Commission
- The Commission must offer an opportunity to be heard to those named in the order being reviewed
    - In August 2021, Bruce Power and OPG both requested an opportunity to be heard before the Commission

Conditions of the Orders

Prior to seeking Commission authorization for restart, [Licensees] shall either:

a. Carry out inspection and maintenance activities that demonstrate with a high degree of confidence that pressure tube [Heq] is within [the Licensee's] licensing basis, per licence condition G.1, and submit results of such activities to CNSC staff;

or

b. Carry out inspection and maintenance activities that demonstrate with a high degree of confidence that no flaws are present in the region of pressure tubes where the models failed to conservatively predict the elevated [Heq], and submit results of such activities to CNSC staff.

Assessment Criteria for Restart After an Outage (1/2)

- CNSC staff established assessment criteria for the review of licensee's requests for restart
- The assessment criteria are applicable to requests for the restart of any units subject to the order
- For both Option (a) and Option (b) criteria, the region of interest shall be defined as the first 75 mm inboard of the outlet burnish mark and the full circumference of the pressure tube

Assessment Criteria for Restart After an Outage (2/2)

Assessment Criteria for Option (a)

1. Licensee shall demonstrate an understanding of the mechanism leading to high Hydrogen equivalent (Heq) concentration in the region of interest, and are able to conservatively model Heq concentration in this region

or

Assessment Criteria for Option (b)

1. Sufficient inspection data shall be available for the reactor unit to justify, with a high degree of certainty, that no flaws are present in the region of interest greater than 0.15 mm in depth
2. Corrective actions shall be implemented for tubes containing flaws greater than the specified depth

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NEXT STEPS

Demonstration of Safe Operation of Units in Extended Operation (1/2)

Short-term (1-3 months) Period of reactor operation to the next planned or unplanned outage

- Review/enhancement of operational procedures to confirm low likelihood of over-pressurization events during shutdowns
- Prepare plans for enhanced inspection activities to provide continued confirmation that there is a low likelihood of flaws in the region of interest

Demonstration of Safe Operation of Units in Extended Operation (2/2)

Medium-term (3-6 months) During next planned or unplanned outage

- Implement enhanced inspection activities

Longer-term (>6 months) Period of reactor operation up to expected refurbishment dates

- Additional material surveillance and research activities to understand the cause of the elevated Heq and assess the impact on pressure tube fitness for service evaluations

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CONCLUSIONS

Overall Conclusions

Based on available information assessed to date, CNSC staff conclude that:

- Continued reactor operation does not pose unreasonable risk
- Existing safety analysis remains valid
- Orders specify conditions that will provide additional assurance of pressure tube fitness for service
- Licensees adequately responded to the discovery and regulatory actions

No reactor will be authorized to operate without a valid safety case

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References (1/3)

[1] Bruce Power Email, J. Thompson to L. Sigouin, "REGDOC-3.1.1 B-2021-98077 DR", July 5, 2021, e-Doc 6600317 (CMD 21-M37.1).

[2] Bruce Power Email, J. Thompson to L. Sigouin, "REGDOC-3.1.1 B-2021-93819", July 8, 2021, e-Doc 6603256 (CMD 21-M37.1)

[3] CNSC Letter, L. Sigouin to M. Burton, "Bruce A and B: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR on Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement – New Action Item 2021-07-23406", July 8, 2021, e-Doc 6600766 (CMD 21-M37.A)

[4] CNSC Letter, L. Sigouin to M. Burton, "Bruce A: CNSC Review of REGDOC-3.1.1 Event Report B-2021-93819 on A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements – New Action Item 2021-07-23424", July 9, 2021, e-Doc 6603183 (CMD 21-M37.A)

[5] CNSC Letter, A. Viktorov to M. Burton, "Bruce A and B: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes", July 13, 2021, e-Doc 6603948 (EN, FR)

[6] CNSC Letter, A. Viktorov to S. Gregoris and J. Franke, "Darlington and Pickering NGS: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Concentration in Pressure Tubes", July 13, 2021, e-Doc 6603931 (EN, FR)

[7] CNSC Letter, A. Viktorov to M. Power, "PLNGS: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes", July 13, 2021, e-Doc 6604246 (EN, FR)

[8] Designated Officer Order, R. Jammal to Bruce Power, "Order by a Designated Officer Under Paragraph 37(2)(f) and Subsection 35(1) of the *Nuclear Safety and Control Act*", July 26, 2021, e-Doc 6612405 (EN, FR)

[9] Designated Officer Order, R. Jammal to Bruce Power, "Order by a Designated Officer Under Paragraph 37(2)(f) and Subsection 35(1) of the *Nuclear Safety and Control Act*", July 26, 2021, e-Doc 6612405 (EN, FR)

[10] Designated Officer Order, R. Jammal to Bruce Power, "Order by a Designated Officer Under Paragraph 37(2)(f) and Subsection 35(1) of the *Nuclear Safety and Control Act*", July 26, 2021, e-Doc 6612405 (EN, FR)

References (2/3)

[11] Event Initial Report, "Bruce A Unit 3 and Bruce B Unit 6 Hydrogen Equivalent Concentration in Pressure Tubes Licence Limit Exceedance", July 16, 2021, e-Doc 6604836 (CMD 21-M39)

[12] Bruce Power Letter, M. Burton to L. Sigouin, "Action Item 2021-07-23406: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR", July 15, 2021, BP-CORR-00531-01853, e-Doc 6607624 (CMD 21-M37.1)

[13] Bruce Power Letter, M. Burton to L. Sigouin, "Action Item 2021-07-23424: CNSC Review of REGDOC-3.1.1 Event Report B-2021-93819", July 16, 2021, BP-CORR-00531-01863, e-Doc 6608104 (CMD 12-M37.1)

[14] Bruce Power Letter, M. Burton to L. Sigouin, "Action Item 2021-07-23406: Bruce A and B: Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements", July 25, 2021, BP-CORR-00531-01883, e-Doc 6612866 (CMD 21-M37.1)

[15] Bruce Power Letter, M. Burton to M. Leblanc and A. Viktorov, "Bruce A and B: Response to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Measurement of Hydrogen Equivalent Concentration in Pressure Tubes", July 19, 2021, BP-CORR-00531-01875, e-Doc 6608974 (CMD 21-M37.1)

[16] Bruce Power Letter, M. Burton to M. Leblanc and A. Viktorov, "Bruce A and B: Response to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Measurement of Hydrogen Equivalent Concentration in Pressure Tubes", July 30, 2021, BP-CORR-00531-01884, e-Doc 6616619 (CMD 21-M37.1)

[17] OPG Letter, M. Knutson to M. Leblanc and A. Viktorov, "OPG Response to Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Concentration in Pressure Tubes", July 19, 2021, N-CORR-00531-22788, e-Doc 6609557 (CMD 21-M37.2)

[18] OPG Letter, M. Knutson to A. Viktorov, "OPG Interim Assessment of High Hydrogen Equivalent Concentration ([Heq]) Discovery Issue at Bruce Power's Units 3 and 6 on Pickering and Darlington Nuclear Generating Stations Pressure Tube Fitness for Service", July 27, 2021, N-CORR-00531-22809, e-Doc 6614320 (CMD 21-M37.2)

References (3/3)

[19] OPG Letter, M. Knutson to M. Leblanc and A. Viktorov, "OPG Response to Request pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*: Responses to Items 1-4 Related to Measurement of Hydrogen Concentration in Pressure Tubes", July 30, 2021, N-CORR-00531-22801, e-Doc 6616028 (CMD 21-M37.2)

[20] NB Power Letter, M. Power to M. Leblanc and A. Viktorov, "Request pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*: Issues Relating to Measurements of Hydrogen Equivalent Concentration in Pressure Tubes", July 19, 2021, e-Doc 6608964 (CMD 21-M37.3)

[21] NB Power Letter, M. Power to M. Leblanc and A. Viktorov, "Request pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*: Issues Relating to Measurements of Hydrogen Equivalent Concentration in Pressure Tubes", July 30, 2021, e-Doc 6616141 (CMD 21-M37.3)