BrucePower
Innovation at work

September 26, 2025

BP-CORR-00531-06660

Ms. Candace Salmon
Commission Registrar
Canadian Nuclear Safety Commission
P.O. Box 1046
280 Slater Street
Ottawa, Ontario
K1P 5S9

Dear Ms. Salmon:

Bruce B Units 7 and 8: Review of Fuel Channel Fitness for Service
Program to Extend Operation up to 310,000 Effective Full Power Hours

The purpose of this letter is to request Commission approval to operate Bruce B Units 7 and 8 to 310,000 Effective Full Power Hours (EFPH), pursuant to the Power Reactor Operating Licence PROL 18.04/2028, Licence Conditions G.1 and 6.1, and the Licence Conditions Handbook, LCH-PR-18.04/2028-R005, Sections G.1 and 6.1, as previously discussed in References 1 and 2 .

The current licensing basis authorizes Bruce A and Bruce B to operate up to a maximum of 300,000 EFPH. Bruce Power is seeking Commission approval to extend operation of Units 7 and 8 to 310,000 EFPH to provide the operational flexibility to optimize the overall Major Component Replacement (MCR) schedule. Although neither unit is expected to operate to the full 310,000 EFPH, this extension of the licence limit will provide the regulatory certainty and operational margin needed to ensure safe execution of these large refurbishment projects. This change remains in accordance with the licensing basis and does not have an impact on heath, safety, security, the environment and Canada's international obligations.

Section 6.1 of the LCH requires the licensee to demonstrate that the predicted condition of fuel channels continues to support safe operation. Accordingly, Bruce Power has conducted a thorough assessment of the degradation mechanisms that are pertinent to extended operation of fuel channels up to 310,000 EFPH. These details are provided in Enclosure 1.

The results of this assessment demonstrate that Bruce Power's fuel channel Fitness for Service (FFS) Program continues to effectively manage all associated degradation mechanisms, and that appropriate programs and measures are in place to support continued operation of Units 7 and 8 up to 310,000 EFPH. These measures include, but are not limited to, on-going in-service inspections and surveillance activities compliant with the requirements of CSA N285.4-14, updating of key fuel channel assessments, and extensive Research and Development (R&D) programs.

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Bruce Power acknowledges that completion of the accelerated R&D program related to elevated Hydrogen Equivalent Concentration (Heq) and closure of the associated Action Item 2023-07-27173 is a key component to demonstrating continued FFS of fuel channels. Accordingly, Bruce Power has also provided a separate submission to CNSC staff (Reference 3), which confirms completion of the committed R&D activities and addresses the necessary closure criteria to complete this action item.

Overall, Bruce Power has a robust, mature FFS program, which has proven to be effective at managing fuel channels in extended operation. The information provided in this submission confirms that the necessary programs and measures are in place to further support operation of the fuel channels beyond 300,000 EFPH, and as such Bruce Power is seeking Commission approval to extend operation of Bruce B Units 7 and 8 to 310,000 EFPH. Extension of this licence limit will help to ensure the safe and efficient execution of Bruce Power's MCR program.

As discussed in Reference 1, Bruce Power requests a hearing and decision by July 31, 2026.

If you require further information or have any questions regarding this submission, please contact Mr. Maury Burton, Senior Director, Regulatory Affairs at maury.burton@brucepower.com.

Yours truly,

Digitally signed by
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Maury Burton
Senior Director, Regulatory Affairs
Bruce Power

cc: CNSC Forms / Formulaires
Ms. Anupama Bulkan, CNSC - Ottawa
Dr. Alexandre Viktorov CNSC - Ottawa

Enclosure:

1. NK29-REP-31100-15SEP2025, Rev000, "Bruce B Units 7 and 8 Fuel Channel Fitness-for-Service Evaluation to Support Extended Operation to 310 kEFPH.

References:

1. Letter, M. Burton to C. Salmon, "Bruce A and B: Notice of Intent to Seek Commission Approval", April 24, 2025, BP-CORR-00531-06431.
2. Letter, C. Salmon to M. Burton, "Notice of Intent to Seek Commission Approval – Bruce A and B", June 16, 2025, BP-CORR-00531-06618.
3. Letter, M. Burton to A. Bulkan, "Bruce A and B: Semi-Annual Update on Industry R&D Plan on Elevated Hydrogen Concentrations, Action Items 2023-07-27173 and 2022-07-26737", September 24, 2025, BP-CORR-00531-06751.

Enclosure 1

NK29-REP-31100-15SEP2025, Rev 000

Bruce B Units 7 and 8 Fuel Channel Fitness-for-Service Evaluation to Support Extended Operation to 310 kEFPH

INTERNAL USE

BRUCE B UNITS 7 AND 8 FUEL CHANNEL FITNESS-FOR-SERVICE EVALUATION TO SUPPORT EXTENDED OPERATION TO 310 KEFPH

NK29-REP-31100-15SEP2025

SEPTEMBER 2025

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1.0 INTRODUCTION

Under the current licensing basis, Bruce Power continues to demonstrate pressure tube (PT) integrity and fitness-for-service (FFS) and has been approved to operate up to 300 kEFPH effective full power hours (EFPH).

Bruce Power will be requesting Commission approval to operate Bruce NGS B Units 7 and 8 up until their respective Major Component Refurbishment (MCR) outages which will exceed the 300 kEFPH limit. Table 1 provides the projected EFPH for Units 7 and 8 at the time of their MCR outages including a planning margin of up to 6 months. The 310 kEFPH value has been selected as the upper limit for the expected operating life of these units prior to MCR. It is therefore necessary to perform an updated review of the various fuel channel (FC) aging mechanisms, identify potential risks and activities required to support operation to 310 kEFPH.

The purpose of this report is to document the assessment to support fuel channel fitness-for-service for Bruce B Units 7 and 8 for extended operation to 310 kEFPH.

2.0 FUEL CHANNEL AGING MECHANISMS AND EVALUATION TO 310 KEFPH

This section provides a review of key fuel channel fitness-for-service areas and aging mechanisms that require ongoing work to support an extended operation to 310 kEFPH for Bruce B Units 7 and 8. Appendix A provides a summary of all fuel channel FFS areas and aging mechanisms, the current fitness-for-service assessment limits for Units 7 and 8, and the evaluation of each area/mechanism to support an extended operation to 310 kEFPH.

2.1 Pressure Tube Axial Elongation

The current requirement as per CSA[1] N285.4 is to operate fuel channels on-bearing, consistent with their registered design to ensure fitness-for-service. During each maintenance outage, FC elongation measurements are performed on both the fixed and free faces to confirm elongation rates and to refine predictions of end-of-bearing (EOB) times.

As noted in Appendix A, the current EOB for Units 7 and 8 are beyond 300 kEFPH but below 310 kEFPH. Reconfiguration for Unit 7 was completed during the 2024 outage (B2471) and reconfiguration for Unit 8 is currently scheduled in the 2026 outage (B2681).

FC elongation measurements will be performed during the B2771/B2681/B2881 outages. Additional margin to the EOB times can be achieved through a combination of shifting a small number of channels and/or selective defueling of channels with the highest elongation rates in future outages (B2771/B2681/B2881) and installation of spacer clips in some channels to reduce the positioning assembly uncertainty to support extended operation of Bruce Units 7 and 8 to 310 kEFPH. Additional margins may also be obtained through analytical refinements if required.

[1] CSA – Canadian Standards Association

2.2 Enhanced Oxidation

PT inspections in Bruce B Units to date have revealed multiple types of oxidation mechanisms which include inlet end rolled joint surface roughness (IRJ SR), outlet end oxidation (OEO) and, inlet rolled joint enhanced oxidation (IRJEO) (specific to Bruce Unit 8 TG3 PTs). In Unit 7, there has been an increased change in the OEO observations between the 2021 (B2171) and 2024 (B2471) V&D inspections for some repeat channels. In Unit 8, apart from the IRJEO observed in TG3 pressure tubes, the non TG3 pressure tubes generally have similar oxidation behaviour as the other Bruce B Units.

The presence of these inside surface conditions has the potential to impact the accuracy of pressure tube dimensional measurements, affect the ability to detect and characterize pressure tube (PT) flaws and, affect the HIC scrape sampling process.

Although there has been limited impact on inspection capability to date, Bruce Power has established a strategy framework since 2022 [R-1] consisting of a multi-staged approach to better understand the prevalence and impact of enhanced oxidation in PTs and identification of activities required to understand and manage these observations. Activities defined in the strategy framework (including activities specific to PT oxides observed in Task Group 3 (TG3)) channels are revised periodically in response to new inspection findings and exploratory work. Annual updates on the progress of these activities have been submitted to the CNSC in [R-2][R-3][R-4].

Operation to 310 kEFPH will not require significant additional work beyond the activities identified in the strategy framework. As identified in the Fuel Channel Life Cycle Management Plan (FCLCMP) [R-5], volumetric and dimensional (V&D) inspections in non TG3 and TG3 channels will continue to be monitored for these various enhanced oxidation phenomena.

2.3 Deuterium Ingress and Channels Exceeding TSSd

Deuterium concentration or $[H]_{eq}$ is a key input in multiple PT fitness-for-service assessments. Deuterium ingress increases the hydrogen equivalent concentration $[H]_{eq}$ within the PT. Increased $[H]_{eq}$ can lead to hydride blister formation at locations of PT-CT contact, which could lead to blister growth and cracking, followed by delayed hydride cracking (DHC) initiation and growth, crack coalescence and PT rupture. Increased $[H]_{eq}$ levels also increase the probability of crack initiation from flaws. High levels of $[H]_{eq}$ results in reduced fracture toughness, impacting the demonstration of leak-before-break (LBB) and fracture protection.

Currently, the $[H]_{eq}$ levels in the PTs are being monitored through in-service scrape sampling which exceed the CSA N285.4 standard body of tube (BOT) and rolled joint (RJ) scrape scope requirements as indicated in the FCLCMP [R-5] and punch sampling from removed PTs. BOT and RJ predictive models have been developed and are used to predict $[H]_{eq}$ concentrations which are compared to corresponding CSA N285.4 $[H]_{eq}$ limits.

2.3.1 BOT (Body of Tube)

In the BOT, if the predicted $[H]_{eq}$ of an inspected pressure tube is expected to exceed TSSd (Terminal Solid Solubility Hydrogen Dissolution) $[H]_{eq}$ (under sustained operations) prior to the MCR outage, a disposition is required as stated in [R-6]. Bruce Power submits a component disposition for PT operation above TSSd using the technical basis documented in [R-7] which has been accepted by CNSC with a limit of 100 pm $[H]_{eq}$ in the BOT region of PTs [R-8]. As noted in Appendix A, there are no tubes in Bruce Units 7 and 8 predicted to have pressure tubes exceed TSSd in the BOT above 100 ppm prior to their MCR outages. For extended operation to 310 kEFPH, it is expected that the $[H]_{eq}$ in the BOT regions may exceed the 100 ppm $[H]_{eq}$ limit before then. An update to the technical basis for exceeding TSSd in [R-7] will be pursued by leveraging the R&D work recently completed through the crack initiation program on elevated $[H]_{eq}$ and recent industry efforts to extend material property validity limits.

Large circumferential variation has been observed in the BOT in Unit 7 2024 outage (B2471) and most recently the Unit 5 2025 outage (B2551). The current BOT D-uptake modeling does not account for circumferential variation and the potential for higher uptake rates in regions exceeding TSSd. Bruce Power will continue to perform scrape sampling in select channels in upcoming outages (B2771 and B2681/B2881). Work is currently ongoing with the industry to develop a methodology to implement the circumferential redistribution at the top of the PTs to enhance the predictive BOT models for Units 7 and 8. No additional effort would be required to support operation to 310 kEFPH beyond the scrape scope activities and predictive BOT model developments discussed above.

2.3.2 RJs (Rolled Joints)

In July 2021, Bruce Power reported elevated $[H]_{eq}$ observations in the outlet RJ regions of surveillance PT B6S13 and from the 2021 Bruce Unit 3 RJ scrape which showed higher than expected RJ $[H]_{eq}$ measurement results exceeding the acceptance criteria as per CSA N285.4. A review of the A2131 scrape measurements identified some PTs with a localized region in the upper half of the PT in the outlet RJ known as the outlet region of interest (OROI) with a large circumferential variation. In November 2021, elevated $[H]_{eq}$ observations were also reported in the inlet RJ region of PT B6S13, specifically a localized peak (i.e., blip) of $[H]_{eq}$ on the outside surface of the PT and 10 mm inboard of the burnish mark (BM) known as the inlet ROI (IROI). As a result, Bruce Power expanded the outage scrape campaign activities in the A2131 outage as well as subsequent outages in Bruce B Units to acquire inlet and outlet RJ measurements at various clock positions and axial positions relative to the inlet/outlet BM.

Since then, Bruce Power and OPG along with industry partners, have established an $[H]_{eq}$ roadmap process to integrate industry efforts related towards a mechanistic understanding and predictive modelling of $[H]_{eq}$ in the inlet and outlet RJs of PTs through extensive activities. These activities included in-service PT H_{eq} PT surveillance monitoring, model development, validity confirmation of existing crack initiation and fracture toughness (FT) models to elevated H_{eq} and PT FFS assessments completed to support the continued operation for Bruce Units 3, 4, 5, 7 and 8 PTs with elevated $[H]_{eq}$ in the inlet and outlet ROIs. A submission providing an update to these activities was provided to the Commission in [R-9]. As a result, CNSC included a requirement in the Bruce Power's LCH, Section 6.2: Fitness-for-Service Program for Fuel Channels in Extended Operation for elevated $[H]_{eq}$.

In CNSC's risk assessment [R-10], CNSC staff determined that elevated $[H]_{eq}$ at the inlet RJ of PTs is not an integrity concern and that continued operation of Bruce A and B pressure tube is not a significant safety concern for a period of up to three years (i.e., by end of 2025).

Bruce Power continued to provide semi-annual progress updates of the $[H]_{eq}$ roadmap activities to the CNSC in [R-11][R-12][R-13][R-14][R-15]. By September 2025, Bruce Power plans to request closure of the remaining CNSC Action Items on elevated $[H]_{eq}$ (i.e., 2023-07-27173, 2022-07-26737) which will involve submission of various reports documenting the completed R&D work activities from the H_{eq} roadmap in order to move from Licence Condition 6.2 back to the compliance verification criteria established in Section 6.1 on Fitness-for-Service for Fuel Channels. Even after the CNSC action items on elevated $[H]_{eq}$ are closed, the industry will continue to address elevated $[H]_{eq}$ through longer term R&D work activities.

No additional effort to address elevated $[H]_{eq}$ would be required to support operation to 310 kEFPH beyond the R&D work activities discussed above. Bruce Power will continue to perform RJ scrape sampling at various clock positions and axial positions relative to the BM in the upcoming B2771/B2681/B2881 outages.

Bruce Power recognizes that extended operation to 310 kEFPH for Units 7 and 8 will be contingent on closure of the remaining CNSC Action Items on elevated $[H]_{eq}$ by end of 2025 as planned.

2.4 Fracture Toughness

The fracture toughness of pressure tubes decreases with increase of hydrogen concentration at a certain range of temperatures. The industry has developed an engineering fracture toughness model to characterize the transition from lower-shelf to the upper-shelf toughness and the model is the Revision 2 Engineering Fracture Toughness model. The Revision 2 Engineering Fracture Toughness model has a validity limit of 100 ppm from the front-end of the tube to 1.5 m location and 140 ppm for the rest of the tube. Bruce Power continues to work with the industry to perform burst tests on hydrided pressure tube sections with different levels of hydrogen concentration and at various temperatures to validate the fracture toughness model. The industry has developed a technical basis to increase the validity limit for the Revision 2 Engineering Fracture Toughness model within 1.5 m from the front end of the pressure tube from 100 ppm to 110 ppm and beyond 1.5 m from the front end from 140 ppm to 200 ppm [R-16]. Various analytical and modeling works are also ongoing to validate

the key assumptions used in the fracture toughness model and to understand tube-to-tube variability. Bruce Power continues to provide semi-annual update on the burst test program and the results generated as per the established process. Bruce Power also continues to provide annual update on the investigation of the patch effect on burst test as per a separate process.

Pressure tube fracture toughness is a key input into the deterministic and probabilistic LBB evaluations and Fracture Protection (FP) evaluations and also into the probabilistic evaluation of the core for flaws. Since the validity limit of the fracture toughness model is based on hydrogen equivalent concentration, the impact of operation to 310 kEFPH on the validity of these evaluations depends on the level of hydrogen concentration predicted at 310 kEFPH for calculation of the corresponding fracture toughness values and also other input parameters in the evaluations. [$H_{]eq}$ concentrations predicted at 310 kEFPH, if found to be higher than the current validity limits for the fracture toughness model, will require CNSC approval.

2.5 PT-CT Contact

Pressure Tube to Calandria Tube (PT-CT) contact is possible when the gap between the PT and CT is reduced due to creep deformation, potential for movement of annulus spacers (garter springs), or a combination thereof. The risk of PT-CT contact is currently dispositioned using a probabilistic methodology [R-17] and maintenance (SLAR or MODAR)[2] which ensures the failure frequency remains below the acceptance criteria in CSA N285.8.

To mitigate the potential for hydride blister formation, the risk posed by PT/CT contact with the loose-fitting Zr-Nb-Cu spacers is minimized using SLAR. To mitigate the potential for hydride blister formation in channels outfitted with tight fitting annulus spacers, the risk posed by predicted PT/CT contact can be minimized via MODAR processing or delayed via selective defueling.

PT/CT contact risk to a channel can also be demonstrated to be acceptably small through channel-specific analysis based on PT/CT gap measurements of the channel, if available. The channel-specific methodology has been accepted for use in Bruce Unit 8 tight fitting spacers as well as selected channels in Unit 7 with have been equipped with tight-fitting spacers (B7M02 and B7U16) [R-18].

The current PT/CT contact disposition limits are provided in Appendix A. For Unit 7, the SLAR program is now complete. A revised Unit 7 PT/CT contact disposition after the B2771 outage inspections will be submitted to CNSC. For Unit 8, PT/CT gap campaigns are scheduled for B2681 and B2881 outages and the results of the PT/CT gap measurements obtained will be used to identify channels for the MODAR scope if required. These activities above will support the extended operation to 310 kEFPH for Units 7 and 8 for PT/CT contact.

[2] SLAR - Spacer Location And Repositioning and MODAR - Modal Detection and Repositioning

2.6 PT Flaw Assessments

Periodic inspection of PTs for flaws is a requirement of CSA N285.4. Detected flaws requiring disposition are evaluated using Clause 5 from CSA N285.8. Flaws currently dispositioned to specific operating limits will be addressed before the limiting conditions (EFPH or startup/shutdown cycles) are reached.

The fuel channel inspection scopes for the upcoming outages in Units 7 and 8 (B2771/B2681/B2881) will be established using an end of evaluation time of 310 kEFPH. During the inspection outages, any new PT flaws will be assessed, replicated (if required) and dispositioned in accordance with CSA N285.4/N285.8 to 310 kEFPH.

Since the discovery of elevated $[H]_{eq}$ observations in the outlet rolled joint regions of PT B6S13 and during the Unit 3 2021 outage (A2131) in July 2021, Bruce Power has been confirming that there are no dispositionable flaws of significance in the inlet and outlet region of interest (ROI) in pressure tubes volumetrically inspected during the Unit 7 and 8 outages (B2171, B2471, B2381). Bruce Power will continue to perform in-service PT flaw monitoring in the inlet and outlet ROIs during B2771, B2681, B2881 V&D inspections.

2.7 Spacer Nip-Up

Spacer nip-up condition is a configuration whereby PT diametral expansion forces the spacer into full circumferential contact with the calandria tube, thereby loading the calandria tube and spacer coils. The calandria tube is not designed for this type of internal loading. Spacer nip-up could therefore impair the structural integrity of the calandria tube and/or spacer.

Current analysis for the loose-fitting spacers shows full nip-up will not occur anywhere in the channel prior to 300 kEFPH.

The nip-up analysis will be updated to the new target end of assessment of 310 kEFPH. The PT diametral creep will continue to be monitored though periodic inspections, especially for TG3 Route 1 tubes.

2.8 Spacer Integrity

All the fuel channels in Bruce Units 1, 2 and 8 and a few channels in Bruce Units 5 and 7 are installed with Inconel X-750 tight-fitting spacers. The rest of the channels are installed with the Zr-Nb-Cu spacers.

For the Inconel X-750 spacers, an assessment has been performed to demonstrate that the spacer integrity is demonstrated to 285 kEFPH, using the Version 4 Engineering Spacer Model [R-19]. In addition, a sensitivity study on the effect of increasing the degradation rate by 10 times demonstrated ample margins to the acceptance criteria at the time of the Bruce Unit 8 MCR. The current plan is to remove a pressure tube with non-optimized Inconel X-750 spacers in the B2881 outage to extend the validity of the Version 4 spacer model to B8 MCR [R-20]. Bruce Power is also evaluating alternative options to further validate the predictions of the Version 4 spacer model in lieu of pressure tube removal during B2881. Should Bruce

Power choose to pursue an alternate approach this will be communicated with CNSC staff in advance.

For the Zr-Nb-Cu spacers, an assessment has been performed to demonstrate that there is no integrity concern of the Zr-Nb-Cu spacers due to its robustness [R-21]. Therefore, there is no concern on the impact of operation to 310 kEFPH on the Zr-Nb-Cu spacer integrity.

3.0 ACTIVITIES TO SUPPORT EXTENDED OPERATION TO 310 KEFPH

To support extended operation of Bruce B Units 7 and 8 to 310 kEFPH, the following activities are ongoing:

- In-service inspections (V&D) and maintenance activities will continue as indicated in the FCLCMP and established outage scope of work.
- Monitoring of the enhanced oxidation phenomena in non-TG3 and Unit 8 TG3 tubes in future V&D and HIC inspections will continue as indicated in the FCLCMP in order to continue to gain known knowledge on extent of surface condition.
- Continued monitoring of high deuterium ingress in the outlet rolled joint regions in the upcoming B2771/B2681/B2881 outages through RJ scrape sampling at various clock positions and axial positions relative to the BM.
- Continued monitoring of flaws in the inlet and outlet ROIs during B2771, B2681 and B2881 volumetric and dimensional inspections.
- Monitoring of elevated $[H]_{eq}$ concentration localized inboard of the inlet burnish mark (i.e., blip) which has been identified on removed pressure tubes. These elevated $[H]_{eq}$ concentration locations will continue to be monitored as part of future material surveillance and R&D activities.
- Revisiting the technical basis for exceeding TSSd by leveraging the R&D work recently completed through the crack initiation program on elevated $[H]_{eq}$ and recent industry efforts to extend material property validity limits.
- Re-assessment of PT fitness for-service assessments, probabilistic core assessments, fracture protection evaluations to an evaluation period of 310 kEFPH.

4.0 REFERENCES

[R-1] Letter, M. Burton to L. Sigouin, “Bruce A and B Units 3-8: Strategy to Address Pressure Tube Regions of Oxides”, June 22, 2022, BP-CORR-00531-02856.

[R-2] Letter, M. Burton to M. Hornof, “Bruce A and B: Strategy to Address Pressure Tube Regions of Oxides, Annual Update”, June 29, 2023, BP-CORR-00531-04123.

[R-3] Letter, M. Burton to A. Bulkan, “Bruce A and B: Annual Update on Strategy to Address Pressure Tube Regions of Oxides”, June 19, 2024, BP-CORR-00531-05312.

[R-4] Letter, M. Burton to A. Bulkan, “Bruce A and B: Annual Update on Strategy to Address Pressure Tube Regions of Oxides”, July 16, 2025, BP-CORR-00531-06587.

[R-5] Bruce Power Fuel Channel Life Cycle Management Plan, B-LCM-31100-00001.

[R-6] Letter, M. Burton to L. Sigouin, “Bruce A and B: Fuel Channel Periodic Inspection Program”, March 2022, BP-CORR-00531-02563.

[R-7] Letter, M. Burton to L. Sigouin, “Bruce B Unit 6 2017 Planned Scrape Reports Request for Disposition of Pressure Tube B6K10”, September 2018, NK29-CORR-00531-15315.

[R-8] Letter, L. Sigouin to M. Burton, “Bruce A and B: Request for Acceptance of the Methodology to Disposition Hydrogen Equivalent Concentration ([H]eq) Exceeding TSSd in Body of Tube Region of Pressure Tubes with a limit of 100 ppm [H]eq”, June 21, 2022, BP-CORR-00531-02948.

[R-9] Letter, M. Burton to A. Viktorov and D. Saumure, “Bruce A and B: Update to the Commission regarding Elevated Hydrogen Equivalent Concentrations – Action Item 2022-07-23135”, July 19, 2022, BP-CORR-00531-02909.

[R-10] Letter, M. Hornof to M. Burton, “Bruce A and B: CNSC Risk Assessment of Elevated Heq at the Inlet Rolled Joint Burnish Mark of Pressure Tubes – New Action Item 2022-07-26737”, December 16, 2022, BP-CORR-00531-03681.

[R-11] Letter, M. Burton to M. Hornof, “Bruce A and B: Update Regarding Elevated Hydrogen Equivalent Concentrations and Response to CNSC Risk Assessment, Action Item 2022-07-26737, Closed Action Item 2022-07-23135”, March 29, 2023, BP-CORR-00531-03855.

[R-12] Letter, M. Burton to M. Hornof, “Bruce A and B: Update Regarding Detailed Plan to Further Evaluate the Effect of Hydrogen Equivalent Concentration on Pressure Tube Fitness for Service, Action Item 2023-07-27173, September 27, 2023, BP-CORR-00531-04393.

[R-13] Letter, M. Burton to K. Lun, “Bruce A and B: Semi-Annual Update on Industry R&D Plan on Elevated Hydrogen Equivalent Concentrations, Action Items 2023-07-27173, 2022-07-26737”, March 25, 2024, BP-CORR-00531-05033.

[R-14] Letter, M. Burton to A. Bulkan, “Bruce A and B: Semi-Annual Update on Industry R&D Plan on Elevated Hydrogen Equivalent [H]eq Concentrations, Action Items 2023-07-27173 and 2022-07-26737”, September 26, 2024, BP-CORR-00531-05650.

[R-15] Letter, M. Burton to A. Bulkan, “Bruce A and B: Semi-Annual Update on Industry R&D Plan on Elevated Hydrogen [H]eq Concentrations, Action Items 2023-07-27173 and 2022-07-26737, March 20, 2025, BP-CORR-00531-06223.

[R-16] Letter, M. Burton to A. Bulkan, “Bruce A and B: Technical Basis for Increased Heq Limits for the Revision 2 Pressure Tube Toughness Model”, November 5, 2024, BP-CORR-00531-05913.

[R-17] Letter, M. Burton to K. Lafrenière, “Technical Basis for Probabilistic Assessments of Pressure Tube to Calandria Tube Contact and Blister Susceptibility”, December 19, 2014, NK21-CORR-00531-11792/NK29-CORR-00531-12181.

[R-18] Letter, M. Burton to L. Sigouin, “Technical Basis for Use of Measured Gap in Channel Specific Probabilistic Assessment of PT/CT Contact and Blister Susceptibility”, September 7, 2018, NK21-CORR-00531-14650/NK29-CORR-00531-15340.

[R-19] T. Gallacher, “Version 4 Engineering Models for Prediction of Maximum Load Carrying Capacity of Non-Optimized Inconel X-750 Spacers in CANDU Fuel Channels”, December 2023, COG-JP-4584-V106.

[R-20] Letter, M. Burton to A. Bulkan, “Fitness-for-Service Evaluation of Non-Optimized Inconel X-750 Annulus Spacers”, August 1, 2025, BP-CORR-00531-06421.

[R-21] T. Gallacher and P. Doddihal, “Assessment of Zr-Nb-Cu Spacer Integrity for Bruce A and B Units”, K-027006-RP-0002.

Table 1: Projected kEFPH for Bruce B Units 7 & 8 by MCR Outage

Bruce B Unit	Current kEFPH[3]	MCR (kEFPH)	MCR+6 months (kEFPH)
7	278.5	305.5	309.5
8	263.6	304.5	308.6

[3] Current EFPH is based on operation to June 1, 2025

APPENDIX A: FUEL CHANNEL FFS AND AGING MECHANISMS FOR BRUCE B UNITS 7 & 8

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
Pressure Tube Axial Elongation	Channel off-bearing operation	Elongation measurements, reconfiguration, channel shifting, selective defuelling	309.3 [A-1]	271.3 [A-2]	**B7:** Full core reconfiguration was completed during the Unit 7 2024 (B2471) outage. Based on the B2471 elongation data, the time to reach end-of-bearing (EOB) is 309.3 kEFPH. **B8:** Based on the B2381 elongation data, the time to reach EOB is 271.3 kEFPH. During the B2381 outage, O15 was selectively defueled due to elongation/fuelling machine (FM) clearances. Installation of positioning assembly spacer clips in eleven B2381 channels was credited to update the available bearing travel (ABT). Reconfiguration is planned in the upcoming B2681 outage will increase the EOB time to 302.2 kEFPH. Additional margin to the EOB times to 310 kEFPH could be obtained through a combination of channel shifts, selective defueling of channels with the highest elongation rates, and installation of spacer clips in some channels (to reduce the positioning assembly uncertainty) in the B2771/B2681 and B2881 outages. Additional margins may also be obtained through analytical refinements.

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
					No additional work beyond those identified in the mitigating activities is required to demonstrate extended operation to 310,000 EFPH for Units 7 and 8.
Pressure Tube Wall Thinning	Exceed design limit, nip-up, higher stress at operating pressures	Periodic dimensional inspection (WT)	375.0[A-3]	362.0 [A-3]	Periodic inspections will continue to provide confirmation that design limits will not be reached. No additional work beyond those identified in the mitigating activities is required to demonstrate extended operation to 310,000 EFPH for Units 7 and 8.
Pressure Tube Diametral Expansion	Exceed design limit, spacer nip-up, higher stress at operating pressures	Periodic dimensional inspection (ID)	327.0 [A-4]	321.0 (non-TG3) [A-4] 303.2 (TG3-RT1) [A-5]	**B7 & B8 (non-TG3):** The results from recent PT ID dimensional assessment show that, with the exception of Bruce Unit 8 TG3 Route 1 pressure tubes (B8P14, B8Q11 and B8R13), PT maximum mean ID are projected to be within the current design allowances to beyond 310 kEFPH. Periodic inspections will continue to provide confirmation that design limits will not be reached. **B8 (TG3):** Fuel channel re-registration package was submitted to TSSA to reflect the updated design PT ID limit for TG3-RT1 tubes [A-6]. Periodic inspections will continue to provide confirmation that design limits will not be reached.
Pressure Tube Sag	CT-LIN (Liquid Injection Nozzle) contact	Periodic dimensional inspections (PT sag)	362.0 [A-7]	336.0 [A-7]	**B7 & B8:** Periodic inspections will continue to provide confirmation that design limits will not be reached.

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
					No additional work beyond those identified in the mitigating activities is required to demonstrate extended operation to 310 kEFPH for Units 7 and 8.
Calandria Tube to LISS Nozzle Contact	CT-LISS contact	Periodic dimensional inspections (PT sag), CT-LISS nozzle gap measurements, detensioning of LISS nozzle	326.0 [A-8]	311.0 [A-9]	**B7:** CT-LIN measurements and detensioning maintenance was completed in the Unit 7 2021 (B2171) outage to increase the predicted contact time to 326.0 kEFPH. **B8:** CT-LIN measurements and detensioning maintenance was completed in the Unit 8 2023 (B2381) outage to increase the predicted contact time to 311.0 kEFPH. No additional work is required beyond those identified in the mitigating activities to demonstrate extended operation to 310 kEFPH for Units 7 and 8.
PT Corrosion (Enhanced Oxidation for non TG3 and TG3 PTs)	Potential to impact the accuracy of PT dimensional measurements, affect the ability to detect and characterize PT flaws and affect HIC sampling process.	Continued monitoring of enhanced oxidation phenomena in pressure tubes through V&D and HIC inspections (both non TG3 and TG3 PTs)	N/A	N/A	**B7 & B8 (non TG3 tubes):** In Unit 7, there has been an increased change in OEO observations between the 2021 (B2171) and 2024 (B2471) V&D inspections for some repeat channels. In Unit 8, apart from the IRJEO observed in TG3 pressure tubes, the non TG3 pressure tubes generally have similar oxidation behaviour as the other Bruce B Units. **B8 (TG3 tubes):** Channels inspected during B2081 and B2381 showed advanced stages of OEO and IRJEO for some TG3 (RT-1).

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
					Monitoring of the enhanced oxidation phenomena in non TG3 and TG3 tubes in future V&D and HIC inspections will continue into B2771/B2681/B2881 outages. No additional work is required beyond those identified in the mitigating activities and activities established in the strategy framework to address PT oxides in order to demonstrate extended operation to 310 kEFPH for Units 7 and 8.
PT Flaws	When a detected flaw indication in a PT does not satisfy Clause 12 of CSA N285.4, an evaluation is required to demonstrate fitness-for-service as per the evaluation procedures specified in CSA N285.8.	Volumetric inspection and replication	300.0 (*309.0*) [A-10][A-11]	276.2 [A-12][A-13]	**B7:** All PT flaws detected in the 2024 Unit 7 outage (B2471) inspection and all previous inspections have been dispositioned to at least 309 kEFPH, with no restriction on the number of allowable heatup/cooldown cycles. In order to align with Bruce Power's PROL, a disposition was requested to 300 kEFPH. **B8:** All PT flaws detected in the 2023 Unit 8 outage (B2381) inspection and all previous inspections have been dispositioned to 276.2 kEFPH, with no restriction on the number of allowable heatup/cooldown cycles. An end of evaluation period of 310 kEFPH will be used to establish the fuel channel inspection scopes for the upcoming outages in Units 7 and 8 (B2771/B2681/B2881). During the inspection outages, any new PT flaws will be assessed, replicated (if required) and dispositioned in

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
					accordance to CSA N285.4/N285.8 to 310 kEFPH. No additional work beyond those identified in the mitigating activities is required to demonstrate extended operation to 310 kEFPH for Units 7 and 8.
Spacer Nip-Up	Non-design configuration that could impair the structural integrity of the calandria tube and/or spacer.	Spacer surveillance examinations	300.0[A-14]	300.0[A-14]	**B7:** The nip-up assessment in [A-14] to predict whether 360° nip-up could occur assumed an end of life of 300 kEFPH. An update to this assessment using PT deformation predictions extended to 310 kEFPH will be performed. Given the margins that exist in the nip-up assessment, this is not expected to challenge B7 where significant margin was predicted to exist at 300 kEFPH. **B8:** The margins to 360° nip-up are even larger (due to smaller TFAS coil diameters), except for TG3 RT1 PTs where margin is minimal for the outlet spacers (the most limiting of all channels / spacers for B7/B8). Additional refinements (including the use of the latest gauging data and PT/CT gap measurements) will be performed to confirm that 360° nip-up is not a concern to 310,000 EFPH.

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
					No additional work beyond those identified above is required to demonstrate extended operation to 310,000 EFPH for Units 7 and 8.
Spacer Integrity	Reduced mechanical strength	Spacer surveillance examinations, irradiated test program (for Inconel X-750)	*Spacer Load Carrying Capacity* 285.0 [A-15] for Inconel X-750 spacers >300.0, for Zr-Nb-Cu spacers [A-16]	285.0 [A-15] for Inconel X-750 spacers	**B7:** It is expected that there would be no issues demonstrating the spacer integrity of Zr-Nb-Cu spacers to 310 kEFPH, due to the large margins (greater than ~9 times) on the required load carrying capacity and no evidence of ongoing degradation. **B8:** In [A-15], the current predictions of non-optimized spacer load carry capacity based on Version 4 support operation to 285.0 kEFPH (~ 125 displacements per atoms (dpa)). Bruce Power is also evaluating alternative options to further validate the predictions of the Version 4 spacer model which include pressure tube removal during B2881 outage. Should Bruce Power choose to pursue an alternate approach, this will be communicated with CNSC staff in advance.
Pressure Tube to Calandria Tube Contact	Hydride blisters, DHC initiation and PT rupture	PT/CT gap measurements, spacer confirmation, SLAR/MODAR (if required)	300.0 (*320.5*) [A-17][A-18]	297.4 [A-19][A-20]	**B7:** PT/CT contact disposition is based on contact and not blister susceptibility. In order to align with Bruce Power's PROL, a disposition was requested to 300 kEFPH. The Unit 7 SLAR program is now complete. A revised Unit 7 PT/CT contact disposition after B2771 outage inspections will be submitted to CNSC.

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
					B8: The current B8 PT/CT contact disposition incorporated the updated inputs based on B2381 outage inspection and maintenance results. PT/CT gap campaigns are scheduled for B2681 and B2881 outages and the results will be used to identify channels for MODAR scope if required. A revised Unit 8 PT/CT contact disposition after each outage (B2681 and B2881) will be submitted to CNSC. No additional work beyond the activities in the mitigating activities is required to demonstrate extended operation to 310,000 EFPH for Units 7 and 8 for PT/CT contact.
Deuterium Ingress (BOT and RJ)	Hydride blister, DHC initiation, DHC growth, crack coalescence and PT rupture.	HIC scrape sampling, material surveillance	N/A	N/A	**BOT:** Large circumferential variation has been observed in the BOT in Unit 7 2024 outage (B2471) and the Unit 5 2025 outage (B2551). Work is currently ongoing with the industry to develop a methodology to implement the circumferential redistribution at the top of the PTs to enhance the predictive BOT models for Units 7 and 8. **RJ:** Elevated $[H]_{eq}$ observations in the inlet/outlet RJs from B6S13 and A2131 scrapes has resulted in an expansion of the scrape scope to obtain measurements at specific rotary and axial locations in subsequent scrape campaigns and will continue for B2771/B2681/B2881 outages.

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
					These high $[H]_{eq}$ concentrations will continue to be monitored as part of future material surveillance. Support for extended operation to 310 kEFPH for Units 7 and 8 will be contingent on closure of the remaining CNSC Action Items on elevated $[H]_{eq}$ by end of 2025 as planned in order to move from Licence Condition 6.2 back to 6.1. No additional effort would be required to support operation to 310 kEFPH beyond the mitigating activities discussed above.
Exceeding Terminal Solid Solubility for Dissolution in BOT	Hydride blister, DHC initiation, DHC growth, crack coalescence and PT rupture.	HIC BOT scrape sampling	*PT H_{eq} Exceeding TSSD in BOT and above 100 ppm $[H]_{eq}$*		**B7 & B8:** There are no pressure tubes in Bruce Units 7 and 8 predicted to have pressure tubes exceed TSSd in the BOT and above 100 ppm at the time of their MCR outages. For extended operation to 310 kEFPH, an update to the technical basis for exceeding TSSd will be pursued by leveraging the R&D work recently completed through the crack initiation program on elevated $[H]_{eq}$ and recent industry efforts to extend material property validity limits. No additional effort would be required to support operation to 310 kEFPH beyond the activities discussed above.
			No at B7 MCR outage [A-21]	No at B8 MCR outage [A-22]	
Fracture Toughness	DHC initiation and Leak Before Break	Burst test program	*Leak-Before-Break*		**B7 & B8:** Probabilistic core assessments of crack initiation due to flaws have been completed for Bruce Units 7 and 8 [A-23][A-24]. Leak-before-break has been assessed probabilistically to 306.6 kEFPH. Assessment of Units 7 and 8 will
			306.6 [A-23]	306.6 [A-24]	

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
					be revised to support extended operation to 310 kEFPH. No additional effort would be required to support operation to 310 kEFPH beyond the activities discussed above.
			Fracture Protection		**B7**: The current Unit 7 deterministic fracture protection evaluation using the limited cold overpressure transient (COPT) design pressure, was assessed to 301.3 kEFPH which corresponded to the time of the B2771 outage including margin. The fracture protection evaluation will need to be updated and extended to 310 kEFPH. A probabilistic fracture protection may also be performed. **B8:** The current Unit 8 deterministic fracture protection evaluation limit of 290 kEFPH can be improved by using the limited COPT design pressure. However, a probabilistic fracture protection may also be performed to extend the operating limit for fracture protection out to 310 kEFPH. It should be noted that this is dependent on the use of the Revision 2 FT model and $[H]_{eq}$ validity limits as discussed on fracture toughness as well as the acceptability of other input parameters in order to operate beyond 300 kEFPH. $[H]_{eq}$ concentrations predicted at 310 kEFPH if found to be higher than the current validity limits for the
			301.3 [A-25]	290.0 [A-26][A-27]	

Aging Mechanism	Consequence	Mitigating Activities	Current Evaluation Limit (kEFPH)		Evaluation of Extended Operation to 310 kEFPH
			B7	B8	
					fracture toughness model, will require CNSC approval.
Material Property Validity Limits	Onset of DHC from a crack	Material surveillance	N/A	N/A	The crack initiation tests under the Elevated $[H]_{eq}$ roadmap to evaluate the impact of $[H]_{eq}$ up to 220 ppm on crack initiation models due to DHC, hydrided region overload and fatigue have been completed. Crack initiation properties such as K_{TH}, p_c, and DHC_R are under evaluation. The industry is developing position papers on the effect of high $[H]_{eq}$ on crack initiation properties. CSA is working on updating Table D-1 of CSA N285.8 to include the validity limits of Heq for each material property.

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