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Written submission from Ontario Power Generation

Mémoire d' Ontario Power Generation

In the Matter of the

À l'égard de la

Opportunity to be heard on the orders issued by a Designated Officer to Bruce Power and Ontario Power Generation

Possibilité d'être entendu au sujet des ordres délivrés par un fonctionnaire désigné à Bruce Power et Ontario Power Generation

Commission Public Hearing

Audience publique de la Commission

September 10, 2021

10 septembre 2021

Canada

OPG Proprietary
(with Confidential Enclosures)

August 06, 2021

CD# N-CORR-00531-22817

MR. M. LEBLANC
Commission Secretary

Canadian Nuclear Safety Commission
280 Slater Street
Ottawa, Ontario
K1P 5S9

Dear Mr. Leblanc:

Pickering and Darlington: OPG Response to Designated Officer Orders and Opportunity to be Heard on Designated Officer Orders

The purpose of this letter is to provide OPG's response to:

- The Designated Officer Orders issued to Ontario Power Generation (References 1 and 2)
- The Opportunity to be Heard on the Designated Officer Orders (References 3 and 4)

OPG confirms its intention to take advantage of the opportunity to be heard regarding both Orders simultaneously (References 3 and 4), via oral representations before the Commission. OPG requests that the opportunity to be heard take place as expeditiously as possible and prior to the separate Commission meeting scheduled for September 3, 2021. In support of the opportunity to be heard, OPG is hereby filing a written submission, as Enclosures 1-3 to this letter. Per the Orders, we understand that, prior to the restart of Darlington Units 1 or 4, and Pickering Units 1,4, or 5-8, following any outage that results in the cooldown of the heat transport system (HTS), OPG shall obtain authorization from the Commission to restart. The requirements to be met prior to seeking such authorization are as stipulated in References 1 and 2. Specifically, OPG shall either:

a. carry out inspection and maintenance activities that demonstrate with a high degree of confidence that pressure tube [Heq] is within OPG'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.

As detailed in Enclosures 1-3 and Reference 5, OPG has a robust scrape sampling and material surveillance program. For years, Rolled Joint (RJ) scrape sampling, as well as additional RJ punch sampling (which are both beyond CSA N285.4 requirements) have been performed to enhance understanding of RJ deuterium ingress. A review of existing OPG data has been performed and compared with the recent Bruce Power B3 and B6S13 results, which indicates that such high levels of [Heq] have not been observed in any OPG units. Based on a review of all past measured [Heq] data, [Heq] values for all OPG units are confirmed to be within the licensing basis, including samples taken from ex-service material in the area of interest from the Bruce Power OPEX.

Therefore, OPG has a high degree of confidence that pressure tube [Heq] values for all OPG units are within the licensing basis, and that the Heq predictive modelling is adequate to support Fitness for Service assessments. Furthermore, our population of flaws in the area of observed high [Heq] from the Bruce Power OPEX is very limited and does not represent a fitness for service concern. This is based on completion of extensive inspections in the region of interest. Thus, continued safe operation of all OPG units is assured, and supported by OPG's robust fitness for service (FFS) program and extensive defence-in-depth measures that are in place. The [Heq] models utilized in FFS assessments, provide conservative upper bound predictions of [Heq] measured via both scrape and ex-service punch sampling.

Per the Fuel Channels Life Cycle Management Plan, Pickering Units 1, 4 and 5-8, and Darlington Unit 4 all plan to perform flaw inspection and scrape sampling in the next respective outage campaigns for continued demonstration of FFS. Additionally, extensive [Heq] testing on material surveillance tubes (P8P10 from P2181, planned SFCR in P2251, D3 inlet RJs) is planned to confirm that [Heq] measurements remain within model bounds.

As enhancements to OPG's FFS program, OPG will endeavour to acquire RJ [Heq] scrape sampling at top dead center (TDC) locations in the P2171, and D2141 outages (see Attached Summary Table). OPG will work with industry partners on any further developments related to the B3 or B6S13 OPEX and will continue to support the industry on future [Heq] modeling developments.

Additionally, as per Enclosures 1-3, OPG has performed a station by station analysis of Darlington Units 1 and 4 and Pickering Units 1,4 and 5-8, documenting the rationale for each unit restart following a unit outage resulting in a cooldown of the heat transport system (HTS). OPG is confident that these Enclosures satisfy the requirement of References 1 and 2, and therefore is requesting both a blanket pre-authorization for

restart of the aforementioned units should they enter an outage with HTS cooldown, and closure of the Designated Officer Orders.

In the meantime, OPG is committed to continue to provide CNSC staff with the following information (and will do so for the D2141 and P2171 outages), per normal practice and consistent with the licensing basis (see Attached Summary Table):

Forced Outages

As per normal practice, OPG continues to evaluate the impact of a forced outage on the existing accepted Fuel Channel FFS dispositions. If the forced outage invalidates any aspect of the component disposition, OPG will take corrective inspection, maintenance, and analysis measures to ensure that the FFS aspects are addressed and accepted by the CNSC before Unit return to service.

Planned Inspection Outages

To further enhance our normal practice, and in addition to the requirements outlined in the specific Station's LCH and CSA N285.4, OPG will provide either:

1. An updated component disposition showing the locations of dispositionable flaws detected during the volumetric and dimensional inspection campaigns, maintaining a high degree of confidence that the flaw population density in the area of observed high [Heq] from the recent Bruce Power B3 and B6 OPEX remains unaffected,

   or

2. As soon as practicable and for information purposes, a summary report highlighting the [Heq] concentration from the outage scrape program showing that the measured [Heq] is within the Units' appropriate licensing basis. A comprehensive report satisfying CSA N285.4 Clause 12.3.6.2 will continue to be submitted to the CNSC 120 days after unit restart.

Thus, in advance of any outage with HTS cooldown and per the requirements of the Orders, OPG requests Commission authorization to restart Darlington Units 1 and 4 and Pickering Units 1,4 and 5-8, based on the supporting technical justification provided in Enclosures 1-3. OPG considers that the enclosures fulfill the requirements of the Orders and requests that the Orders be closed.

If you have any questions or require any clarification regarding this submission, please contact Dr. Jack Vecchiarelli, Vice President, Nuclear Regulatory Affairs at (905) 706-4121 or by email at jack.vecchiarelli@opg.com.

Sincerely,

Steve Gregoris
Senior Vice President
Darlington Nuclear
Ontario Power Generation Inc.

Jon Franke
Senior Vice President
Pickering Nuclear
Ontario Power Generation Inc.

cc:
R. Jammal	-CNSC (Ottawa)
A. Viktorov	-CNSC (Ottawa)
K. Campbell	-CNSC (Ottawa)
J. Burta	-CNSC (Ottawa)
C. Chan	- CNSC Site Office (Pickering)
E. Leader	- CNSC Site Office (Pickering)

References:

1. CNSC Letter, R. Jammal to J. Franke, “Designated Officer Order issued to Ontario Power Generation”, July 26, 2021, e-Doc 6612802, CD# P-CORR-00531-22706.

2. CNSC Letter, R. Jammal to S. Gregoris, “Designated Officer Order issued to Ontario Power Generation”, July 26, 2021, e-Doc 6612869, CD# NK38-CORR-00531-22721

3. CNSC Letter, M. Leblanc to J. Franke, “Opportunity to be Heard on Designated Officer Order (Pickering)”, July 28, 2021, e-Doc 6614749, CD# P-CORR-00531-22707.

4. CNSC Letter, M. Leblanc to S. Gregoris, “Opportunity to be Heard on Designated Officer Order (Darlington)”, July 28, 2021, e-Doc 6614742, CD# NK38-CORR-00531-22723.

5. 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 Item 1-4 Related to Measurement of Hydrogen Concentration in Pressure Tubes”, July 30, 2021, CD# N-CORR-00531-22801.

TABLE 1

Summary of Regulatory Actions Undertaken in this Submission

Submission Title: "Pickering and Darlington: OPG Response to Designated Officer Orders and Opportunity to be Heard on Designated Officer Orders"

Regulatory Management Action (REGC):

No.	Commitment Description	Target Completion Date
1.	OPG will endeavour to acquire RJ [Heq] scrape sampling at top dead center (TDC) locations in the P2171, and D2141 outages.	P2171 and D2141 outages
2.	OPG is committed to continue to provide CNSC staff with the following information (and will do so for the D2141 and P2171 outages), per normal practice and consistent with the licensing basis: **Forced Outages** As per normal practice, OPG continues to evaluate the impact of a forced outage on the existing accepted Fuel Channel FFS dispositions. If the forced outage invalidates any aspect of the component disposition, OPG will take corrective inspection, maintenance, and analysis measures to ensure that the FFS aspects are addressed and accepted by the CNSC before Unit return to service. **Planned Inspection Outages** OPG will provide either: 1. An updated component disposition showing the locations of dispositionable flaws detected during the volumetric and dimensional inspection campaigns, maintaining a high degree of confidence that the flaw population density in the area	Effective immediately

No.	Commitment Description	Target Completion Date
	of observed high [Heq] from the recent Bruce Power B3 and B6 OPEX remains unaffected, or 2. As soon as practicable and for information purposes, a summary report highlighting the [Heq] concentration from the outage scrape program showing that the measured [Heq] is within the Units' appropriate licensing basis. A comprehensive report satisfying CSA N285.4 Clause 12.3.6.2 will continue to be submitted to the CNSC 120 days after unit restart.	

ONTARIO POWER GENERATION

MEMORANDUM

OPG Confidential

August 7, 2021

File No.: NA44-CORR-31100-0940802

Fitness-for-Service Justification to Support Pickering Unit 1&4 Restart

1.0 INTRODUCTION

On July 26, 2021, CNSC provided an order by a designated officer under paragraph 37(2)(f) and Subsection 35(1) of the *Nuclear Safety and Control A*ct for all Pickering Units [1]. The CNSC order is as follows:

Prior to the restart of any of Units 1, 4, 5, 6, 7 or 8, following any outage that results in the cooldown of the heat transport system, OPG shall obtain authorization from the CNSC to restart.

Prior to seeking such authorization, OPG shall either:

a) Carry out inspection and maintenance activities that demonstrate with high degree of confidence that pressure tube [Heq] is within OPG'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 model failed to conservatively predict the elevated [Heq], and submit results of such activities to CNSC staff

The purpose of this memorandum is to document the fitness-for-service (FFS) justification, demonstrating the basis for confidence in pressure tube (PT) hydrogen equivalent concentrations ([Heq]) and very low population of flaws in the high [Heq] area of interest based on Bruce Power OPEX at Pickering Units 1 and 4. Based on this information, this memorandum supports Pickering Units 1 or 4 restart should the Units be required to cooldown as part of a planned maintenance outage or an unplanned forced outage without the need to increase the inspection scope beyond the LCMP requirements [6]. The information

provided herein supplements justifications of FFS previously submitted to the CNSC in [5].

2.0 LICENSING

Based on the review of Bruce Power's B3 and B6S13 relevant data, Pickering 1&4 measurements collected to date, and the assessment and engineering evaluation provided in [5], OPG's existing FFS assessment remain valid. PT [Heq] values for all OPG Units are confirmed to be within CSA requirements and the licensing basis.

The approach to restart from an unplanned outage is consistent with the Licensing Basis and specifically the requirements of License Condition Handbook Sections 6.1 and 15.3.

3.0 BACKGROUND

In July 2021, Bruce Power reported two events related to [Heq] measured in Bruce Units 3 (B3) and 6 (B6):

1) Measurements obtained from the A2131 outage scrape campaign showed elevated [Heq] values were greater than expected which potentially exceeded parameters of the fracture toughness model in CSA N285.8-15 Update 1, Clause D.13.2.3.1.2 (a), hence, potentially not meeting Clause 4.5.1.3 [2].

2) Following the removal of pressure tube S13 in Bruce Power Unit 6, higher than expected [Heq] values were found in the pressure tube which potentially exceeded the parameters of the fracture toughness model in CSA N285.8-15 Update 1, Clause D.13.2.3.1.2 (a), hence, potentially not meeting Clause 4.5.1.3 [3].

CNSC subsequently provided a letter to OPG [4] which was made pursuant to subsection 12(2) of the General Nuclear Safety and Control Regulations. OPG was requested to review the impact of the Bruce Power [Heq] PT sampling result, as it relates to OPG PT FFS. OPG submitted a response to CNSC which included an Engineering Evaluation along with a FFS impact memo which provided evidence that there is no impact on Pickering FFS [5].

4.0 PICKERING UNIT 1&4 FITNESS-FOR-SERVICE JUSTIFICATION

4.1 Pickering Unit 1&4 Manufacturing and Operation

Pickering Unit 1 (P1) and Unit 4 (P4) have the youngest operating pressure tubes at Pickering station. P1&4 PTs were replaced in September 1987 and March 1993 [6], respectively. As part of the PT manufacturing, an improved material specification compared to the first generation of PTs was implemented. Table 1 provides the initial hydrogen concentration ([Hinitial]) information for P1&4 [7], [8].

Table 1: Pickering Units 1 and 4 [Hinitial] values

Unit	Average PT Hinitial (ppm)	Maximum PT Hinitial (ppm)
P1	7	15
P4	3.9	7.1

As a result of P1&4 PT replacements, the predicted hot hours (HH) at end of life are significantly less than that of B3 and B6. The conservatively calculated HH for P1&4 at the end of target operating life (assuming 100% full power operation) will be less than either B3 or B6 current HH values by ~72,000 and ~100,000 HH, respectively, as shown in Table 2, Table 3, and Table 4.

Table 2: Bruce Power Units 3 and 6 Hot Hours

Unit	Hot Hours	Notes
B3	271,330	As of A2131
B6	271,729	As of MCR

Table 3: Pickering Unit 1 Hot Hours

	Approximate Hot Hours	Approximate Date
P1 Currently	172,600	Jul 2021
Next Planned P1 Outage (P2211)	182,150	Aug 2022
P1 End of Life	199,900	Dec 2024

Table 4: Pickering Unit 4 Hot Hours

	Approximate Hot Hours	Approximate Date
P4 Currently	141,500	Jul 2021
Next Planned P4 Outage (P2341)	156,000	Mar 2023
P4 End of Life	169,700	Dec 2024

With greater than 70,000 HH difference at end of life, along with different operating parameters (e.g. lower flux and lower operating pressures), elevated outlet rolled joint (RJ) [Heq] measured late in the life of B3 and B6 PTs is not applicable to P1&4 PTs.

4.2 Scrape

Pickering Units 1&4 have been performing scrapes in both the inlet and outlet RJs and the body-of-tube (BOT) which exceeds CSA N285.4-05 requirements. Table 5 provides past performed and future to be performed scrapes in the upcoming outages. Scrape will continue to be scoped into the upcoming outages, as indicated in Table 6 and as per the Fuel Channel Life Cycle Management Plan [6].

Table 5: Pickering Unit 1 and 4 Scrapes

Unit	Number of BOT Scrapes	Number of RJ scrapes	Number of future BOT Scrapes	Number of future RJ Scrapes
P1&4	70	9	20	4

Table 6: Pickering Units 1 and 4 History, Most Recent, and Next Planned Scrape Campaigns

Unit	First Scrape BOT	Most Recent Scrape BOT	Upcoming Planned Scrape BOT	First Scrape RJ	Most Recent Scrape RJ	Upcoming Planned Scrape RJ
P1	2004	2020	2022	2017	2020	2022
P4	2014	2018	2023	2016	2020	N/A

As an enhancement to incorporate the B3 and B6 OPEX, OPG will endeavor for future scrapes at P1&4 to be performed at PT Top Dead Center (TDC, 12 o'clock orientation), where scrape overlap would not exist. This measure will ensure condition monitoring is as conservative as possible, despite no evidence of observations similar to those seen in B3 and B6 late life PTs.

4.3 [Heq] Predictions

As part of the scrape program in Pickering Units 1 and 4, following scrape execution, the scrape samples are analyzed to determine the [Heq] values and to ensure the models in place are still supported for FFS evaluations.

Figure 1 and Figure 2 [9] below provide the outlet and inlet, respectively, for the past outages scrape data versus the current model predictions. There remains significant margin between scrape samples [Heq] values and the model predictions for both the inlet and outlet rolled joints for Pickering Units 1 and 4.

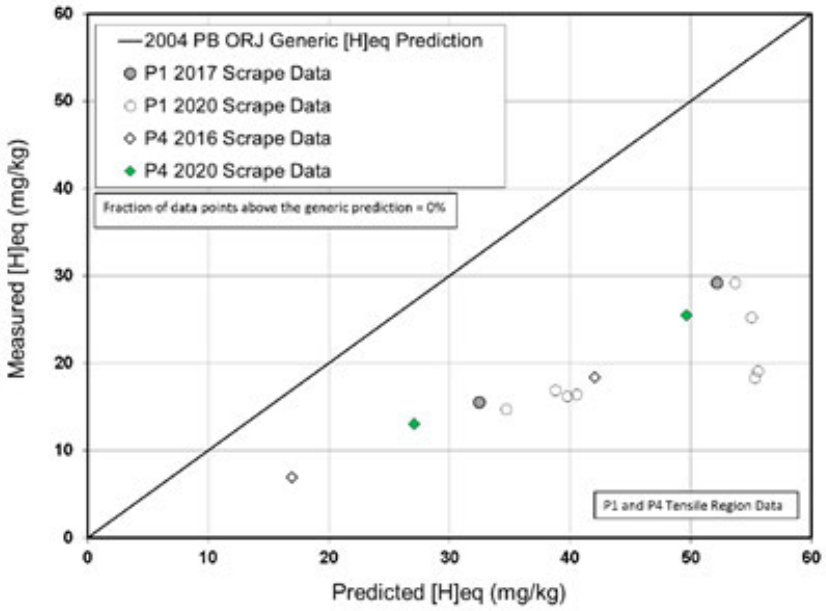

Figure 1 - Comparison of Measured [Heq] and the 2004 Generic Deterministic ORJ [Heq] Predictions for Tensile Region Locations of the P1&4 ORJs

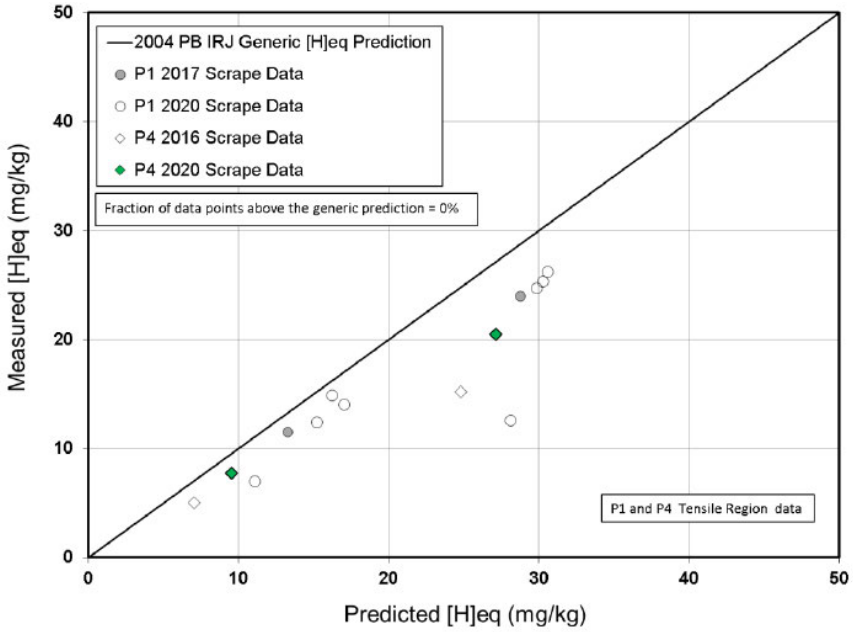

Figure 2 - Comparison of Measured [Heq] and the 2004 Generic Deterministic IRJ [Heq] Predictions for Tensile Region Locations of the P1&4 IRJs

Figure 3, Figure 4, Figure 5 and Figure 6 below provide the 1.5m, 4m, 5m and 5.6m [Heq] measurements, respectively, for the past outages scrape data versus the model predictions [10]. The scrape data obtained from past outages largely remains near the mean or lower bound of the model at each axial location.

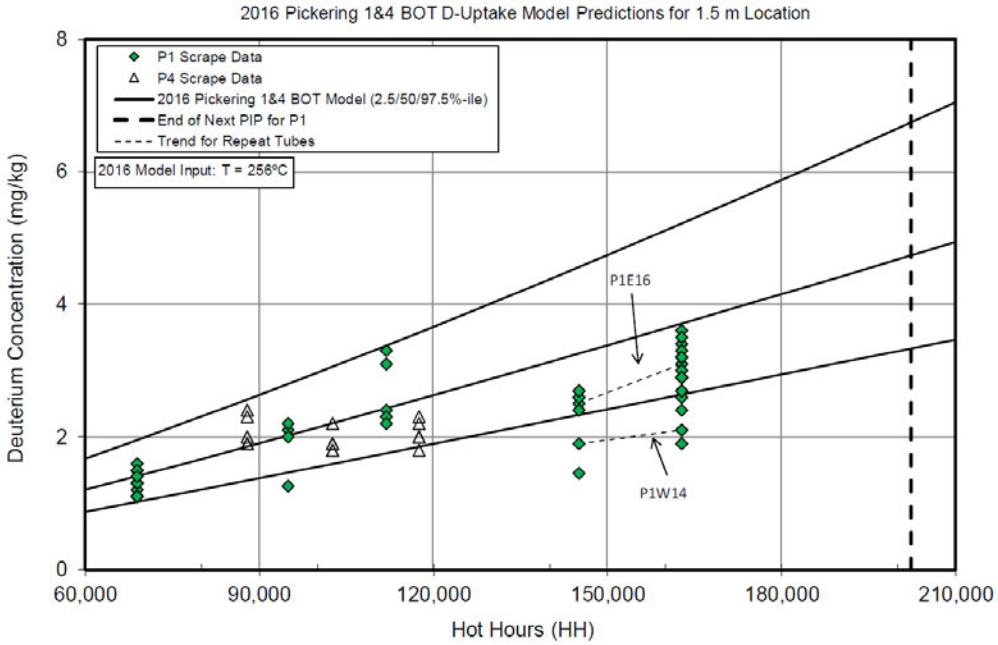

Figure 3 - Measured BOT Deuterium Ingress Comparison with the Maximum Allowable [Heq] Limit and the 2016 P1&4 BOT D-Uptake Model Predictions at the 1.5m Location

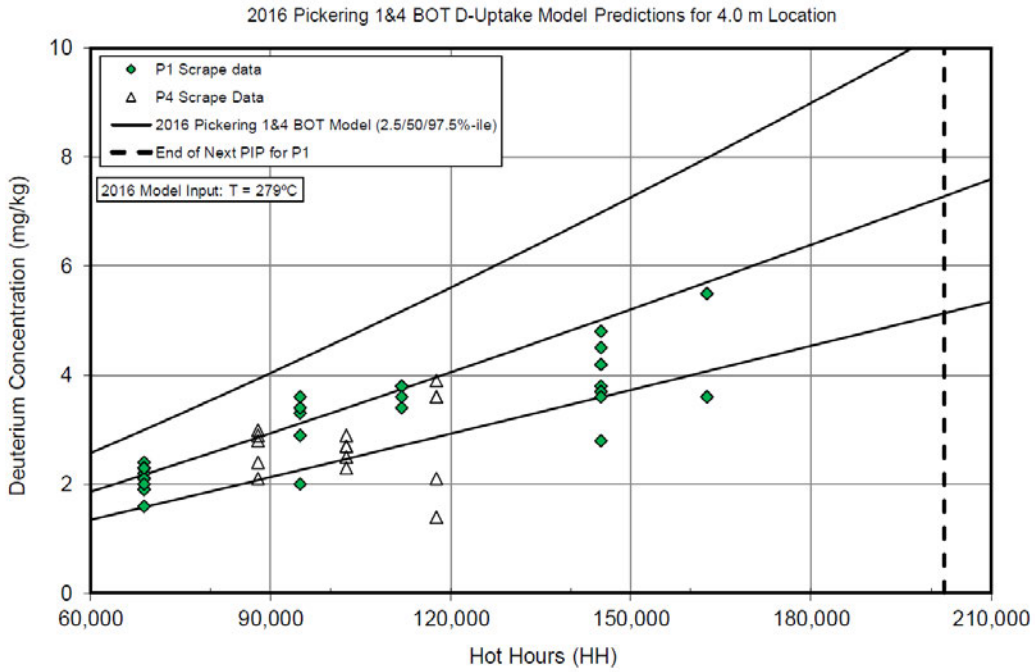

Figure 4 - Measured BOT Deuterium Ingress Comparison with the Maximum Allowable [Heq] Limit and the 2016 P1&4 BOT D-Uptake Model Predictions at the 4.0m Location

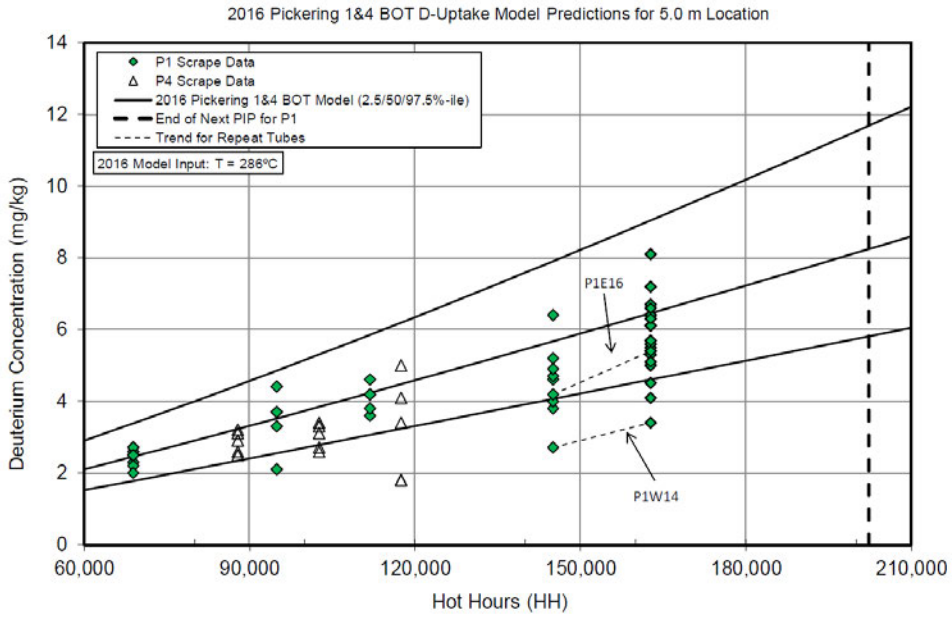

Figure 5 - Measured BOT Deuterium Ingress Comparison with the Maximum Allowable [Heq] Limit and the 2016 P1&4 BOT D-Uptake Model Predictions at the 5.0m Location

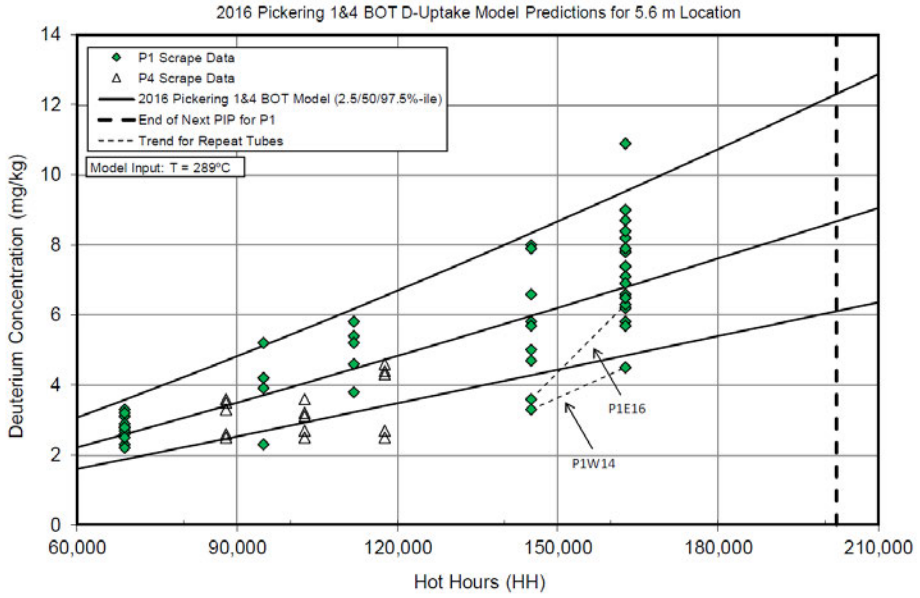

Figure 6 - Measured BOT Deuterium Ingress Comparison with the Maximum Allowable [Heq] Limit and the 2016 P1&4 BOT D-Uptake Model Predictions at the 5.6m Location

Based on the inspection and maintenance scrape activities performed to date, Pickering Units 1 and 4 [Heq] models provide conservative upper bound predictions of [H]eq measured via scrape. These results establish a high degree of confidence that pressure tube [Heq] is within OPG's licensing basis, per licence condition G.1. Proactively, [Heq] modelling enhancements are being pursued as discussed in Section 5.2.

4.4 Flaw Population near the Outlet Burnish Mark

A review of the inspected channels was performed to determine the number of dispositionable flaws 100mm inboard of the outlet burnish mark. Table 7 provides the information for the flaws found within the region of interest (upper half of the pressure tube). Figure 7 provides the facemap of the inspected channels (highlighted in green) for Pickering Units 1 and 4.

Table 7 - Pickering Unit 1 and 4 Top of PT Flaws within 100mm of the Outlet Burnish Mark

Pressure Tube	Outlet BM to Flaw Start (mm)	Outlet BM to Flaw End (mm)	Flaw Depth (mm)	Rotary Start (deg, 0/360 is TDC)	Width (deg)
P1N13	40.6	51	0.2	335.3	5
P1N13	-13.3	16.9	0.55	333.2	6.6
P4S15	-4.3	46.9	0.2	358.3	6.0

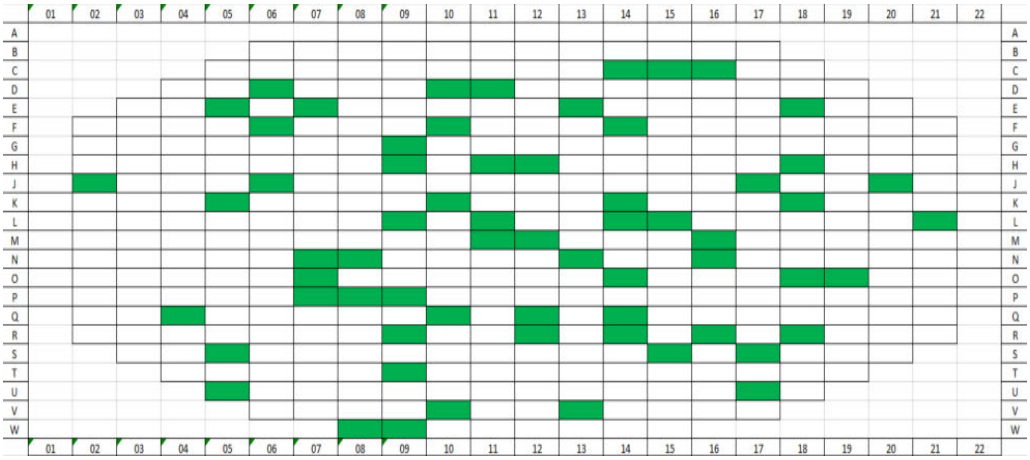

Figure 7 - Inspected Channels at Pickering 1&4[1]

Out of 73 inspected channels [11], there have only been 2 channels with dispositionable flaws located within 100mm of the outlet RJ in the high [Heq] area of interest based on Bruce Power OPEX. The remaining 71 channels did not have any indications in the area of interest at the time of the inspection, and therefore the large majority of channels remain free of flaws in the high [Heq] area of interest. This confirms that the prevalence of outlet RJ top of tube flaws is very low in Pickering 1&4 units. This also highlights the conservatism built into the fracture protection assessments discussed in Section 4.6.2, where undetected through-wall flaws are postulated to exist for the purpose of

[1] Some channels identifications numbers may have been inspected in both Pickering Unit 1 and Unit 4

assessment, despite OPG never having observed a through-wall flaw in any OPG reactor with current generation PTs installed.

4.5 Operating Envelope

The Pickering Units 1 and 4 operating envelope for the heatup/cooldown of the Units were modified in 2014 to account for changing fracture toughness properties due to increased bulk [Heq] levels. Station operating envelopes are re-validated when input models/parameters are updated to ensure the risk of PT rupture or initiation of delayed hydride cracking (DHC) is minimized

Following any type of cooldown transient or forced outage, OPG proactively reviews the actual pressure and temperature conditions during the cooldown in order to determine the impact on FFS and to ensure fracture toughness limits have not been exceeded and flaws remain acceptable per the CSA standard requirements. When a cooldown occurs, flaw acceptability is confirmed for all affected PT flaws prior to restart of the unit.

4.6 Core Assessment

4.6.1 PT-CT contact

Due to the low levels of [Heq] at Pickering Units 1 and 4, PT-CT contact is dispositioned through a demonstration that the predicted [Heq] remains below the blister formation threshold (BFT) and/or adequate PT-CT gap remains available.

The axial region of interest from the B3 and B6S13 OPEX is immediately inboard of the ORJ BM. The circumferential region of interest from the B3 and B6S13 OPEX is at the top of the PT (nominally the 12 o'clock orientation). Since PT-CT contact occurs at the bottom of the PT (nominally the 6 o'clock orientation) and contact is geometrically precluded so close to the ORJ BM in the axial direction, existing PT-CT contact dispositions [12] for Pickering Units 1 and 4 remain valid (i.e., there is no FFS impact of the B3 and B6S13 OPEX as it relates to PT-CT contact).

4.6.2 DFP (Deterministic Fracture Protection)

As part of the Bruce Power findings [2] [3], OPG submitted an Engineering Evaluation which performed a deterministic fracture protection evaluation for Pickering Unit 1 (bounding Unit for the station) [5]. Although the maximum projected Outlet RJ [Heq] at end of life based on measured values was projected to be 45 ppm, a sensitivity case with 100ppm was assessed. These values were bounding of the D1U09 [Heq] axially-shifted profiles performed in [13]. All Pickering Unit 1 transients remained acceptable per CSA N285.8 requirements using the Revision 1 and Revision 2 fracture toughness models.

4.6.3 PCA (Probabilistic Core Assessment)

As a result of the D1U09 inlet rolled joint high localized [Heq] region, a sensitivity assessment was performed for Pickering Unit 1 (bounding Unit for Pickering 1&4) where axial-shifted [Heq] profiles were used to bound D1U09 [Heq]

measurements. Based on the sensitivity assessment results of 1.11e-3 failures per calendar-year [13], the PCA remains below the CSA N285.8-15 Table C.1 acceptance criteria [14] of 1.0e-2 failures per calendar-year to 175,200 EFPH.

4.6.4 PLBB (Probabilistic Leak-Before-Break)

As was similarly performed for the PCA, sensitivity assessment was performed for Pickering Unit 1 (bounding Unit for P1&4) where axial-shifted [Heq] profiles were used to bound D1U09 [Heq] measurements. The conditional probabilities of break-before-leak of 0.0362 [13], obtained from the impact evaluation with P1 evaluated to 180,000 EFPH, were below the CSA N285.8-15 Clause 7.4.3.2 [14] acceptance criteria of 0.1.

5.0 ENHACEMENTS

5.1 Inspection Enhancements

As part of incorporating the B3 and B6S13 OPEX, OPG will endeavour for future scrapes at Pickering Units 1&4 to be performed at PT Top Dead Center (TDC, 12 o'clock orientation) where scrape overlap can be avoided. With consideration given to the limitations imposed by previous circumferentially offset scrapes, this measure will ensure condition monitoring is as conservative as possible (per the BP OPEX). This measure is being pursued despite elevated [H]eq similar to that seen in B3 and B6S13 PTs never having been observed in Pickering Units 1&4.

5.2 [Heq] Modelling Enhancements

[Heq] modelling enhancements including use of 3D Finite Element Analysis considering fuel channel geometries, local temperatures, location-specific [Heq], and material stress states are being pursued. Note that these proactive enhancements were already in progress prior to the B3 and B6S13 findings. OPG, with industry alignment, intends to submit modelling enhancements for CNSC acceptance once fully validated.

6.0 CONCLUSION

Pickering Units 1 and 4 are currently the youngest operating Units (other than Darlington Unit 2) and have shown low [Heq] over the life of the reactors. [Heq] models continue to remain conservative for use in FFS assessments. High [Heq] values inboard of the ORJ BM as reported via the B3 and B6S13 OPEX have not been observed in Pickering Units. OPG has, and will continue to, perform in-service scrape and ex-service material surveillance in excess of CSA N285.4-05 requirements to monitor PT FFS and [H]eq predictive model validity.

Based on the inspected PTs, there remains a very low probability of flaws existing in the ORJ top of PT region of interest. Conservative sensitivity assessments have been performed for Pickering Units 1&4 and demonstrate that the Units remain within the licensing basis and fit-for-service.

7.0 REFERENCES

1. CNSC Letter, R. Jammal to J. Franke, “Designated Officer Order issued to Ontario Power Generation”, OPG CD# P-CORR-00531-22706 (e-Doc 6612802, 6612567), July 26, 2021

2. Bruce Power CNSC Event Report, “A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements”, B-2021-93819, July 8, 2021

3. Bruce Power CNSC Event Report, “Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement”, B-2021-98077, July 5, 2021

4. CNSC Letter, “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”, OPG CD# N-CORR-00531-22783, July 13, 2021

5. OPG Letter, M. Knutson to A. Viktorov, “OPG Response to Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Responses to Item 1-4 Related to Measurement of Hydrogen Concentration in Pressure Tubes”, OPG CD# N-CORR-00531-22801, July 30, 2021

6. R. Wu, “Fuel Channels Life Cycle Management Plan”, OPG CD# N-PLAN-01060-10002-R021, September 16, 2020

7. M. Lazaroski, “Update Of Recommended Initial Hydrogen Concentrations For Pressure Tubes In Pickering Unit 4 August 2017”, OPG CD# NA44-CORR-31100-00007, August 25, 2017

8. M. Lazaroski, “Update of Recommended Initial Hydrogen Concentrations for Pressure Tubes in Pickering Unit 1 – July 2018”, OPG CD# NA44-CORR-31100-00011, July 9, 2018

9. M. Lazaroski, “Assessment of 2020 Pickering Unit 4 Rolled Joint Scrape Sample Measurements Results”, OPG CD# NA44-REP-31100-00138, March 10, 2021

10. C. Nam, “Assessment of 2020 Pickering Unit 1 Pressure tube Body-of-Tube Hydrogen Isotope Concentration Measurements”, OPG CD# NA44-REP-31100-00129, September 8, 2020

11. OPG Letter, “Pickering NGS –Information to Support Integrated Implementation Plan (IIP) Action G01-RS1-06-01.4 and CNSC Action Item 2014-48-5348”, OPG CD# P-CORR-00531-22567, March 17, 2021

12. CNSC Letter, “Pickering NGS, Unit 1 and 4 – CNSC Acceptance of Revised Component Disposition, Pressure Tube to Calandria Tube Contact”, OPG CD# NA44-CORR-00531-36898 (e-Doc 6461923), January 13, 2021

13. C. Manu, S. Wang and K. Huang, “Impact of Pressure Tube D1U09 Inlet Rolled Joint Hydrogen Equivalent Concentration Measurements on Pickering Pressure Tube Fitness for Service Evaluations”, OPG CD# P-REP-31100-00006, July 16, 2020

14. CAN/CSA N285.8-15 Update No. 1, “Technical Requirements for In-Service Evaluation of Zirconium Allow Pressure Tubes in CANDU Reactors”, CSA Group, October 2019

ONTARIO POWER GENERATION

MEMORANDUM

OPG Confidential

August 07, 2021

File No.: NK30-CORR-31100-0941210 P

Fitness-for-Service Justification to Support Pickering Unit 5-8 Restart

1.0 INTRODUCTION

On July 26, 2021, CNSC provided an order by a designated officer under paragraph 37(2)(f) and Subsection 35(1) of the *Nuclear Safety and Control Act* for Pickering Units [1]. The CNSC order is as follows:

Prior to the restart of Pickering Units 1, 4, 5, 6, 7, or 8, following any outage that results in the cooldown of the heat transport system, OPG shall obtain authorization from the Commission to restart.

Prior to seeking such authorization, OPG shall either:

a) Carry out inspection and maintenance activities that demonstrate with a high degree of confidence that pressure tube [Heq] is within OPG'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 model failed to conservatively predict the elevated [Heq], and submit results of such activities to CNSC staff.

The purpose of this memorandum is to document the Fitness-for-Service (FFS) justification, demonstrate the basis for confidence in pressure tube (PT) hydrogen equivalent concentrations ([Heq]) and very low population of flaws in the high [Heq] area of interest based on Bruce Power OPEX at Pickering Units 5 to 8. Based on this information, this memorandum supports Pickering Units 5 to 8 restart, should the Units be required to cooldown as part of a planned maintenance outage or an unplanned forced outage without the need to exceed the Life Cycle Management Plan (LCMP) scheduled inspection scope [2]. The information provided herein supplements justifications of FFS previously submitted to the CNSC in [3].

2.0 COMPLIANCE WITH LICENSING BASIS

Based on a review of Bruce Power's B3 and B6S13 relevant data [4][5], Pickering 5 to 8 hydrogen equivalent concentration ([Heq]) measurements collected to date, and the assessment and engineering evaluation provided in [3], OPG's existing FFS assessments remain valid. PT [Heq] values for all OPG Units are confirmed to be within the licensing basis and based on measurements, no PTs have been predicted or measured to be in excess of 120ppm [Heq].

This approach to restart from an unplanned outage is consistent with the Licensing Basis and specifically the requirements of License Condition Handbook Sections 6.1 and 15.3.

3.0 BACKGROUND

In July 2021, Bruce Power reported two events related to [Heq] measured in Bruce Units 3 (B3) and 6 (B6):

1) Measurements obtained from the B3 A2131 outage scrape campaign showed elevated [Heq] values were greater than expected which potentially exceeded parameters of the fracture toughness model in CSA N285.8-15 Update 1, Clause D.13.2.3.1.2 (a), hence, potentially not meeting Clause 4.5.1.3 [4].

2) Following the removal of PT S13 in Bruce Power Unit 6, higher than expected [Heq] values were found in the pressure tube which potentially exceeded the parameters of the fracture toughness model in CSA N285.8-15 Update 1, Clause D.13.2.3.1.2 (a), hence, potentially not meeting Clause 4.5.1.3 [5].

CNSC subsequently provided a letter to OPG [6] which was made pursuant to subsection 12(2) of the General Nuclear Safety and Control Regulations. OPG was requested to review the impact of the Bruce Power PT [Heq] sampling result, as it relates to OPG PT FFS. OPG submitted a response to the CNSC which included an Engineering Evaluation along with a FFS impact memo which provided evidence that there is no impact on Pickering FFS [3].

4.0 PICKERING UNIT 5 TO 8 FITNESS-FOR-SERVICE JUSTIFICATION

4.1 Pickering Unit 5 to 8 Manufacturing and Operation

Pickering Units 5 to 8 units are licensed to operate to the end of 2024. Units 5 to 8 were brought into service in December 1982, November 1983, November 1984, and January 1986, respectively [2]. Table 1 provides the initial hydrogen concentration ([Hinitial]) information for Pickering Units 5 to 8 [7].

Table 1: Pickering Units 5 to 8 [Hinitial] Values

Unit	Average PT [Hinitial] (ppm)	Maximum PT [Hinitial] (ppm)
P5	6.5	19.5
P6	6.4	14.0
P7	7.8	16.6
P8	8.2	15.6

As shown in Table 2 to Table 6, below, the Hot Hours (HH) of Pickering Units 5 to 8 are roughly equivalent to that of Bruce Power Units 3 and 6.

Table 2: Bruce Power Units 3 and 6 Hot Hours

Unit	Hot Hours	Notes
B3	271,330	As of A2131
B6	271,729	As of MCR

The conservatively calculated end of life target operating HH values for Pickering Units 5 to 8 are as shown below in Table 3 to Table 6.

Table 3: Pickering Unit 5 Hot Hours

	Approximate Hot Hours	Approximate Date
P5 Currently	268000	July 2021
Next Planned P5 Outage (P2251)	273000	Jan 2022
P5 EOL (Licensing Limit)	302000	Dec 31, 2024

Table 4: Pickering Unit 6 Hot Hours

	Approximate Hot Hours	Approximate Date
P6 Currently	274000	July 2021
Next Planned P6 Outage (P2361)	288000	Jan 2023
P6 EOL (Licensing Limit)	310000	Dec 31, 2024

Table 5: Pickering Unit 7 Hot Hours

	Approximate Hot Hours	Approximate Date
P7 Currently	267000	July 2021
Next Planned P7 Outage (P2171)	269000	Sep 2021
P7 EOL (Licensing Limit)	301000	Dec 31, 2024

Table 6: Pickering Unit 8 Hot Hours

	Approximate Hot Hours	Approximate Date
P8 Currently	250000	July 2021
Next Planned P8 Outage (P2381)	270000	Sep 2023
P8 EOL (Licensing Limit)	288000	Dec 31, 2024

While Pickering 5 to 8 and Bruce 3 and 6 HH values are similar, it is important to note that Pickering 5 to 8 PTs operate in less severe environment than the PTs in Bruce Power reactors. Pickering 5 to 8 PTs have historically exhibited lower deuterium uptake rates than Bruce Power PTs, while also experiencing lower operating pressures.

Results of Pickering 5 to 8 in-service scrape and ex-service material surveillance sampling are provided in Sections 4.2 and 4.3, respectively.

4.2 In-Service Scrape

Pickering Units 5 to 8 scrapes are obtained from the Body-of-Tube (BOT) as well as both the inlet and outlet Rolled Joints (RJs) which exceeds CSA N285.4-05 requirements.

Table 7, below, provides past performed and future to be performed scrapes scheduled in upcoming outages. The first scrape campaign in Pickering Units 5 to 8 was performed in the BOT in 1992, with additional scrape campaigns performed regularly since that time. Within the last 12 months, scrape has been performed in both Pickering Unit 6 and Pickering Unit 8. Within the next 6 months, scrape will be performed in Pickering Unit 5 and Pickering Unit 7. Scrape will continue to be scoped into future outages, as indicated in Table 8 and the Fuel Channel LCMP [2].

Table 7: Pickering Units 5 to 8 Scrapes

Unit	Number of BOT Scrapes	Number of RJ scrapes	Number of future BOT Scrapes	Number of future RJ Scrapes
P5-8	278	116	80	80

Table 8: Pickering Units 5 to 8 History, Most Recent, and Next Planned Scrape Campaigns

Unit	First Scrape BOT	Most Recent Scrape BOT	Upcoming Planned Scrape BOT	First Scrape RJ	Most Recent Scrape RJ	Upcoming Planned Scrape RJ
P5	1992	2019	2022	2009	2019	2022
P6	1995	2020	2023	2009	2020	2023
P7	2000	2019	2021	2010	2019	2021
P8	1999	2021	2023	2010	2021	2023

Proactively, enhancements to the Pickering 5 to 8 scrape program are being investigated in response to the Bruce Unit 3 and B6S13 OPEX as documented in Section 5.1. These enhancements would ensure condition monitoring is as conservative as possible, despite no evidence of observations similar to those seen in B3 and B6 late life PTs.

4.3 Ex-Service Material Surveillance

Pickering Units 5 to 8 through-wall punch/cut samples are obtained from the BOT as well as both the inlet and outlet RJs when ex-service material surveillance is performed.

Table 9, below identifies past performed and future to be performed material surveillance sampling scheduled for Pickering Units 5 to 8. The first ex-service material surveillance campaign in Pickering Units 5 to 8 was performed in 1990. Ex-service material surveillance, will continue to be performed for Pickering Units 5 to 8 PTs as indicated in Table 9 and the Fuel Channel LCMP [2].

Table 9: Pickering Units 5 to 8 PT Removals

Removed PT	Year Removed
P8S15	1990
P6M14	2007
P7A13	2008
P7O07	2016
P8P10	2021
P5 SFCR	2022 (Planned)

For recently removed PTs from across the OPG nuclear fleet, industry has performed extensive [Heq] sampling to characterize circumferential variation in the RJ regions. Continued sampling of Pickering Units 5 to 8 removed PTs at multiple axial and all clock positions in the RJ regions will be performed including:

- Sampling in the RJ regions of PT P8P10 (removed during P2181), and
- Sampling in the RJ regions of the PT scheduled for removal during the next planned P5 outage (P2251).

[Heq] results from Pickering Units 5 to 8 ex-service PT material surveillance are consistent with model predictions. Figure 1 and Figure 2, below, plot measured [H]eq from punch samples removed from PT P7O07 (latest tube with measurements available). This plot shows that Pickering Units 5 to 8 PTs sampled at the 12 o'clock orientation of the ORJ have not exhibited elevated [H]eq as seen in the B3 and B6S13 OPEX.

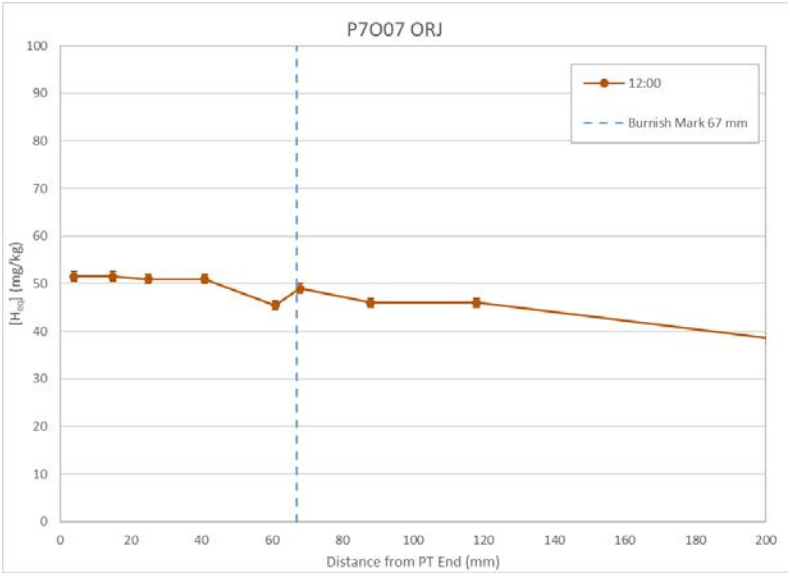

Figure 1: P7O07 Outlet RJ [Heq] Measurements

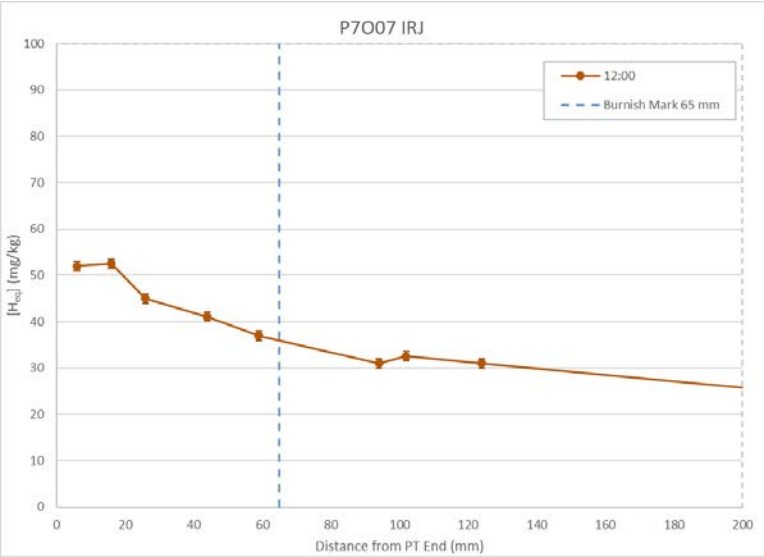

Figure 2: P7O07 Inlet RJ [Heq] Measurements

4.4 [Heq] Predictions

As part of the Pickering 5 to 8 in-service scrape and ex-service material surveillance programs, [Heq] sampling results are evaluated to ensure that predictive models continue to be appropriate for use in FFS evaluations.

Figure 3, below, plots measured vs. predicted [Heq] from past Outlet Rolled Joint (ORJ) tensile region punch and scrape sampling performed for Pickering Units 5 to 8 [8].

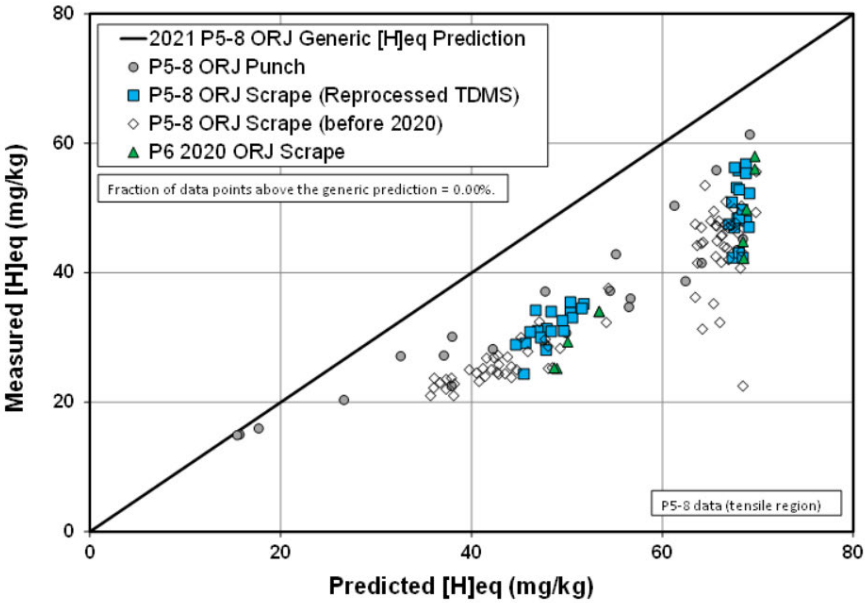

Figure 3: Comparison of Measured [Heq] and the 2021 Generic Deterministic Outlet RJ [Heq] Predictions for Tensile Region Locations of the P5-8 Outlet RJs

Figure 4, below, plots measured vs. predicted [Heq] from past Inlet Rolled Joint (IRJ) tensile region punch and scrape sampling performed for Pickering Units 5 to 8 [8].

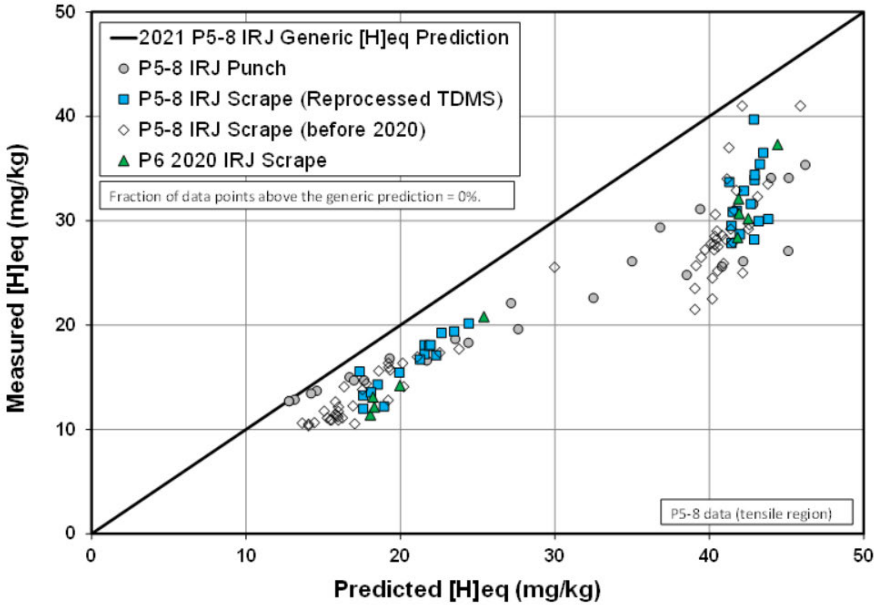

Figure 4: Comparison of Measured [Heq] and the 2021 Generic Deterministic Inlet RJ [Heq] Predictions for Tensile Region Locations of the P5-8 Inlet RJs

Figure 5 to Figure 8, below, plot measured vs. predicted [Heq] from past BOT punch and scrapes performed at Pickering Units 5 to 8 at the 1.5, 4.0, 5.0, and 5.6 m axial locations of the PT respectively (with respect to the PT inlet) [9].

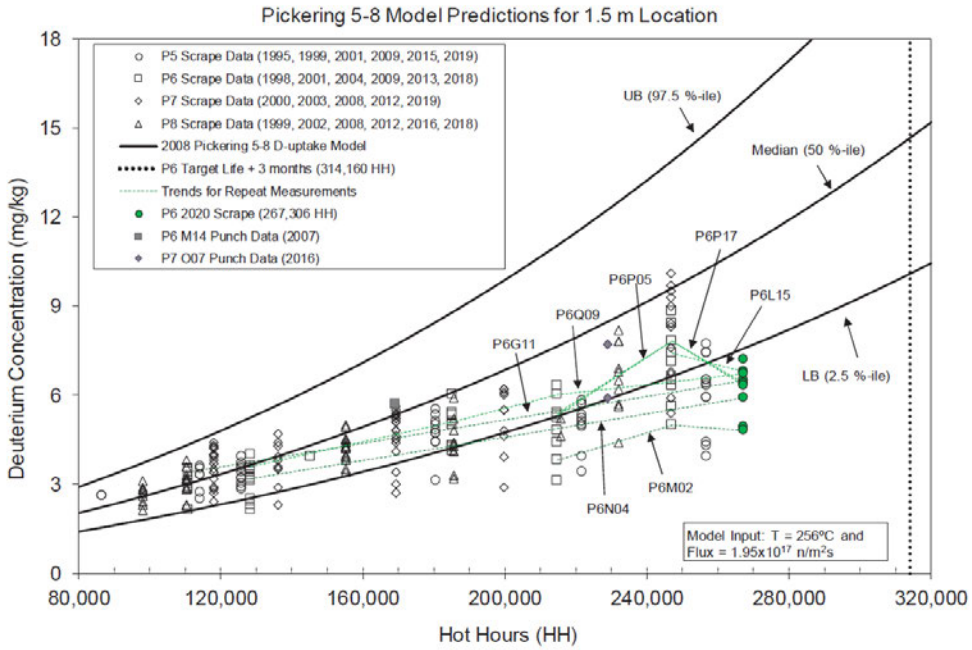

Figure 5: Measured BOT Deuterium Ingress Comparison with the Maximum Allowable [Heq] Limit (Limit above Plot Range) and the 2008 P5-8 BOT D-Uptake Model Predictions at the 1.5m Location

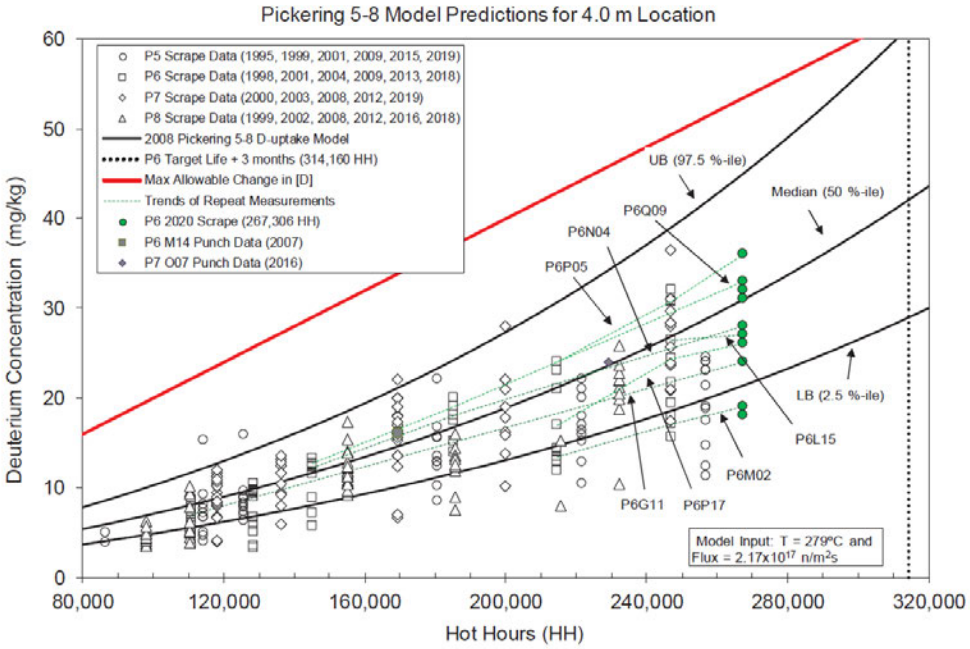

Figure 6: Measured BOT Deuterium Ingress Comparison with the Maximum Allowable [Heq] Limit and the 2008 P5-8 BOT D-Uptake Model Predictions at the 4.0m Location

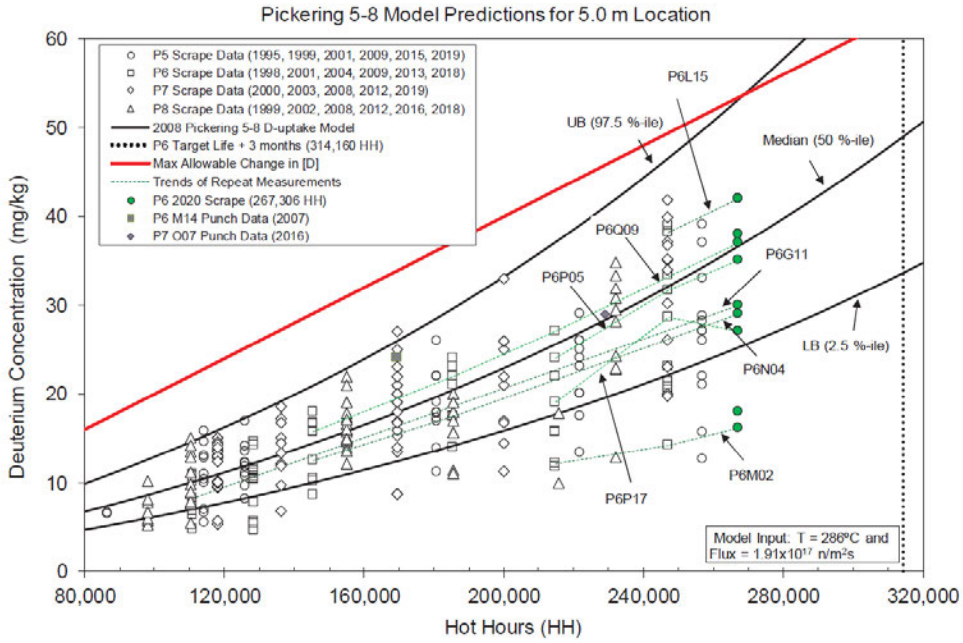

Figure 7: Measured BOT Deuterium Ingress Comparison with the Maximum Allowable [Heq] Limit and the 2008 P5-8 BOT D-Uptake Model Predictions at the 5.0m Location

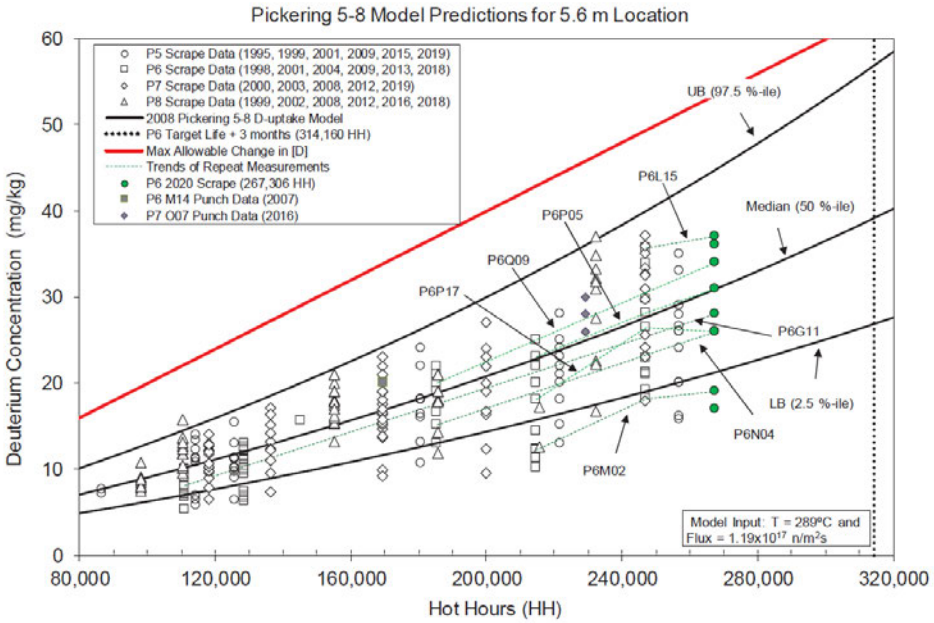

Figure 8: Measured BOT Deuterium Ingress Comparison with the Maximum Allowable [Heq] Limit and the 2008 P5-8 BOT D-Uptake Model Predictions at the 5.6m Location

As depicted in the plots above, Pickering 5 to 8 [Heq] models provide conservative upper bound predictions of [Heq] measured via both scrape and ex-service punch/cut. These results establish a high degree of confidence that pressure tube [Heq] is within OPG's licensing basis, per licence condition G.1. As a proactive measure, [Heq] modelling enhancements are being pursued as discussed in Section 5.2.

4.5 Flaw Population near the Outlet Burnish Mark

A review of inspected channels was performed to determine the number of dispositionable flaws within 100mm inboard of the outlet Burnish Mark (BM) in Pickering Units 5 to 8. Table 10 provides the information for the flaws found within the region of interest on the top half of the PT.

Table 10: Pickering Unit 5 to 8 Top of PT Flaws within 100mm of the Outlet Burnish Mark

Pressure Tube	Outlet BM to Flaw Start (mm)	Outlet BM to Flaw End (mm)	Flaw Depth (mm)	Rotary Start (deg, 0/360 is TDC))	Width (mm)
P5M07	18.7	46.9	0.2	31.3	4.8
P5Q05	18.9	47.0	0.2	326.3	4.5

Out of 226 unique Pickering 5 to 8 PTs that have received a Volumetric and Dimensional (V&D) inspection [10], there have only been 2 dispositionable flaws located within 100mm of the outlet RJ on the upper half of the PT (2 PTs with 1 flaw each). This confirms that the prevalence of outlet RJ top of tube flaws is very low in Pickering Units 5 to 8. This also highlights the conservatism built into the fracture protection assessments discussed in Section 4.7.2, where undetected through-wall flaws are postulated to exist for the purpose of assessment, despite OPG never having observed a through-wall flaw in any OPG reactor with current generation PTs installed.

Figure 9, below, provides a face map of PTs where V&D inspections have been performed as of the end of 2020 including data from all Pickering 5 to 8 Units [10]. *Note that for some channels shown in Figure 9, inspections have been performed multiple times and/or across multiple Pickering 5 to 8 units.*

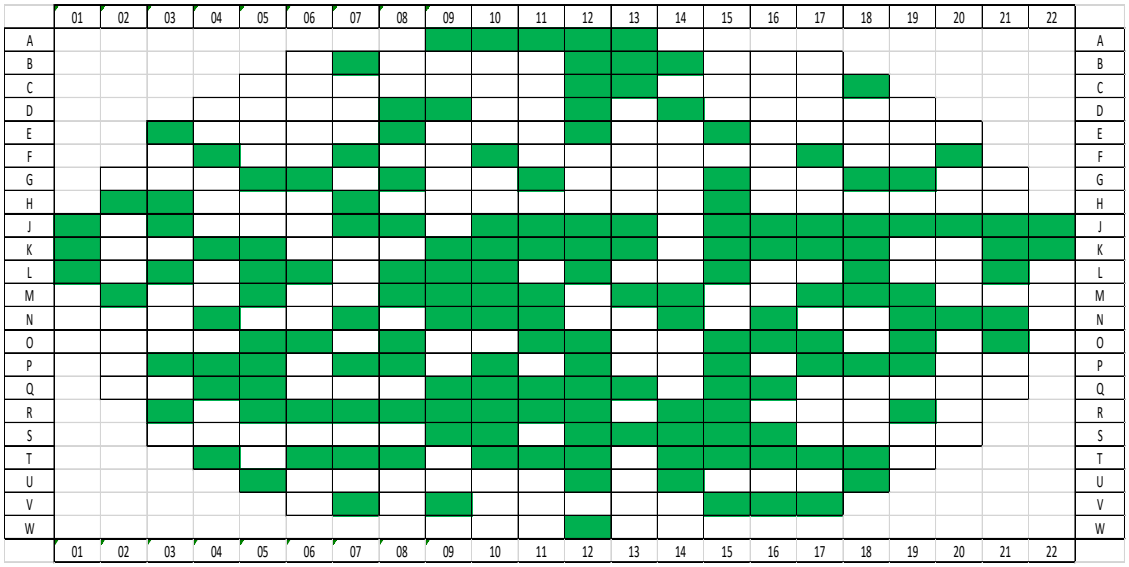

Figure 9: Pickering 5 to 8 Historical V&D Inspections

As shown in Figure 9, a large subset of Pickering Units 5 to 8 PTs have been inspected, covering the full distribution of flux and temperature conditions for the facility. Based on PT V&D results obtained to date, OPG has high confidence in the flaw populations for Pickering Units 5 to 8 (which have been shown to be acceptable per CSA N285.8).

4.6 Operating Envelope

The Pickering Units 5 to 8 operating envelope for the heatup/cooldown of the Units was modified in 2014 to account for changing fracture toughness properties due to increased bulk [Heq] levels and to maintain conservative margins. Station operating envelopes are re-validated when input models/parameters are updated to ensure the risk of PT rupture or initiation of delayed hydride cracking (DHC) is minimized.

Following any type of cooldown transient or forced outage, OPG proactively reviews the actual pressure and temperature conditions during the cooldown in order to determine the impact on FFS and to ensure fracture toughness limits have not been exceeded. When a cooldown occurs, flaw acceptability per CSA N285.8 is confirmed for all affected PT flaws prior to restart of the unit.

4.7 Core Assessment

4.7.1 PT-CT (Pressure Tube to Calandria Tube) Contact

PT-CT contact at Pickering Units 5 to 8 is dispositioned based on measured gap and spacer location inspection results in accordance with the Probabilistic Blister Susceptibility Assessment (PBSA).

The axial region of interest from the B3 and B6S13 OPEX is immediately inboard of the ORJ BM. The circumferential region of interest from the B3 and B6S13 OPEX is at the top of the PT (nominally the 12 o'clock orientation). Since PT-CT contact occurs at the bottom of the PT (nominally the 6 o'clock orientation) and contact is geometrically precluded so close to the ORJ BM in the axial direction, existing PT-CT contact dispositions for Pickering Units 5 to 8 remain valid [11][12][13][14] (i.e., there is no FFS impact of the B3 and B6S13 OPEX as it relates to PT-CT contact).

4.7.2 DFP (Deterministic Fracture Protection)

As part of the Bruce Power findings [4][5], OPG submitted an Engineering Evaluation which performed a Pickering 5 to 8 DFP evaluation [3]. Although the maximum projected ORJ [Heq] at end of life based on measured values was projected to be 108 ppm for Pickering Units 5 to 8, a base and sensitivity case with 120 and 140ppm were assessed. *Note that the engineering evaluation submitted in [3] concluded that there is no basis for postulating high [Heq] levels observed in B3 and B6 PTs in formal FFS assessments based on OPG's lower measured concentrations and top-to-bottom [Heq] differences compared to Bruce Power observations*.

Pickering Units 5 to 8 met the required safety factors (SFs) for the heatup/cooldown transients. For the Pickering Units 5 to 8 Rapid Cooldown transient (Level B), safety factors on internal pressure were all above 1.10 but less than the required safety factor of 1.30. It is recognized that these safety factors are based on the conservative 97.5% lower prediction bound on the fracture toughness that was predicted using the Revision 1 or Revision 2 engineering fracture toughness models. Based on operating experience that a rapid cooldown transient has never occurred in Pickering Units 5 to 8 [15][16][17][18], it was considered more appropriate to treat the rapid cooldown transient as Service Level C. For the Pickering Units 5 to 8 Rapid Cooldown transient treated as a Level C, all of the safety factors on internal pressure are greater than the required safety factor of 1.0. These safety factors are considered adequate for the purpose of demonstrating FFS of Pickering Units 5 to 8 for the Rapid Cooldown transient [3].

As communicated to the CNSC in [19], OPG is in the process of transitioning the Pickering Units 5 to 8 DFP assessments to Probabilistic Fracture Protection (PFP) assessments. The first PFP submission for Pickering Units 5 to 8 PTs is planned for Q1 of 2022 [20].

4.7.3 PCA (Probabilistic Core Assessment)

As a result of the D1U09 inlet rolled joint high localized [Heq] region [21], a sensitivity assessment was performed for Pickering Units 5 to 8 where axial-shifted [Heq] profiles were used to bound D1U09 [Heq] measurements [22]. This sensitivity case was applied to both the inlet and outlet RJ regions. Based on the sensitivity assessment upper bound mean failure frequency of 3.24E-04, the PCA remains below the CSA N285.8-15 Table C.1 acceptance criteria of 1E-02 to the end of the assessed interval (265,000 EFPH) with significant margin.

4.7.4 PLBB (Probabilistic Leak-Before-Break)

As with the PCA, a similar sensitivity assessment was performed for Pickering Units 5 to 8 where axial-shifted [Heq] profiles were used to bound D1U09 [Heq] measurements [22].This sensitivity case was applied to both the inlet and outlet RJ regions. Based on the sensitivity assessment upper bound conditional probability of break-before-leak of 0.0099, the PLBB assessment remains below the CSA 285.8-15 Clause 7.4.3.2 acceptance criteria of 0.10 to the end of the assessed interval (280,000 EFPH) with significant margin.

5.0 PROGRAM ENHANCEMENTS

5.1 Inspection Enhancements

As part of incorporating the B3 and B6S13 OPEX, OPG will endeavor to perform future scrapes at Pickering Units 5 to 8 at PT Top Dead Center (TDC, 12 o'clock orientation) where scrape overlap can be avoided. This is planned to ensure sampling occurs at the at the most limiting circumferential orientation of the PT (per BP OPEX), with consideration given to the limitations imposed by previous circumferentially offset scrapes.

In the upcoming P2171 outage planned to start in September 2021, OPG has scheduled a large number of scrape inspections as documented in the Life Cycle Management Plan [2]. This scope is entirely above and beyond the Periodic Inspection Program (PIP) requirements of CSA N285.4-05. Pickering Unit 7 is the lead unit in Pickering for [Heq] modelling purposes and bounding channels having been selected for inspection during P2171. Currently planned P2171 scope will provide extensive coverage of Pickering 5 to 8 PTs, addressing the B3 and B6S13 OPEX.

OPG will endeavor to accelerate processing of Pickering Unit 7 ORJ scrape samples for analysis prior to the end of the P2171 outage. As soon as practicable and for information purposes, a summary report highlighting the [Heq] concentration from the outage scrape program will be provided. All P2171 scrape assessment results will be provided to the CNSC in a formal report per the existing CSA N285.4-05 120 day reporting schedule.

5.2 Modelling Enhancements

[Heq] modelling enhancements including use of 3D Finite Element Analysis considering fuel channel geometries, local temperatures, location-specific [Heq], and material stress states are being pursued. Note that these proactive enhancements were already in progress prior to the B3 and B6S13 findings. OPG, with industry alignment, intends to submit modelling enhancements for CNSC acceptance once fully validated.

6.0 CONCLUSION

Pickering Units 5 to 8 [Heq] models provide conservative upper bound predictions of [Heq] measured via both in-service scrape and ex-service punch/cut. High [Heq] values inboard of the ORJ BM as reported via the B3 and B6S13 OPEX have not been observed in Pickering Units. OPG has, and will

continue to perform in-service scrape and ex-service material surveillance in excess of CSA N285.4-05 requirements to monitor PT FFS and [H]eq predictive model validity.

Based on the inspected PTs, there remains a very low probability of flaws existing in the ORJ top of PT region of interest. Conservative sensitivity assessments postulating higher than measured [Heq] in consideration of the B3 and B6S13 OPEX have been performed. These assessments demonstrate that Pickering Units 5 to 8 remain within the licensing basis and fit-for-service.

7.0 REFERENCES

[1] CNSC Letter, R. Jammal to J. Franke, "*Designated Officer Order issued to Ontario Power Generation*", OPG CD# P-CORR-00531-22706 (e-Doc 6612802, 6612567), July 26, 2021.

[2] R. Wu, "*Fuel Channels Life Cycle Management Plan*", OPG CD# N-PLAN-01060-10002-R021, September 18, 2020.

[3] OPG Letter, M.R. 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 Item 1-4 Related to Measurement of Hydrogen Concentration in Pressure Tubes*", OPG CD# N-CORR-00531-22801, July 30, 2021.

[4] Bruce Power CNSC Event Report, "*A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements*", B-2021-93819, July 8, 2021.

[5] Bruce Power CNSC Event Report, "*Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement*", B-2021-98077, July 5, 2021.

[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*", OPG CD# N-CORR-00531-22783, e-Doc 6603931, July 13, 2021.

[7] D. Gao and M. Lazaroski, "*Update of Recommended Initial Hydrogen Concentrations for Pressure Tubes in Pickering Unit 5 to 8 – August 2017*", OPG CD# NK30-CORR-31100-0662315, August 3, 2017.

[8] Email, L. Popescu to S. Lowe, "*2021 PB RJ Deterministic Model Requested Plots*", OPG CD# NK30-CORR-31100-0941213, August 4, 2021.

[9] M. Micuda, "*Assessment of 2020 Pickering Unit 6 Pressure Tube Body-of-Tube Hydrogen Isotope Concentration Measurement and P1861/P1971/P1881 TDMS Reprocessed [D] Results*", OPG CD# NK30-REP-31100-10394, April 1, 2021.

[10] OPG Letter, J. Franke to K. Campbell, "*Pickering NGS – Information to Support Integrated Implementation Plan (IIP) Action G01-RS1-06-01.4 and CNSC Action Item 2014-48-5348*", OPG CD# P-CORR-00531-22567, March 17, 2021.

[11] H. Indermohan, "*Pickering Unit 5 PT-CT Contact Disposition*", OPG CD# NK30-EVAL-31100-00013 R014, November 27, 2021.

[12] E. Nadeau, "*Pickering Unit 6 PT-CT Contact Disposition*", OPG CD# NK30-EVAL-31100-00011 R014, February 4, 2019.

[13] P. Simons, "*Pickering Unit 7 PT-CT Contact Disposition*", OPG CD# NK30-EVAL-31100-00019 R012, April 28, 2020.

[14] P. Simons, "*Pickering Unit 8 PT-CT Contact Disposition*", OPG CD# NK30-EVAL-31100-00016 R012, November 14, 2019.

[15] T. Rodger, "*Pickering Unit 5 – Operational Service Level B Transient Cycle Counts For Use In Fuel Channel Fitness For Service Assessments*", OPG CD# NK30-CORR-31100-0662837-R01, July 24, 2019.

[16] M. Pajor, "*Pickering Unit 6 – Operational Service Level B Transient Cycle Counts For Use In Fuel Channel Fitness For Service Assessments*", OPG CD# NK30-CORR-31100-0662398-R02, April 26, 2021.

[17] T. Rodger, "*Pickering Unit 7 – Operational Service Level B Transient Cycle Counts For Use In Fuel Channel Fitness For Service Assessments*", OPG CD# NK30-CORR-31100-0660071-R01, July 22, 2019.

[18] T. Rodger, "*Pickering Unit 8 – Operational Service Level B Transient Cycle Counts For Use In Fuel Channel Fitness For Service Assessments*", OPG CD# NK30-CORR-31100-0636072-R02, May 20, 2021.

[19] OPG Letter, J. Franke to K. Campbell, "*Pickering NGS: Units 5-8 – Response to CNSC Comments on Treatment of the Rapid Cooldown Transient for Pickering Units 5-8 Pressure Tubes*", OPG CD# NK30-CORR-00531-08168, June 30, 2021.

[20] OPG Letter, M.R. Knutson to K. Campbell and J. Burta, "*Darlington and Pickering NGS – Revised Core Assessment Submission Schedule*", OPG CD# N-CORR-00531-22773, August 3, 2021.

[21] OPG CNSC Event Report, "*Research Findings: Darlington Pressure Tube Inlet Rolled Joint Hydrogen Equivalent Concentration ([Heq]) Results Above CSA N285.4 Acceptance Criteria*", NK38-WER-00531-19215, April 15, 2020.

[22] C. Manu, S. Wang, K. Huang, "*Impact of Pressure Tube D1U09 Inlet Rolled Joint Region Hydrogen Equivalent Concentration Measurements on Pickering Pressure Tube Fitness for Service Evaluations*", OPG CD# P-REP-31100-00006, July 16, 2020.

ONTARIO POWER GENERATION

MEMORANDUM

OPG Confidential

August 7, 2021

File No.: NK38-CORR-31100-0940953

Fitness-for-Service Justification to Support Darlington Units 1&4 Restart

1.0 INTRODUCTION

On July 26, 2021, CNSC provided an order by a designated officer under paragraph 37(2)(f) and Subsection 35(1) of the *Nuclear Safety and Control Act* for Darlington Units 1&4 [1]. The CNSC order is as follows:

Prior to the restart of Units 1 or 4, following any outage that results in the cooldown of the heat transport system, OPG shall obtain authorization from the Commission to restart.

Prior to seeking such authorization, OPG shall either:

a) Carry out inspection and maintenance activities that demonstrate with high degree of confidence that pressure tube [Heq] is within OPG'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 model failed to conservatively predict the elevated [Heq], and submit results of such activities to CNSC staff.

The purpose of this memorandum is to document the fitness-for-service (FFS) justification, demonstrate the basis for confidence in pressure tube (PT) hydrogen equivalent concentrations ([Heq]) and that there are no flaws in the high [Heq] area of interest based on Bruce Power OPEX at Darlington Units 1 and 4. Based on this information, this memorandum supports Darlington Units 1 or 4 restart, should the Units be required to cooldown as part of planned maintenance or an unplanned forced outage without the need to increase the

inspection scope beyond the LCMP requirements [6]. The information provided herein supplements justifications of FFS previously submitted to the CNSC in [2].

2.0 COMPLIANCE WITH LICENSING BASIS

Based on the review of Bruce Power's B3 and B6S13 relevant data, and Darlington Unit 1 and 4 measurements collected to date, the assessment and engineering evaluation provided in [2], OPG's existing FFS assessment remain valid. Based on measurements, no PTs have been predicted or measured to be in excess of 120ppm [Heq].

The approach to restart from an unplanned outage is consistent with the Licensing Basis and specifically the requirements of License Condition Handbook (LCH) Section 6.1.

3.0 BACKGROUND

In July 2021, Bruce Power reported two events related to [Heq] measured in Bruce Units 3 and 6:

1) Measurements obtained from the A2131 outage scrape campaign showed elevated [Heq] values were greater than expected which potentially exceeded parameters of the fracture toughness model in CSA N285.8-15 Update 1, Clause D.13.2.3.1.2 (a), hence, potentially not meeting Clause 4.5.1.3 [3].

2) Following the removal of pressure tube S13 in Bruce Power Unit 6, higher than expected [Heq] values were found in the pressure tube which potentially exceeded the parameters of the fracture toughness model in CSA N285.8-15 Update 1, Clause D.13.2.3.1.2 (a), hence, potentially not meeting Clause 4.5.1.3 [4].

CNSC subsequently provided a letter to OPG [5] which was made pursuant to subsection 12(2) of the General Nuclear Safety and Control Regulations. OPG was requested to review the impact of the Bruce Power [Heq] PT sampling result, as it relates to OPG PT FFS. OPG submitted a response to CNSC which included a FFS impact memo supported by an Engineering Evaluation which provided evidence that there is no impact on Darlington FFS [2].

4.0 DARLINGTON UNITS 1 AND 4 FITNESS-FOR-SERVICE JUSTIFICATION

4.1 DARLINGTON UNITS 1 AND 4 OPERATION

Darlington Units 1 and 4 are the two remaining Darlington units which are planned for refurbishment in February 2022 and July 2023, respectively. The units were brought into service in December 1990 and April 1993 [6], respectively.

Table 1 provides the initial hydrogen concentration ([Hinitial]) from the manufacturing process for Darlington Units 1 and 4 [7], [8].

Table 1 – Darlington 1 and 4 [Hinitial] Values

Unit	Average PT [Hinitial] (ppm)	Maximum PT [Hinitial] (ppm)
Darlington Unit 1	10.2	22.0
Darlington Unit 4	7.8	14.3

As shown in Tables 2 and 3, the predicted hot hours (HH) are significantly less than that of Bruce Power Units 3 and 6. Furthermore, the conservatively calculated end of life target operating HH (assuming 100% operation) for Units 1 and 4 will be ~30,000 HH less than either Bruce Unit 3 or 6.

Table 2 – Bruce Power Units 3 and 6 Hot Hours

Unit	Hot Hours	Notes
Bruce Unit 3	~271,330	As of A2131
Bruce Unit 6	271,729	As of MCR

Table 3 – Darlington 1 and 4 Hot Hours

	Approximate Hot Hours	Approximate Date
Darlington Unit 1 Currently	232,300	July 2021
D1 End of Life	237,200	February 2022
Darlington Unit 4 Currently	223,500	July 2021
Next Planned D4 Outage (D2141)	225,000	October 2021
D4 End of Life	238,400	July 2023

Darlington Units 1 and 4 have also been oriented with the front end (FE) of the PT at the inlet, resulting in lower [Heq] for the FE material. This is in contrast to the B3 channels which are oriented with FE material at the outlet.

With greater than 30,000 HH difference at end of life, and D1 and D4 [Heq] measurements to date (discussed in Sections 4.2 and 4.3), there is margin to the elevated ORJ [Heq] measured late in the life of B3 and B6 PTs.

4.2 SCRAPE

Darlington Units 1&4 have been performing scrapes in both the inlet and outlet rolled joints (RJ) and the body-of-tube (BOT) which exceeds the CSA N285.4 requirement. Table 4 provides past performed and future to be performed scrapes in the upcoming outages. Scrape will continue to be scoped into the upcoming outages, as indicated in Table 5 and as per the Fuel Channel Life Cycle Management Plan [6].

Table 4 - Darlington Scrapes

Unit	Number of BOT Scrape Channels	Number of RJ Scrape Channels	Number of Future BOT Scrape Channels*	Number of Future RJ Scrape Channels*
D1, D2, D3 and D4	215	87	15	6

*Only includes BOT and RJ scrape channels prior to refurbishment

Table 5 - History of Initial, Most Recent and Next Planned Scrape Campaigns

Unit	First Scrape BOT	Most Recent Scrape BOT	Upcoming Planned Scrape BOT	First Scrape RJ	Most Recent Scrape RJ	Upcoming Planned Scrape RJ
D1	2011	2020	N/A*	2008	2021	N/A*
D2	2001	2013	After refurbishment	2010	2013	After refurbishment
D3	2002	2018	After refurbishment	2009	2018	After refurbishment
D4	2010	2019	2021	2010	2019	2021

*No further BOT or RJ scrape prior to Darlington refurbishment

Proactive enhancements to the Darlington scrape program are being investigated in response to the Bruce Unit 3 and B6S13 OPEX as documented in Section 5.1. These enhancements would ensure condition monitoring is as conservative as possible, despite no evidence of observations similar to those seen in B3 and B6 late life PTs.

4.3 EX-SERVICE MATERIAL SURVEILLANCE

Darlington has been performing material surveillance measurements on pressure tubes with [Heq] sampling locations in both the inlet and outlet RJs and BOT. Recent tube removals have expanded the sampling to include several axial positions and all clock positions (samples from material surveillance are obtained via through-wall punches typically focused at the 12 o'clock top dead centre (TDC) location and more recently, at multiple clock positions). Table 6 provides a summary of Darlington single fuel channel replacements (SFCRs). Removal of 4 additional RJ sections is scheduled during Darlington Unit 3 Refurbishment (planned removal in 2021) as part of Inconel X-750 spacer retrieval and to allow for additional [Heq] testing.

Table 6: Summary of Darlington SFCRs

Unit	Channel	Year of Removal
D2	O18	2005
D3	Q13	2009
D2	M09	2013
D2	4 inlet RJ PT sections including D2O23 and D2N15	2016
D1	U09	2017
D3	S13	2020
D3	4 Inlet RJ PT sections	2021

As a result of the D1U09 (removed in 2017) localized high [Heq] region measured in the inlet RJ, extensive measurements were performed in the inlet RJs of D2N15 and D2O23 (both removed in 2016). D3S13 (removed in 2020) is part of the continued investigation on the extent of circumferential gradients in hydrogen isotope concentrations in the RJs region of PTs under a COG research and development work package.

The results from D3S13 have shown a localized [Heq] region just inboard of the inlet and outlet burnish marks (BMs) with a peak [Heq] of 89ppm and 75ppm, respectively [9]. The maximum [Heq] measurement at nominally 20mm inboard of the BM is 46ppm and 60ppm, respectively. Figures 1 and 2 show D3S13 outlet and inlet RJ measurements at all clock positions, respectively.

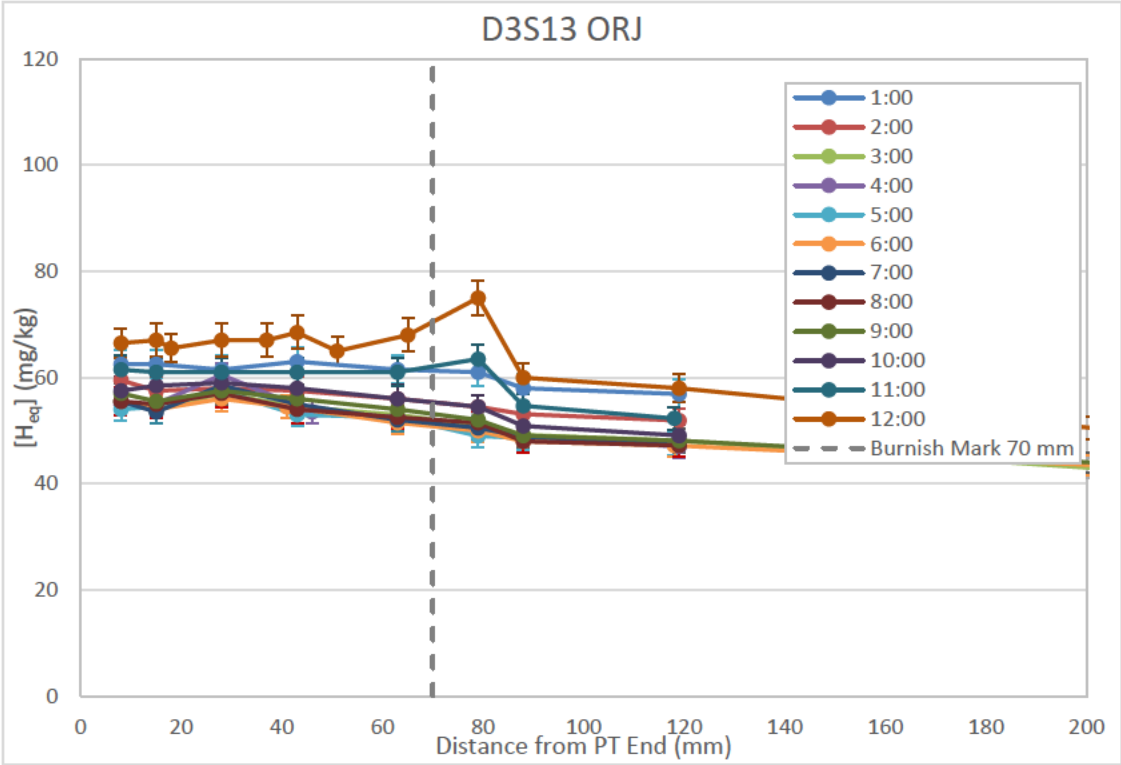

Figure 1 – D3S13 Outlet RJ Measurements from All Clock Positions

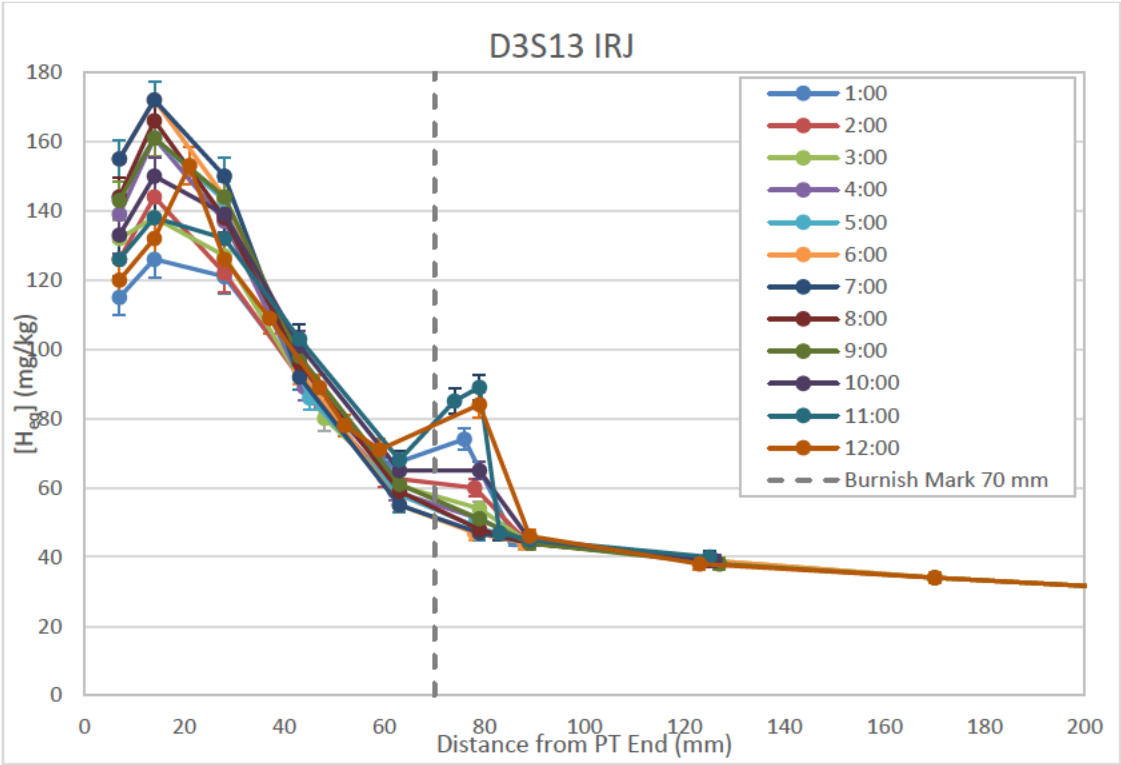

Figure 2 – D3S13 Inlet RJ Measurements from All Clock Positions

The results from D3S13 material surveillance demonstrate the [Heq] measurements 20mm inboard of the BM (relevant to deterministic fracture protection) meet the requirements of CSA N285.4 and all tube measurements satisfy the validity limits of the Revision 2 cohesive zone fracture toughness model [10].

Based on the extensive material surveillance [Heq] sampling results to date in numerous tubes and at multiple clock and axial positions, the Darlington [Heq] models utilized in FFS assessments provide conservative upper bound predictions of [Heq] measurements, as shown in Section 4.4.

4.4 [Heq] PREDICTIONS

As part of the scrape and material surveillance program in Darlington Units 1 and 4, the samples are analyzed to determine the [Heq] values and ensure the models in place are still supported for FFS evaluations.

Figure 3 and Figure 4 [11] below provide the outlet and inlet RJ, respectively, for the past outage scrape and punch sampling data versus the models predictions, which demonstrate the [Heq] data is bounded based on the most recent models. Darlington has recently updated the inlet RJ deterministic predictions to provide bounding [Heq] predictions accounting for material surveillance results from D1U09.

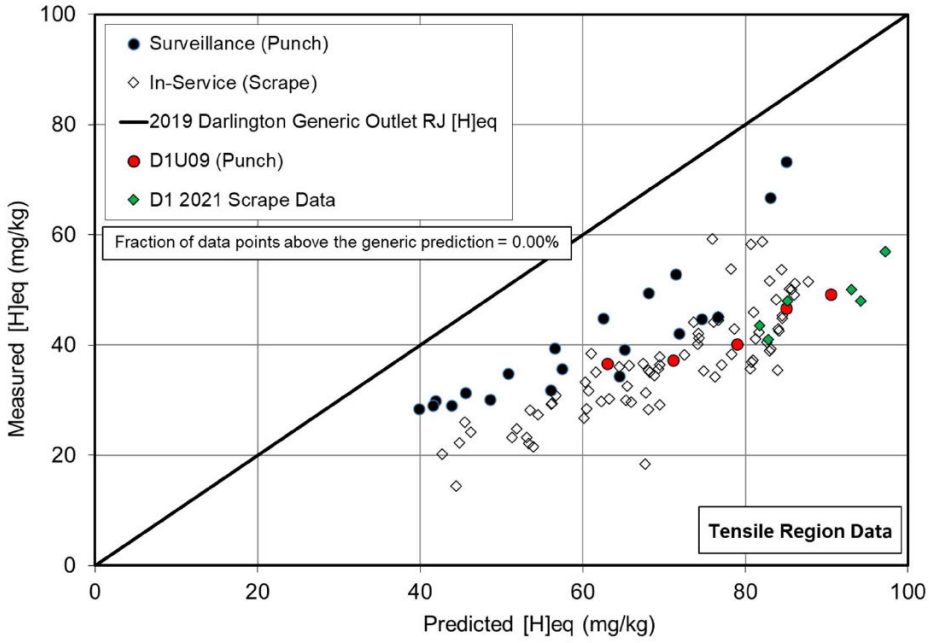

Figure 3 - Comparison of All Darlington Measured [Heq] and the 2019 Darlington Units Outlet RJ [Heq] Generic Deterministic Predictions for Tensile Region Locations of the D1 and D4 Outlet RJ

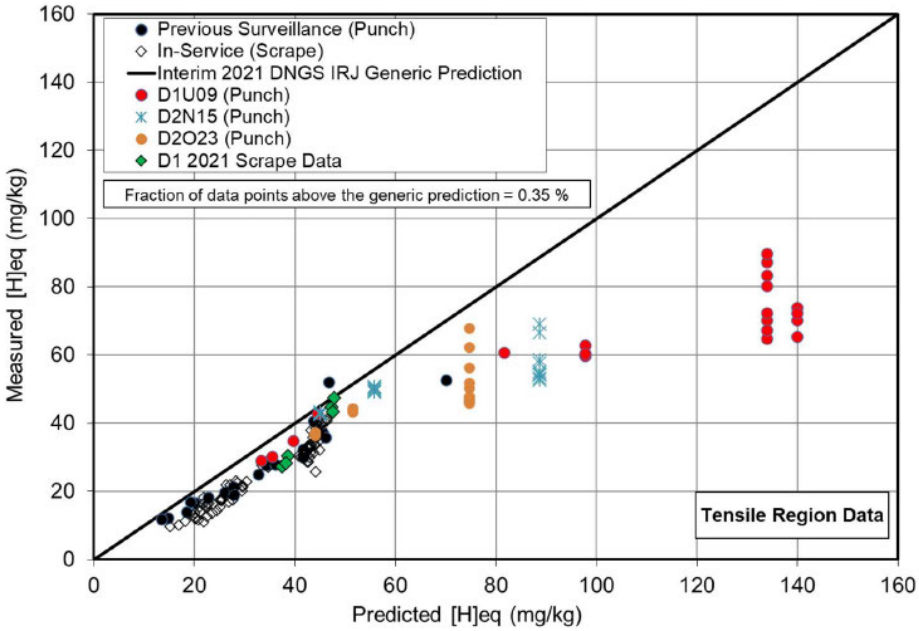

Figure 4 - Comparison of All Darlington Measured [Heq] and the 2021 Interim Darlington Units Inlet RJ [Heq] Generic Deterministic Predictions for Tensile Region Locations of the D1 and D4 Inlet RJ

Figures 5, 6, 7 and 8 [12] below provide, the 1.5m, 4m, 5m and 5.6m, respectively, for the past outages scrape data versus the models predictions.

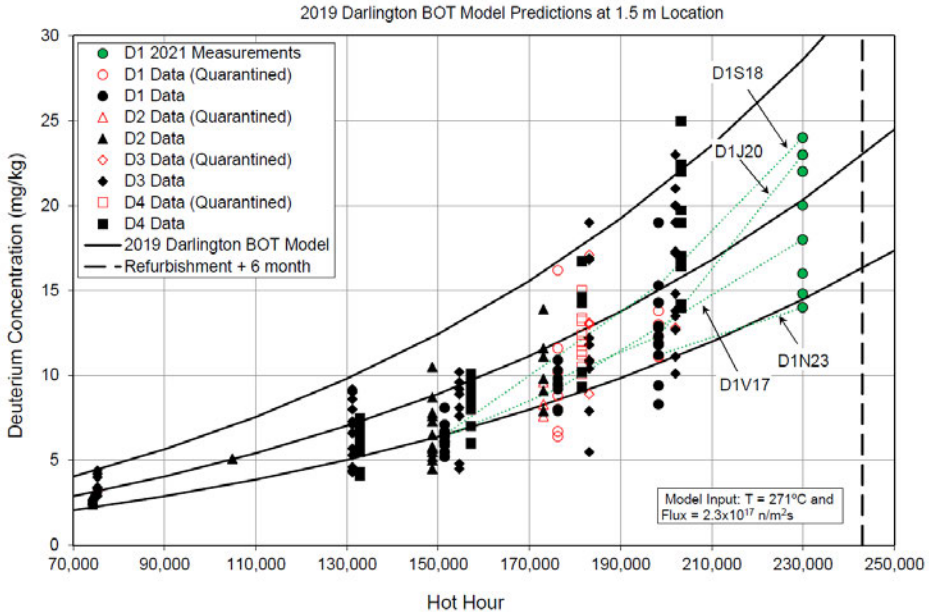

Figure 5 – Measured Darlington Units 1 &4 BOT Deuterium Ingress Comparison with the 2019 Darlington BOT D-Uptake Model Predictions at the 1.5m Location

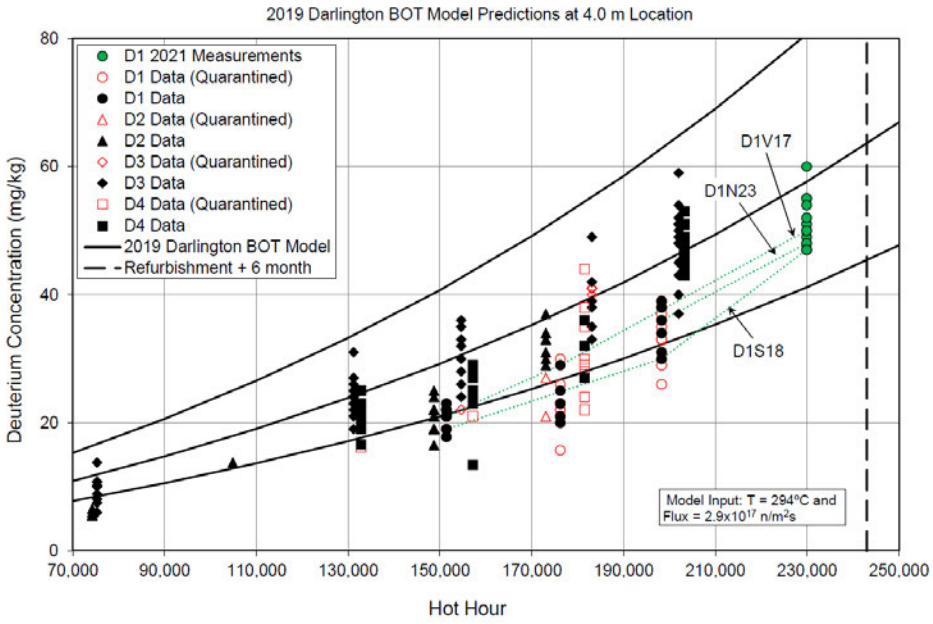

Figure 6 - Measured Darlington Units 1 &4 BOT Deuterium Ingress Comparison with the 2019 Darlington BOT D-Uptake Model Predictions at the 4m Location

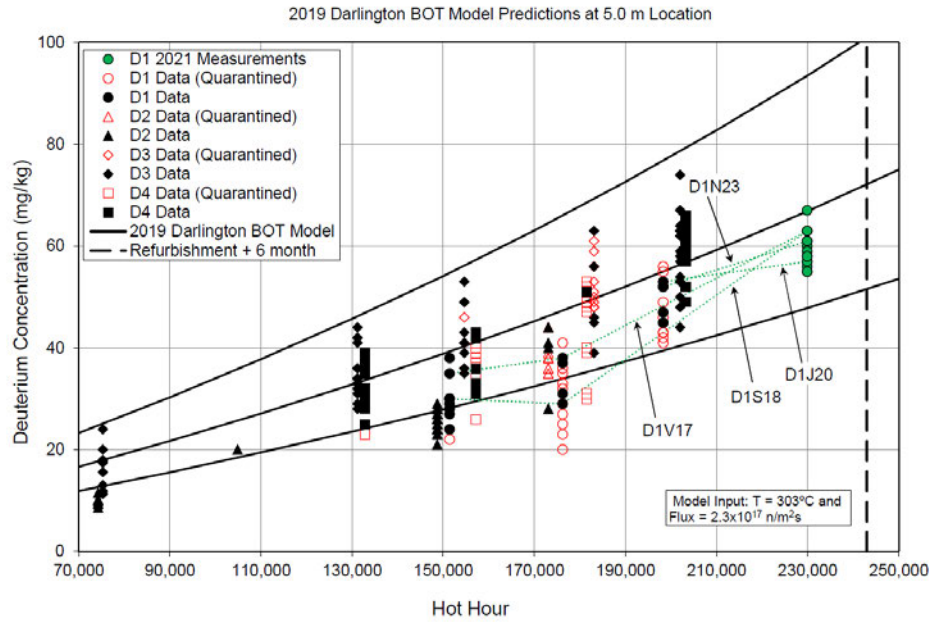

Figure 7 - Measured Darlington Units 1 &4 BOT Deuterium Ingress Comparison with the 2019 Darlington BOT D-Uptake Model Predictions at the 5.0m Location

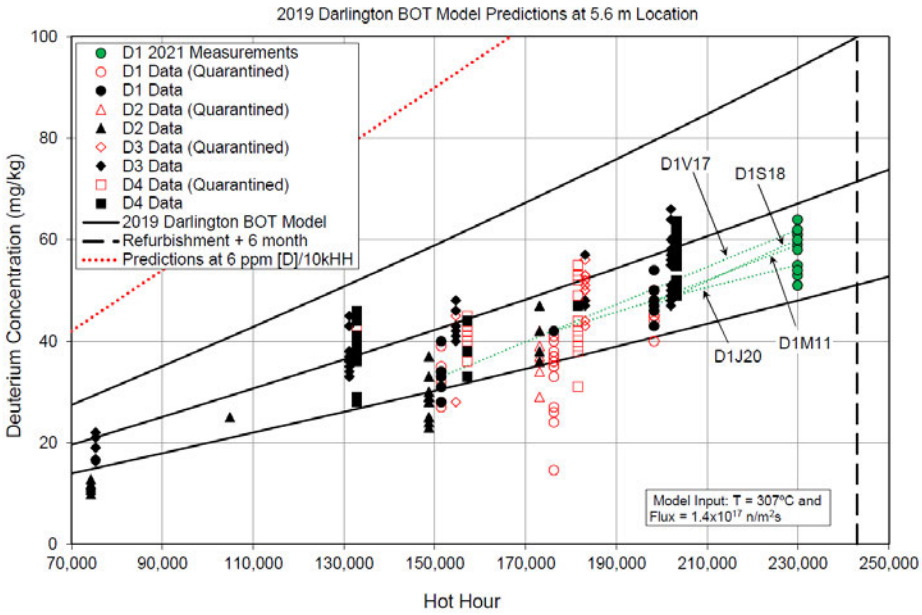

Figure 8 – Measured Darlington Units 1 &4 BOT Deuterium Ingress Comparison with the 2019 Darlington BOT D-Uptake Model Predictions at the 5.6m Location

As shown in Figures 5, 6, 7 and 8, Darlington [Heq] models provide conservative upper bound predictions of [Heq] measured via both scrape and ex-service punch. The vast majority of the scrape data obtained from past outages remains between the upper and lower bound predictions at each axial location, providing confidence that the [Heq] models are supported in FFS assessments. These results establish a high degree of confidence that pressure tube [Heq] is within OPG's licensing basis, per licence condition G.1.

As a proactive measure, [Heq] modelling enhancements are being pursued as discussed in Section 5.2.

4.5 FLAW POPULATION NEAR THE OUTLET BURNISH MARK

A review of the inspected channels was performed to determine the number of dispositionable flaws 100mm inboard of the outlet burnish mark. Out of 131 unique inspected channels [13] in Darlington Units 1 and 4 as of March 2021, there are no dispositionable flaws located within 100mm of the outlet RJ on the upper half of the PT, thus providing confidence that there are no dispositionable flaws in the area of interest from the BP OPEX. Figure 9 below provides a facemap of all full length volumetric and dimensional (V&D) inspected channels (highlighted in green) in Darlington Units 1, 2, 3 and 4 as of March 2021. Note that for some channels shown in Figure 9, inspections have been performed multiple times and/or across multiple Darlington Units.

Figure 9 – Full Length V&D Inspected Channels in Darlington Units 1, 2, 3 and 4

Based on the pressure tube volumetric and dimensional activities performed to date, OPG has high confidence in the flaw populations for Darlington Units 1 and 4, which have been shown to be acceptable per CSA N285.8. Channels which may have been exposed to specific flaw formation conditions are targeted for inspection. The combination of targeted channels and extent of inspections provides high confidence that there are no flaws in Darlington Units 1 and 4 in the region of interest. This also highlights the conservatism built into the fracture protection assessments discussed in Section 4.7.2, where undetected through-wall flaws are postulated to exist for the purpose of assessment, despite OPG never having observed a through-wall flaw in any OPG reactor with current generation PTs installed.

4.6 Operating Envelope

The Darlington Units 1 and 4 operating envelope for the heatup/cooldown of the Units were modified in 2014 to account for changing fracture toughness properties due to increased bulk [Heq] levels. Station operating envelopes are re-validated when input models/parameters are updated to ensure the risk of PT rupture or initiation of delayed hydride cracking (DHC) is minimized.

Following any type of cooldown transient or forced outage, OPG proactively reviews the actual pressure and temperature conditions during the cooldown in order to determine the impact on FFS and to ensure fracture toughness limits have not been exceeded. When a cooldown occurs, flaw acceptability per CSA N285.8 is confirmed for all PT flaws prior to restart of the unit.

4.7 Core Assessments

4.7.1 Pressure Tube-to-Calandria Tube (PT-CT) Contact

PT-CT contact assessments are performed for the reactor core as extensive inspections have demonstrated there has been no movement of tight-fitting spacers from design locations in Darlington. PT-CT contact assessments of Darlington Units have shown no contact prior to the refurbishment dates including 35% margin [14]. The high [Heq] measurements from B3 and B6S13 have no impact on the assessments as the area of concern for PT-CT contact is at the 6 o'clock (bottom of tube).

4.7.2 Deterministic Fracture Protection (DFP)

As part of the Bruce Power findings [3] [4], OPG submitted an engineering evaluation which performed a deterministic fracture protection evaluation for Darlington Units 1 and 4 [2]. Darlington Unit 2 has been operating for a little over one year with new pressure tubes and would not have sufficient enough [Heq] uptake to observe this finding. Although the maximum projected Outlet RJ [Heq] at end of life based on measured values was projected to be 97ppm, base and sensitivity cases with 120ppm and 140ppm, respectively, were assessed. These [Heq] values were bounding of the D1U09 [Heq] axially-shifted profiles performed in [15]. It should be noted that the engineering evaluation concluded there is no basis for postulating the high [Heq] levels observed in B3 and B6 in formal FFS assessments based on OPG's lower measured concentrations and top-to-bottom [Heq] differences which are significantly lower than B6S13.

Darlington Unit 1 and 4 met the required safety factors (SFs) for the heatup/cooldown transients. For Darlington rapid cooldown transient (Level B), the SF is below 1.0. It is recognized that these safety factors are based on the conservative 97.5% lower prediction bound on the fracture toughness that was predicted using the Revision 1 or Revision 2 engineering fracture toughness models. Based on operating experience that a rapid cooldown transient has never occurred in Darlington Units 1 and 4 [16], [17], it was considered more appropriate to treat the rapid cooldown transient as Service Level C. With the exception of the sensitivity case of Darlington with an [Heq] of 140ppm, the safety factors are greater than the required SF of 1.0 for Service Level C. The SF for Darlington with an [Heq] of 140ppm is 0.98, which is slightly lower than the required safety factor. The SFs are considered adequate for the purpose of demonstrating FFS in the engineering evaluation [2].

4.7.3 Probabilistic Fracture Protection (PFP)

As a result of the D1U09 inlet rolled joint high localized [Heq] region, impact assessments were performed for Darlington [15] where axially-shifted [Heq] profiles were used to bound the D1U09 [Heq] measurements. Based on the impact assessment results, the results met the acceptance criteria for the reactor core and single channel conditional probabilities of failure. For Darlington Unit 1, the upper bound (UB) of the mean total condition probability of rupture for Service Levels A, B, C and D for the reactor core were 0.0056, 0.00723, 0.00283, and 0.00022, respectively, compared to the acceptance criteria of 0.01 to an evaluation period of 230,000 equivalent full power hours (EFPH). For Darlington Unit 4, the corresponding results for the reactor core were 0.00118, 0.00222, 0.000372, and 0.00003 for Service Levels A, B, C and D, respectively, to an evaluation period of 235,000 EFPH. For Darlington Unit 1, the single channel conditional probabilities of failure for Service Levels A, B, C and D were 0.0288, 0.0298, 0.0146, 0.0118, respectively, compared to the acceptance criteria of 0.04. For Darlington Unit 4, the corresponding results for the single channel were 0.000733, 0.00277, 0.000341, and 0.00 for Service Levels A, B, C and D, respectively.

Based on [15], the conditional probabilities of rupture for Darlington Units 1 and 4 are below the acceptance criteria of 0.01 for the evaluation of the reactor core and 0.04 for the single channel evaluation.

4.7.4 Probabilistic Core Assessment (PCA)

As was similarly performed for the PFP, an impact assessment was performed on the PCA for Darlington [15] where the axially-shifted [Heq] profile was utilized. Based on the impact assessment results, the PCAs for Darlington Units 1 and 4 remain significantly below the CSA N285.8 acceptance criteria of 0.01. For Darlington Units 1 and 4, the UB of the mean failure frequency is 0.000312 and 0.000164, respectively, to an evaluation period of 235,000 EFPH.

Based on [15], the annual failure frequencies for Darlington Units 1 and 4 are below the CSA N285.8 Table C.1 acceptance criteria of 0.01.

4.7.5 Probabilistic Leak-Before-Break (PLBB)

As was similarly performed for the PFP and PCA, an impact assessment was performed on the PLBB for Darlington [15], [18] where the axially-shifted [Heq] profile was utilized. Based on the impact assessment results, the PLBBs for Darlington Units 1 and 4 remain below the CSA N285.8 acceptance criteria of 0.10. For Darlington Unit 1, the UB of the mean conditional probability of break-before-leak (BBL) is 0.0368 to an evaluation period of 235,000 EFPH. For Darlington Unit 4, the corresponding result is 0.0376 to an evaluation period of 225,000 EFPH.

Based on [15] and [18], the conditional probabilities of BBL for Darlington Units 1 and 4 are below the CSA N285.8 Clause 7.4.3.2 acceptance criteria of 0.10.

5.0 ENHANCEMENTS

5.1 INSPECTION ENHANCEMENTS

As part of incorporating the B3 and B6S13 OPEX, OPG will endeavor to perform future scrapes at Darlington at PT TDC (12 o'clock orientation) where scrape overlap can be avoided. With consideration given to the limitations imposed by previous circumferentially offset scrapes, this measure will ensure condition monitoring is as conservative as possible (per the BP OPEX). This measure is being pursued despite elevated [H]eq similar to that seen in B3 and B6S13 PTs never having been observed in Darlington. In the upcoming D2141 outage planned to start in October 2021, OPG has scheduled RJ and BOT scrape inspections as documented in the Life Cycle Management Plan [6].

OPG will endeavor to accelerate processing of scrapes from the ORJ of Darlington Unit 4 prior to the end of the D2141 outage. As soon as practicable and for information purposes, a summary report highlighting the [Heq] concentration from the outage scrape program will be provided. All D2141 scrape assessment results will be provided to the CNSC in a formal report per the existing CSA N285.4-14 120 day reporting schedule.

5.2 [Heq] MODELLING ENHANCEMENTS

[Heq] modelling enhancements including use of 3D Finite Element Analysis considering fuel channel geometries, local temperatures, location-specific [Heq], and material stress states are being pursued. Note that these proactive enhancements were already in progress prior to the B3 and B6S13 findings. OPG, with industry alignment, intends to submit modelling enhancements for CNSC acceptance once fully validated.

6.0 CONCLUSION

Darlington [Heq] models provide conservative upper bound predictions of [Heq] measured via both in-service scrape and ex-service punch/cut. High [Heq] values inboard of the ORJ BM as reported via the B3 and B6S13 OPEX have not been observed in Darlington Units. OPG has, and will continue to, perform in-service scrape and ex-service material surveillance in excess of CSA N285.4-14 requirements to monitor PT FFS and [H]eq predictive model validity.

Based on the inspected pressure tubes, there are no flaws detected historically in the high [Heq] location of interest. The combination of targeted channels and extent of inspections provides high confidence that there are no flaws in Darlington Units 1 and 4 in this region. Conservative sensitivity assessments have been performed for Darlington Units 1 and 4 and demonstrate that the Units remain within the licensing basis and fit for service.

7.0 REFERENCES

1. CNSC Letter, R. Jammal to S. Gregoris, “Designated Officer Order issued to Ontario Power Generation”, OPG CD# NK38-CORR-00531-22723 (e-Docs 6612869, 6612592), July 26, 2021.

2. OPG Letter, M.R. 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 Item 1-4 Related to Measurement of Hydrogen Concentration in Pressure Tubes”, OPG CD# N-CORR-00531-22801, July 30, 2021.

3. Bruce Power CNSC Event Report, “A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements”, B-2021-93819, July 8, 2021.

4. Bruce Power CNSC Event Report, “Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement”, B-2021-98077, July 5, 2021.

5. 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, CD# N-CORR-00531-22783.

6. R. Wu, "Fuel Channels Life Cycle Management Plan", OPG CD# N-PLAN-01060-10002-R021, September 18, 2020.

7. Memo, M. Micuda to J. Bai, "Update of Recommended Initial Hydrogen Concentrations for Pressure Tubes in Darlington Unit 1 – March 2020", OPG CD# NK38-CORR-31100-0920931, March 9, 2020.

8. Memo, M. Lazaroski to M. Craven, "Update of Recommended Initial Hydrogen Concentrations for Pressure Tubes in Darlington Unit 4 – July 2017", OPG CD# NK38-CORR-31100-0746615, July 26, 2017.

9. D. Broad to J. Lam et al., "Results of Hydrogen Isotope Concentration Analysis from Pressure Tube D3S13", OPG CD# NK38-CORR-31100-0935379, July 16, 2021.

10. D.A. Scarth and L. Gutkin, "Revision 2 of Engineering Fracture Toughness Model Based on Cohesive-Zone Model for Zr-2.5Nb Pressure Tubes", COG-JP-4583-V094, May 2021.

11. L. Popescu, "Assessment of 2021 Darlington Unit 1 Rolled Joint Scrape Sample Measurement Results", OPG CD# NK38-REP-31100-10280, July 13, 2021.

12. C. Nam, "Assessment of 2021 Darlington Unit 1 Pressure Tube Body-of-Tube Hydrogen Isotope Concentration Measurements", NK38-REP-31100-10281, July 13, 2021.

13. OPG letter, S. Gregoris to K. Hazelton, "Darlington NGS – Response to CNSC Staff's Proposed Path Forward for the Probabilistic Core Assessment Flaw Removal Issue", NK38-CORR-00531-22427, March 10, 2021.

14. S. Rice, "Darlington PT/CT Contact Assessment", OPG CD# NK38-REP-31100-10250, October 7, 2019.

15. C. Manu, S. Wang and K. Harrison, "Impact of Pressure Tube D1U09 Inlet Rolled Joint Hydrogen Equivalent Concentration Measurements on Darlington Pressure Tube Fitness for Service Evaluations", OPG CD# NK38-REP-31100-10262, March 25, 2020.

16. M. Craven, "Darlington Unit 1 – Operational Service Level B Transient Cycle Counts For Use In Fuel Channel Fitness For Service Assessments", OPG CD# NK38-CORR-31100-0662833-R01, February 8, 2021.

17. M. Costache, "Darlington Unit 4 – Operational Service Level B Transient Cycle Counts For Use In Fuel Channel Fitness For Service

Assessments", OPG CD# NK38-CORR-31100-0660648-R00, November 21, 2017.

18. C. Manu, "Probabilistic Evaluation of Pressure Tube Leak-Before-Break in Darlington Unit 1 – Extension to 235,000 EFPH", NK38-REP-31100-10275, May 20, 2021.