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Supplementary written submission from Ontario Power Generation

Mémoire supplémentaire 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

ONTARIO POWER GENERATION

September 8, 2021 **OPG PROPRIETARY**

CD# N-CORR-00531-22866

MR. M. LEBLANC
Commission Secretary

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

Dear Mr. Leblanc:

Pickering and Darlington NGS: Submission of Supplemental Information in Response to Designated Officer Orders and to Support Opportunity to be Heard Public Hearing

The purpose of this letter is for OPG to provide supplemental information, in addition to the enclosures provided in Reference 1, to support the Opportunity to be Heard Public Hearing on September 10, 2021.

OPG provided an initial response to the Designated Officer Orders (References 2 and 3) and the Opportunity to be Heard on the Designated Officer Orders (References 4 and 5) on August 8, 2021 (Reference 1).

Enclosure 1 of this letter provides additional analysis, focusing on pressure tube flaws, in light of the recent Bruce Power OPEX. The enclosure demonstrates that Darlington Units 1 and 4 have no flaws in the region of interest related to the Bruce Power OPEX. At Pickering NGS, there are two flaws in Unit 5 in the region of interest. They are due to known operational conditions and corrective actions were implemented in 2015 to prevent recurrence. Furthermore, sensitivity analysis, provided in Enclosure 1, demonstrates that these flaws are fit for service to the end of Pickering Unit 5's commercial operation date even if hydrogen equivalent concentration in the region is greater than 350ppm. Pickering Units 1 and 4 will not operate to 210,000 EFPH (i.e., not "extended operations") and they are not expected to exhibit any hydrogen equivalent concentrations consistent with the Bruce Power OPEX. Despite this, OPG has assessed known flaws in the region of interest in Pickering Units 1 and 4, and Enclosure 1 offers additional assurance of the fitness-for-service of Pickering Unit 1 and 4 pressure tubes.

Enclosure 1 demonstrates that the pressure tubes in OPG's reactors are not susceptible to crack initiation, with a high degree of confidence. The cause of all flaws >0.15mm in depth is known, actions have been implemented to preclude recurrence, and the flaws are shown to be fit for service in accordance with the flaw assessment methodologies even at elevated hydrogen equivalent concentrations. It is demonstrated that the impact of elevated hydrogen equivalent concentration on flaws in the region of interest does not challenge the results of the current core assessments related to pressure tube fitness for service.

The cause of the flaws in the region of interest in OPG’s pressure tubes are known. Inspections have not detected any flaws of random nature in any of the Units’ pressure tubes. OPG will provide by November 30th, 2021 an additional confirmatory assessment documenting that the probability of a random flaw in the region of interest is very low, as indicated in Table 1.

The flaw assessment results provided in Enclosure 1 utilize the current crack initiation model that has been validated experimentally up to 120 ppm. OPG will provide, by October 30, 2021, additional confirmatory evidence that this model has not shown dependence upon bulk hydrogen equivalent concentration in the historical validation work. In addition, OPG will provide, by December 30, 2021, experimental validation of the crack initiation model using concentrations that reflect the Bruce Power operating experience (see Summary Table 1).

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,

Val

Val Bevacqua for Jon Franke

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

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

Encl.

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

References:

1. OPG Letter, S. Gregoris and J. Franke to M. Leblanc, “Pickering and Darlington: OPG Response to Designated Officer Orders and Opportunity to be Heard on Designated Officer Orders”, August 8, 2021, CD# N-CORR-00531-22817.
2. 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.
3. 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
4. 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.
5. 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.

TABLE 1

Summary of Regulatory Actions Undertaken in this Submission

Submission Title: “Pickering and Darlington NGS: Submission of Supplemental Information in Response to Designated Officer Orders and to Support Opportunity to be Heard Public Hearing”

Regulatory Management Action (REGC):

No.	Commitment Description	Target Completion Date
1.	Provide a confirmatory assessment documenting the probability of a random flaw in the region of concern.	November 30, 2021
2.	Provide confirmatory evidence that the current crack initiation model does not shown dependence upon bulk hydrogen equivalent concentration in the historical validation work.	October 30, 2021
3.	Provide experimental validation of the crack initiation model using concentrations that reflect the Bruce Power operating experience.	December 30, 2021

ENCLOSURE 1

OPG MEMORANDUM

Flaw Populations in the Region of Interest to Support Justification of Pickering Units 1, 4, 5, 6, 7, 8 and Darlington Units 1 and 4 Restart

September 8, 2021

N-CORR-31100-0947760

ONTARIO POWER GENERATION

MEMORANDUM

OPG Proprietary

September 8, 2021

File No.: N-CORR-31100-0947760 P

Flaw Populations in the Region of Interest to Support Justification of Pickering Units 1, 4, 5, 6, 7, 8 and Darlington Units 1 and 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 Pickering and Darlington Units with conditions to obtain authorization from the Commission to restart [1], [2].

CNSC technical staff also provided the required assessment criteria for restart of any unit for extended operation following any outage that results in the cooldown of the heat transport system [3], [4]. The region of interest defined by CNSC staff is the first 75mm inboard of the outlet burnish mark and full circumference of the pressure tube. The restart criteria is as follows:

Option (a):

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

Or,

Option (b):

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

The Option (a) and (b) restart criteria are the same for planned or unplanned outages.

More specifically, for Option (b), OPG shall provide a technical justification, which includes a quantitative evaluation, to demonstrate that sufficient volumetric inspections have been completed in the reactor unit to confirm that the risk of a *pressure tube rupture event does not challenge the safety case documented in the applicable station Safety Report.*

The purpose of this memorandum is to provide additional information on the cases of no flaws, and known benign dispositionable flaws in the high [Heq] region of interest based on Bruce Power (BP) OPEX at Darlington Units 1 and 4 and Pickering Units 1, 4, 5, 6, 7 and 8, respectively. The known dispositionable flaws are understood and from operational events. Based on this information, this memorandum supports Pickering and Darlington restart, should the Units be required to cooldown as part of a planned maintenance outage or an unplanned forced outage without the need for any additional inspections to those planned in the Life Cycle Management Plan (LCMP) [5]. The information provided herein supplements justifications of fitness for service (FFS) previously submitted to the CNSC in [6], [7].

2.0 REGION OF INTEREST

2.1 Location of Region of Interest

Based on current understanding and modeling of the BP OPEX, which postulates that flow by-pass at the outlet end of the pressure tube could result in lower temperatures at the top of the tube, it is expected that bulk hydrogen in the vicinity would migrate to the colder location (12 o'clock top dead center), resulting in a localized hydrogen equivalent concentration ([Heq]) accumulation at the top of the tube. This is supported by measurements from the B6S13 and D3S13 (Figures 1 and 2) that demonstrate that the high [Heq] measurements are limited to the top region of the tube. There is no evidence that measurements of a similar magnitude are occurring at the bottom of the tube (6 o'clock position), consistent with the postulated mechanism which is leading to the BP OPEX.

Based on this evidence, OPG therefore considers the top of the tube (120 degrees or 10:00 to 2:00 o'clock positions) and within 75mm of the outlet burnish mark (BM) to be the region of interest.

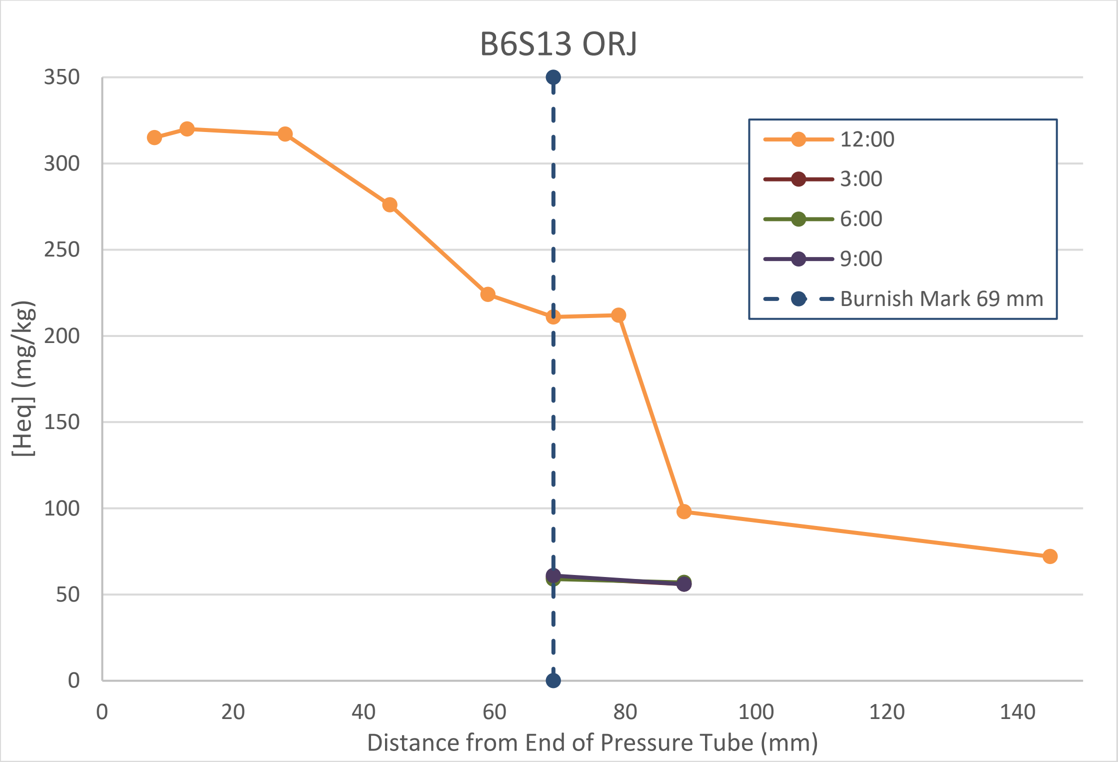

Figure 1: B3S13 Outlet RJ Measurements [8]

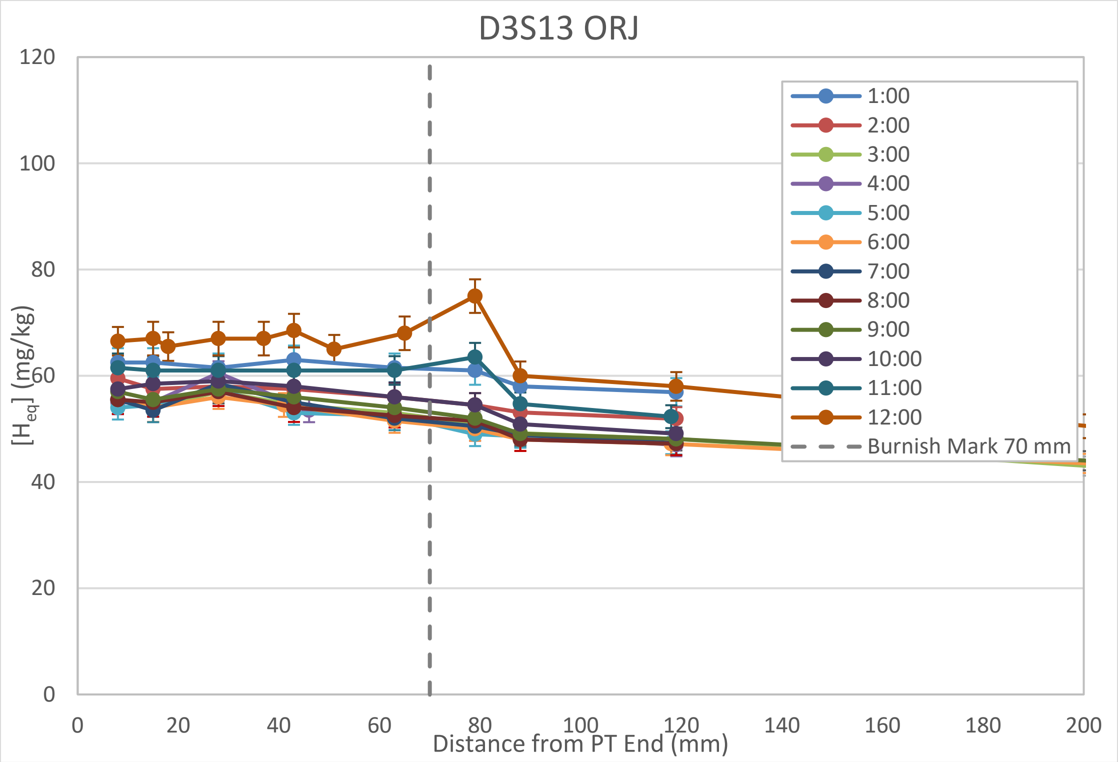

Figure 2: D3S13 Outlet RJ Measurements from All Clock Positions [9]

2.2 Pressure Tube Failure Requirements

In order for a failure of pressure tube to occur, two things are required:

- Sufficiently high hydrogen and;
- A flaw of sufficient stress concentration (sharp features) that hydrides will accumulate and initiate into flaw growth

Based on the benign geometry of cross flow flaws, no crack initiation is predicted. Therefore, even if high [Heq] is found at OPG (which has not been observed with similar magnitude as Bruce Power), these pressure tubes flaws will not initiate and grow to failure.

3.0 SUPPLEMENTAL INFORMATION ON FLAWS IN PICKERING 5 TO 8

3.1 Flaw Population Near the Outlet Burnish Mark

A review of inspected channels was performed to determine the number of dispositionable flaws within 75mm inboard of the outlet BM in Pickering Units 5 to 8. Table 1 provides the information for the flaws found within the region of interest.

Table 1: Pickering Unit 5 to 8 Top of PT Flaws within 75mm of the Outlet Burnish Mark

Pressure Tube, Flaw ID	Outlet BM to Flaw Start (mm)	Outlet BM to Flaw End (mm)	Flaw Depth (mm)	Rotary Start (deg, 0/360 is TDC))	Width (Deg)	Flaw Type and Cause
P5M07-IND1	18.7	46.9	0.2	31.3	4.8	Bearing pad, Cross flow
P5Q05-IND1	18.9	47.0	0.2	326.3	4.5	Bearing pad, Cross flow

Out of 226 unique Pickering 5 to 8 pressure tubes (PTs) that have been subjected to full length volumetric and dimensional (V&D) inspection [10], there are 2 dispositionable flaws located within 75mm of the outlet RJ in the upper half of the PT (2 PTs with 1 flaw each). This confirms that the flaws at the top of the tube are caused by operationally driven events. Procedures are now in place to prevent further flaw creation (more information is provided in Section 3.3).

3.2 Outlet Channel Configuration and Flaws Near the Outlet Burnish Mark

In Pickering 5 to 8, during normal operating conditions, the shield plug holds the fuel string in position in the fuel channel against the forces applied by the flow of the coolant through the channel. Figure 3 shows an overlay of the last fuel bundle at the outlet end with the locations of dispositionable flaws in Pickering Units 5 to 8. The figure demonstrates that the shield plug is situated in the region of interest, thereby preventing flaw formation during normal operating conditions. This is supported by the fact that the majority of flaws correspond to either the fuel bundle bearing pads or the end plate positions in the bottom half of the PT. Therefore, fuel bundles are only in contact with the region of interest during fueling operations as they continuously move throughout the fueling operation and pose no risk of flaw formation during normal operation. Fueling operations are of insufficient duration to result in the creation of dispositionable fretting flaws.

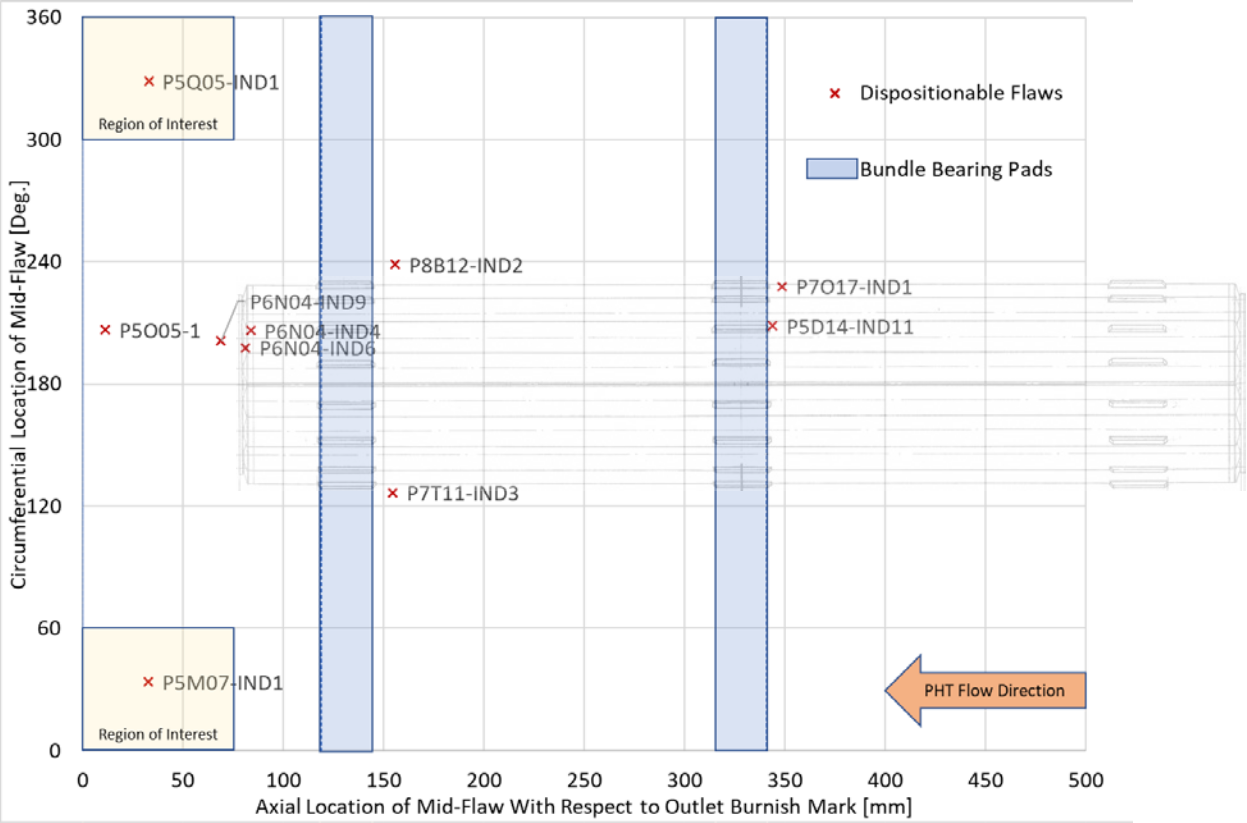

Figure 3: Overlay of Outlet End Fuel Bundle with Dispositionable Flaws in Pickering 5 to 8

3.3 Causes of Flaws Near the Outlet Burnish Mark

During fueling, cross flow conditions occur when a fuel bundle is transitioned through the reactor for fueling and it passes over the flow holes in the liner tube. Damage to the fuel bundle and/or pressure tube can occur if the fuel bundle remains in this position for an extended period of time as the turbulent flow may eventually cause fuel bundle damage. The bundles remain in this position due to fueling machine issues preventing fuel bundle movement through the cross flow region. Fuel bundles in cross flow for extended durations are rare event given the frequency of channel fueling. Fuel bundle damage may cause the bearing pads to fret against the PT. Figure 4 provides a schematic of the position of fuel bundle P49540C during an extended cross flow event, which resulted in P5Q05-IND1 [11].

OPG tracks and records cross flow events in Station Condition Records (SCRs) and station operating logs. A review of SCRs was completed for cross flow events of extended duration which indicates that both dispositionable flaws in P5 in the region of interest were due to cross flow events. The fuel program also reviews fuel bundles that are flagged for inspection to determine if damage has occurred. These fuel bundles are inspected and results are documented.

Based on OPEX from fuel bundle and pressure tube events, OPG implemented operational procedure changes in 2015 that reduced the allowable time for irradiated fuel in cross flow conditions from 48 to 24 hours. Within 24 hours, the bundle must be removed from cross flow conditions or the Unit is required to be shutdown. Additionally, as a result of the cross flow flaws from P1N13 and P5Q05, channels which experienced significant cross flow conditions were added to the V&D channel selection criteria used for each planned maintenance outage.

Table 2 provides a history of cross flow events of extended duration that occurred prior to 2015, the corresponding inspection year and any dispositionable flaws in the region of interest. With the exception of P5E06, OPG has performed V&D inspections on all cross flow events of extended duration which have demonstrated there are either no cross flow flaws or flaws have been dispositioned as acceptable per the methodologies in CSA N285.8 beyond the target operating life. There were no damaged fuel bundles removed from P5E06 following the cross flow event, therefore no flaws are expected in the region of interest of this channel.

V&D inspections on channels that experienced cross flow conditions after the 2015 procedural changes have shown no dispositionable flaws within 75mm of the outlet BM (P7O17 and P4H12 both with 21 hours in cross flow were inspected in 2019 and 2020, respectively). These inspection results provide confidence that the operational changes are adequate for preventing cross flow flaws.

Based on operational procedure changes which ensure no irradiated fuel bundles remain in cross flow conditions beyond 24 hours, recent inspection results that confirm the adequacy of operational changes and the benign flaw profile (discussed in Section 3.4), OPG has high confidence that any cross flow flaws in the region of interest will not initiate cracking or result in PT failure.

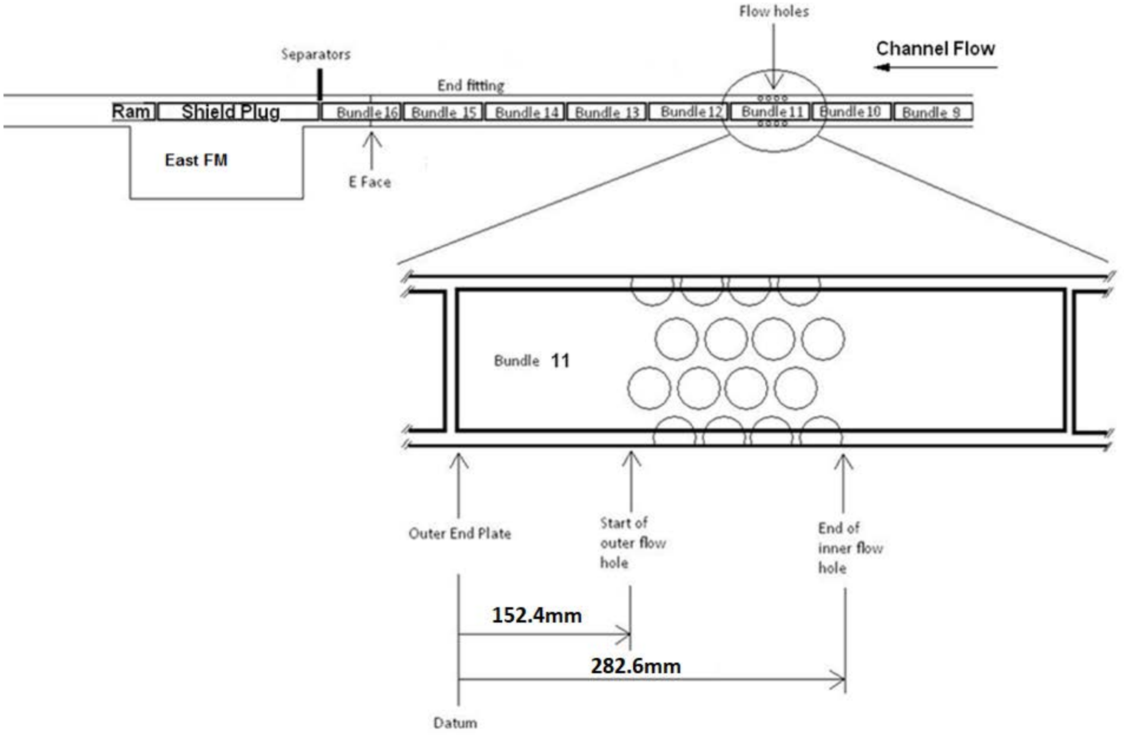

Figure 4: Location of Fuel Bundle from P5Q05 from January 2012 Cross Flow Event [11]

Table 2: History of Cross Flow Events of Extended Duration Prior to 2015 in Pickering 5 to 8

Year	Unit	Channel	Length of Time Fuel in Cross Flow at PT Outlet [hours]	V&D Inspection Year	Dispositionable Flaws in Region of Interest	Fuel Bundle Damage
2013	8	J15	42	2018	None	Yes - Minor
2012	5	Q05	29	2015	P5Q05-IND1	Yes –Endplate Damage
2011	5	M07	24	2017	P5M07-IND1	Yes – Endplate Damage
2009	5	E06	27		N/A	No
2007	8	V08	31	2016	None	No
2006	6	H15	22	2018	None	Yes – Spacer pad wear

3.4 Geometry of Flaws Due to Cross Flow in the Region of Interest

V&D inspection provides information such as flaw length, depth and location. Additional flaw characterization can be obtained through application of a replica compound to establish the flaw size, shape and orientation. Replicas of flaws from cross flow events have demonstrated that these flaws are typical of a bearing pad fret flaw as shown in Figure 5. Bearing pad fret flaws are volumetric flaws created by fretting between the fuel bundle bearing pad and the pressure tube, which results in local removal of material with a relatively large root radii in both the circumferential and axial directions (blunt flaws). These flaws are not an integrity issue (not predicted to initiate) due to the smooth and relatively large root radius which results in a lower stress concentration compared to sharp flaws.

Figure 5: Optical Image of P5Q05-IND1 Flaw Replica [12]

3.5 Risk of Crack Initiation

A deterministic flaw assessment was completed for Enclosure 2 of [6] for the dispositionable flaws within 100mm inboard of the outlet BM applying postulated elevated [Heq] levels of 120ppm (base case) and 140ppm (sensitivity case). A second sensitivity case assessment of the flaws within 75mm inboard of the BM from Table 1 was completed with excess [Heq] levels which bound the B3 and B6 OPEX and demonstrates that these flaws meet the minimum allowable safety factors against fracture initiation and plastic collapse. These flaws were conservatively assessed as planar (crack-like) and demonstrate that the flaws remain fit-for-service to the target operating life, therefore pressure tube failure will not occur. Increasing [Heq] further would have no impact on flaw acceptability. Detailed assessment results are included in Appendix A.

3.6 Flaws in the Bottom Half of the PT Within 75mm of the BM

During operation, debris may become trapped under fuel bundles leading to debris flaws in the bottom half of the PT. Based on the current understanding of the Bruce Power high [Heq] OPEX mechanism, these flaws will not experience high [Heq] values. For information, a sensitivity assessment has been performed for the flaws located within 75mm of the BM in the bottom half of the pressure tube. These flaws have been assessed with excess [Heq] levels which bound the B3 and B6 OPEX and demonstrates that these flaws remain fit-for-service to the target operating life. Increasing [Heq] further would have no impact on flaw acceptability. Detailed assessment results are included in Appendix A.

3.7 Impact on Reactor Core Assessments

As a result of the D1U09 inlet rolled joint high localized [Heq] region, impact assessments for Pickering 8 (lead unit for these assessments) were completed for the probabilistic core assessment (PCA), leak before break (LBB) and deterministic fracture protection assessments (DFP) [13]. Although the high localized [Heq] was only observed at the inlet rolled joint, the impact assessment conservatively increased the [Heq] predictions at both the inlet and outlet rolled joints.

As all PTs with significant cross flow events have been inspected and operational procedures are now in place to prevent further flaw creation, cross flow flaws do not have to be accounted for in the uninspected population. Thus there is no impact on PCA or PLBB results.

There is no impact to fracture protection assessments as a through wall flaw is already postulated.

4.0 SUPPLEMENTAL INFORMATION ON FLAWS IN PICKERING 1 AND 4

4.1 Flaw Population Near the Outlet Burnish Mark

A review of inspected channels was performed to determine the number of dispositionable flaws within 75mm inboard of the outlet BM in Pickering Units 1 and 4. Table 3 provides the information for the flaws found within the region of interest.

Table 3: Pickering Unit 1 and 4 Top of PT Flaws within 75mm of the Outlet Burnish Mark

Pressure Tube, Flaw ID	Outlet BM to Flaw Start (mm)	Outlet BM to Flaw End (mm)	Flaw Depth (mm)	Rotary Start (deg, 0/360 is TDC))	Width (Deg)	Flaw Type and Cause
P1N13-IND33	40.6	51	0.2	335.3	5	Debris, Cross flow
P1N13-IND34	-13.3	16.9	0.55	333.2	6.6	Bearing pad, Cross flow
P4S15-IND6	-4.3	46.9	0.2	358.3	6.0	Mechanical damage

Out of 73 unique Pickering 1 and 4 PTs that have been subjected to a V&D inspection [10], there are 3 dispositionable flaws located within 75mm of the outlet RJ on the upper half of the PT (2 PTs with 2 and 1 flaws in each). This confirms that the flaws at the top of tube are caused by operationally driven events. Procedures are now in place to prevent further flaw creation (more information is provided in Section 4.3).

4.2 Outlet Channel Configuration and Flaws Near the Outlet Burnish Mark

Similar to Pickering 5 to 8, the shield plug in Pickering 1 and 4 holds the fuel string in position in the fuel channel against the forces applied by the flow of the coolant through the channel. Figure 6 shows an overlay of the last fuel bundle at the outlet end with the locations of dispositionable flaws. The shield plug is situated in the region of interest, thereby preventing flaw formation during normal operating conditions. This is supported by the fact that the majority of flaws correspond to either the fuel bundle bearing pad or the end plate positions in the bottom half of the PT. Therefore, fuel bundles are only in contact with the region of interest during fueling operations as they continuously move throughout the fueling operation and pose no risk of flaw formation during normal operation. Fueling operations are of insufficient duration to result in the creation of dispositionable fretting flaws.

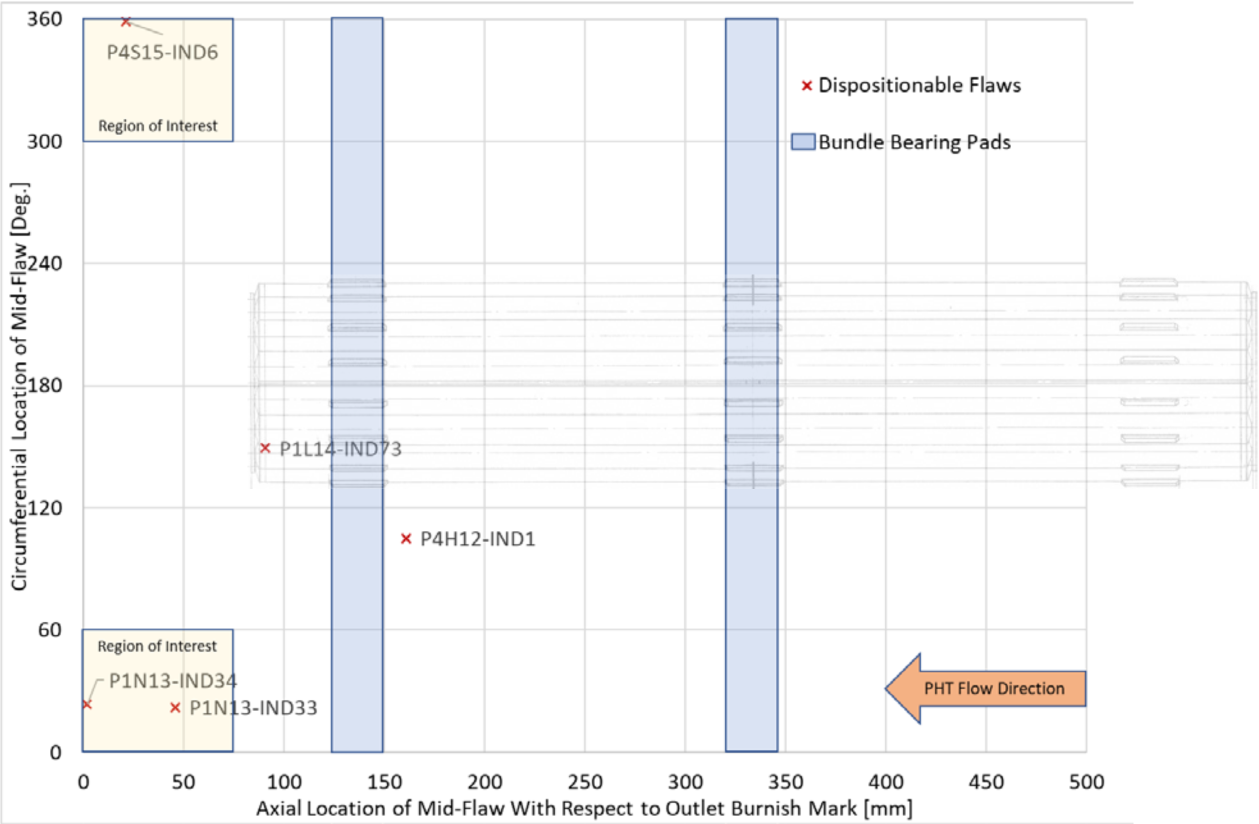

Figure 6: Overlay of Outlet End Fuel Bundle with Dispositionable Flaws in Pickering 1 and 4

4.3 Causes of Flaws Near the Outlet Burnish Mark

Similar to Pickering 5 to 8, cross flow conditions occur when a fuel bundle is transitioned through the reactor for fueling and it passes over the flow holes in the liner tube. Damage to the fuel bundle and/or pressure tube can occur if the fuel bundle remains in this position for an extended period of time.

A review of SCRs was completed for cross flow events of extended duration which indicates that the dispositionable flaws in P1 in the region of interest were due to cross flow events. The fuel program also reviews fuel bundles that are flagged for inspection to determine if damage has occurred. These fuel bundles are inspected and results are documented.

Based on OPEX from fuel bundle and pressure tube events observed, OPG introduced operational procedure changes in 2015 that reduced the allowable time for irradiated fuel in cross flow conditions from 48 to 24 hours. At which point, the bundle must be removed from cross flow conditions within 24 hours or the Unit is required to be shutdown. Additionally, as a result of the cross flow flaws from P1N13 and P5Q05, channels which experience significant cross flow conditions were added to the V&D channel selection criteria used for each planned maintenance outage.

Table 4 provides a history of cross flow events of extended duration that occurred prior to 2015, the corresponding inspection year and any dispositionable flaws in the region of interest. OPG has performed V&D inspections on the longest cross flow event at Pickering 1 and 4 and demonstrated that all flaws are acceptable per the methodologies in CSA N285.8 beyond the target operating life.

V&D inspections on channels that experience cross flow conditions after the 2015 procedural changes have shown no dispositionable flaws in the region of interest (P7O17 and P4H12 both with 21 hours in cross flow were inspected in 2019 and 2020 respectively). These inspection results provide confidence that the operational changes are adequate for preventing cross flow flaws.

Based on operational procedure changes which ensure no irradiated fuel bundles remain in cross flow conditions beyond 24 hours, recent inspection results that confirm the adequacy of operational changes and the benign flaw profile (discussed in Section 4.4), OPG has high confidence that any cross flow flaws in the region of interest will not initiate and result in PT failure.

For P4S15-IND6, this flaw was detected after a Fueling Machine interaction that occurred during the P2041 outage (mechanical damage flaw was also observed on the bottom of the tube which was attributed to the Fueling Machine event). This is considered a unique one-time event and corrective actions have been implemented.

Table 4: History of Cross Flow Events of Extended Duration Prior to 2015 in Pickering 1 and 4

Year	**Unit**	**Channel**	**Length of Time Fuel in Cross Flow at PT Outlet [hours]**	**V&D Inspection Year**	**Dispositionable Flaws in Region of Interest**	**Fuel Bundle Damage**
2014	4	B11	27		N/A	No
2014	1	N13	45	2015	P1N13-IND33, P1N13-IND34	Yes – Endplate Damage
2008	4	O18	22		N/A	No

4.4 Geometry of Flaws in the Region of Interest

Replicas of the cross flow flaw in P1N13-IND34 has been shown to be typical of a bearing pad flaw, as shown in Figure 7. These flaws are not an integrity issue due to the smooth and relatively large root radius which results in a lower stress concentration compared to sharp flaws. Based on the location of flaw P1N13-IND33 (same circumferential location as IND34), IND33 is expected to be also due to the same cross flow event.

Due to the proximity of P4S15-IND6 to P4S15-IND5, the two flaws were combined and assessed using bounding dimensions. Based on review of the cross-section of the replica, a flat bottom bearing pad fret was utilized to represent the flaw while accounting for residual stresses for mechanical damage flaws [15]. The flaw is blunt with a relatively large root radius of 0.113mm and a depth of 0.2mm (which is slightly larger than the dispositionable limit of 0.15mm) [16].

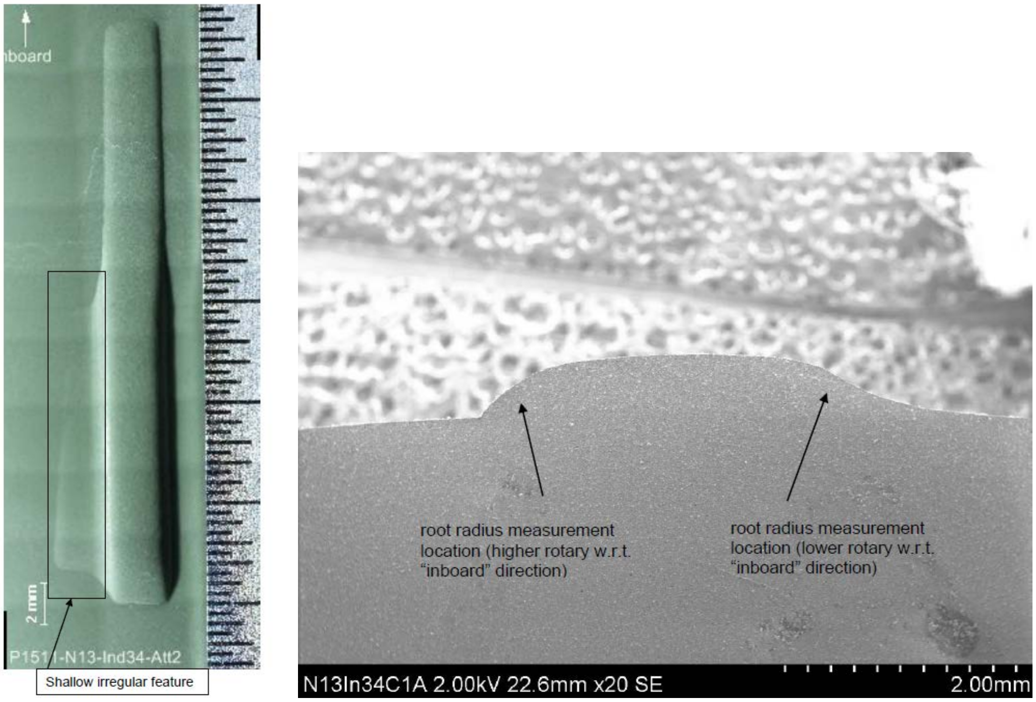

Figure 7: Optical Image of P1N13-IND34 Flaw Replica and Example of Sectioning Cut [14]

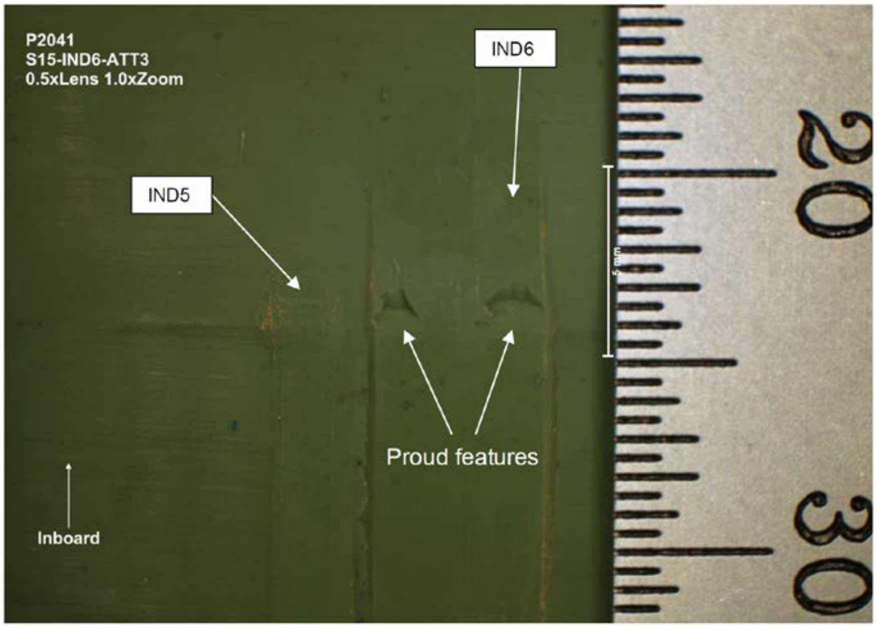

Figure 8: Optical Image of P4S15-IND5 and P4S15-IND6 Flaw Replica [16]

4.5 Risk of Crack Initiation

The engineering evaluation (Enclosure 2 of [6]) completed a deterministic flaw assessment on the dispositionable flaws within 100mm inboard of the outlet BM applying postulated elevated [Heq] levels of 80ppm (base case) and 100ppm (sensitivity case). A second sensitivity case assessment of the cross flow flaws within 75mm inboard of the BM from Table 3 was completed with excess [Heq] levels which bound the B3 and B6 OPEX and demonstrates that the flaws remain fit-for-service to the target operating life, therefore pressure tube failure will not occur. Increasing [Heq] further would have no impact on flaw acceptability. Detailed assessment results are included in Appendix A.

As Pickering Unit 1 and 4 target end of life of the Units is not in extended operation (greater than 210,000 EFPH), and due to low [Heq] levels in the pressure tubes, Pickering Units 1 and 4 flaws do not pose any fitness-for-service concerns based on the Bruce Power high [Heq] OPEX.

4.6 Flaws in the Bottom Half of the PT Within 75mm of the BM

During operation debris may become trapped under fuel bundles leading to debris flaws in the bottom half of the PT. Based on the current understanding of the Bruce Power high [Heq] OPEX mechanism, these flaws will not experience high [Heq] values. Based on the review of inspected channels, there are no flaws in the bottom half of the PT within 75mm inboard of the outlet burnish mark at Pickering Units 1 or 4.

4.7 Impact on Reactor Core Assessments

As a result of the D1U09 inlet rolled joint high localized [Heq] region, an impact evaluation for Pickering 1 (lead unit for these assessments) was completed for the probabilistic core assessment (PCA), leak before break (LBB) and deterministic fracture protection assessments (DFP) [13]. Although the high localized [Heq] was only observed at the inlet rolled joint, the impact assessment conservatively increased the [Heq] predictions at both the inlet and outlet rolled joints.

As all PTs with significant cross flow events have been inspected and operational procedures are now in place to prevent further flaw creation, cross flow flaws do not have to be accounted for in the uninspected population. Thus there is no impact on PCA or PLBB results.

There is no impact to fracture protection assessments as a through wall flaw is already postulated.

As Pickering Unit 1 and 4 target end of life of the Units is not in extended operation (greater than 210,000 EFPH), and due to low [Heq] levels in the pressure tubes, Pickering Units 1 and 4 reactor core assessments are not impacted by the high [Heq] Bruce Power OPEX.

5.0 SUPPLEMENTAL INFORMATION ON FLAWS IN DARLINGTON

5.1 Flaw Population Near the Outlet Burnish Mark

A review of inspected channels was performed to determine the number of dispositionable flaws 75mm inboard of the outlet burnish mark. Out of 131 unique inspected channels [17] in Darlington Units 1 and 4, there are no dispositionable flaws located within 75mm of the outlet RJ on the upper half of the PT. No flaws can mechanistically be formed in this axial region during operation (see Section 5.2), thus providing confidence that there are no dispositionable flaws in the region of interest from the BP OPEX.

5.2 Outlet Channel Configuration and Flaws Near the Outlet Burnish Mark

In Darlington the shield plug is situated outboard of the region of interest and the fuel bundle therefore straddles the region of interest. Figure 9 shows an overlay of the last fuel bundle at the outlet end with the locations of dispositionable flaws. The fuel bundles are positioned in the channel to ensure that the fuel bundle bearing pads are not located in the region of interest, thereby preventing flaw formation during normal operating conditions. This is supported by the fact that all dispositionable flaws near the outlet correspond to the fuel bundle bearing pad positions.

During fueling at Darlington Units 1 and 4, an irradiated fuel carrier is used to remove the fuel from the fuel channel. This fuel carrier supports the fuel as it moves through cross flow conditions which prevents fuel bundle damage and therefore pressure tube fretting.

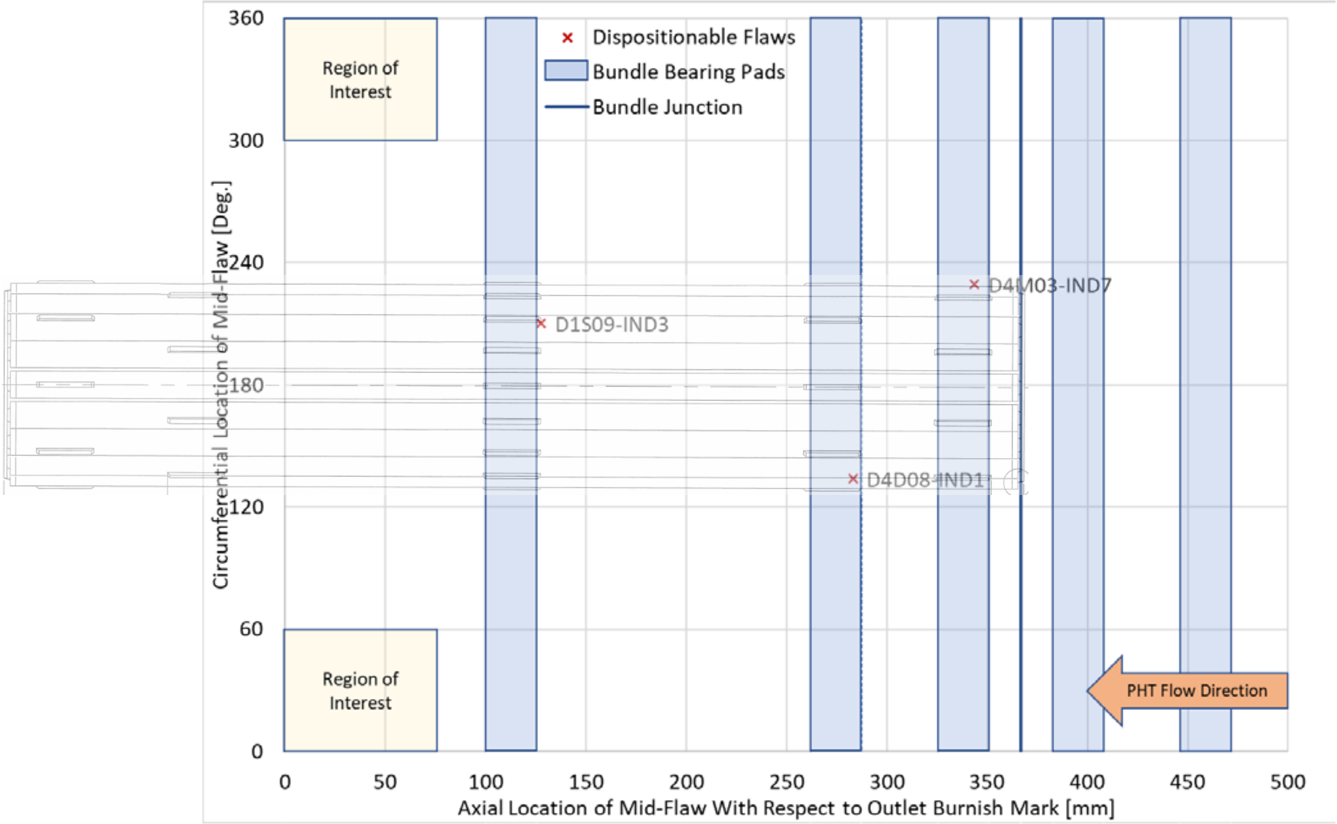

Figure 9: Overlay of Outlet End Fuel Bundle with Dispositionable Flaws in Darlington 1 and 4

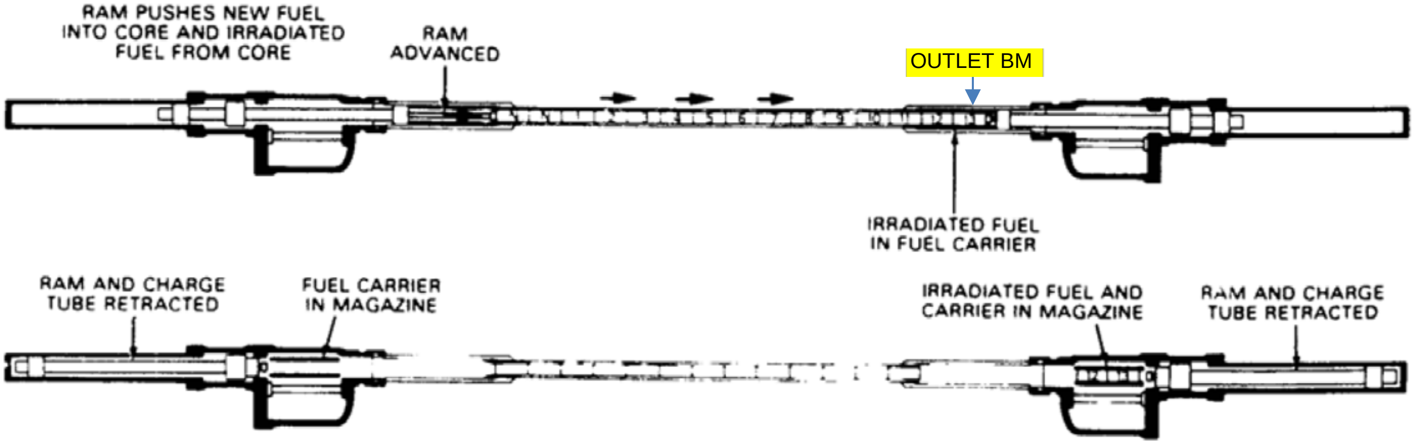

Figure 10: Fuel Carrier at Darlington

5.3 Flaws in the Bottom Half of the PT Within 75mm of the BM

During operation debris may become trapped under fuel bundles leading to debris flaws in the bottom half of the PT. Based on the current understanding of the Bruce Power high [Heq] OPEX mechanism, these flaws will not experience high [Heq] values. Based on the review of inspected channels, there are no flaws in the bottom half of the PT within 75mm inboard of the outlet burnish mark at Darlington Units 1 or 4.

5.4 Impact on Reactor Core Assessments

As a result of the D1U09 inlet rolled joint high localized [Heq] region, impact assessments for Darlington Units 1 and 4 were completed for the probabilistic core assessment (PCA), leak before break (LBB) and deterministic fracture protection assessments (DFP) [18], [19]. Although the high localized [Heq] was only observed at the inlet rolled joint, the impact assessment increased the [Heq] predications at both the inlet and outlet rolled joints.

As there are no flaws in the region of interest, there is no impact to the core assessments.

6.0 CONCLUSION

Based on the current understanding and modeling of the Bruce Power OPEX and the measurements obtained from removed pressure tubes, there is no evidence of increased [Heq] at the bottom outlet rolled joint of any pressure tube. OPG therefore considers the top of the tube and within 75mm of the outlet burnish mark to be the region of interest.

A review of the Pickering Units 5-8 dispositionable flaws in the region of interest shows there are two flaws that were as a result of fuel bundles in cross flow. Cross flow flaws are operationally created and are not an integrity concern due to the smooth nature of the flaws and relatively large root radius which results in a lower stress concentration compared to sharp flaws. Sensitivity assessment of the known flaws demonstrates that these flaws are fit-for-service with increased [Heq]. As well, operational procedures are now in place to preclude the creation of any more bearing pad fret flaws during cross flow events. Cross flow flaws do not have to be accounted for in the uninspected population as all significant cross flow events have been inspected.

A review of the Pickering Units 1 and 4 dispositionable flaws in the region of interest show that they were as a result of fuel bundles in cross flow or were operationally created. Cross flow flaws are operationally created and are not an integrity concern due to the smooth nature of the flaws and relatively large root radius which results in a lower stress concentration compared to sharp flaws. Sensitivity assessment of the known cross flow flaws demonstrates that these flaws are fit-for-service with increased [Heq]. Operational procedures are now in place to prevent the creation of further flaws during cross flow events. Pickering Units 1 and 4 will be shutdown prior to extended operation and therefore is not impacted by the Bruce Power high [Heq] OPEX.

No dispositionable flaws are located in the region of interest in Darlington. Cross flow events which may cause flaws at the top of the pressure tube at the Pickering Units do not occur at Darlington due to the fuel carrier. There is no impact to core assessments.

Based on the information presented, flaws which are greater than 0.15mm in depth remain fit-for-service in light of the Bruce Power high [Heq] OPEX. This memorandum supports the CNSC restart criteria and therefore supports Pickering and Darlington 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 LCMP scheduled inspection scope.

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] 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.

[3] CNSC Letter, A. Viktorov to J. Franke, “Pickering NGS - CNSC Staff Assessment Criteria for Restart Requirements”, OPG CD# P-CORR-00531-22720 (e-Doc 6621914), August 12, 2021.

[4] CNSC Letter, A. Viktorov to S. Gregoris, “Darlington NGS, Units 1 and 4 - CNSC Staff Assessment Criteria for Restart Requirements”, OPG CD# NK38-CORR-00531-22738 (e-Doc 6621921), August 12, 2021.

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

[6] 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.

[7] OPG Letter, S. Gregoris and J. Franke to M. Leblanc, “Pickering and Darlington: OPG Response to Designated Officer Orders and Opportunity to be Heard on Designated Officer Orders”, OPG CD# N-CORR-00531-22817, August 6, 2021.

[8] I. Muir to L. Micuda, “Early Observations from the Outlet End Rolled Joint Region of Tube B6S13”, CNL File 153-31113-401-000, July 9, 2021.

[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] 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] OPG Memo, J. Denis, “Correlation Correlation of Bearing Pad Fret Observed in Channel P5Q05 During P1551 with Bundle Location During 2012 Crossflow Event”, OPG CD# NK30-CORR-31100-0538952, April 07, 2015.

[12] M.H. Jorgensen, “Assessment of Pickering Unit 5 Pressure Tube Flaws Following 2015 Outage Inspection”, OPG CD# NK30-REP-31100-10147, April 7, 2015.

[13] 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.

[14] S. Motomura, “Pickering Unit 1 Replica Evaluation Report 2015”, OPG CD# NA44-REP-31100-00073, September 17, 2015.

[15] L. Coltatu and C. Manu, “Pickering Unit 4 – Assessment Of Pressure Tube Flaws Detected in 2020 (P2041) Inspection and Re-assessment of Previously Detected Flaws”, OPG CD# NA44-REP-31100-00131, December 6, 2020.

[16] A. Sze, “Pickering Unit 4 Replica Evaluation Report 2020”, OPG CD# NA44-REP-31100-00134, May 7, 2021.

[17] 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.

[18] 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

[19] C. Manu, “Probabilistic Evaluation of Pressure Tube Leak-Before-Break in Darlington Unit 1 – Extension to 235,000 EFPH”, OPG CD# NK38-REP-31100-10275, May 20, 2021

Prepared by:	Jessica Lam 8-SEP-2021 Jessica Lam Senior Technical Expert MCED-Fuel Channels	Verified by:	Sept 8, 2021 P. Le Dreff-Kerwin Technical Engineer MCED-Fuel Channels

Approved by:

Sept 8 2021
T. Carneiro
Manager
MCED-Fuel Channels

Appendix A: Increased [Heq] Flaw Impact Assessment

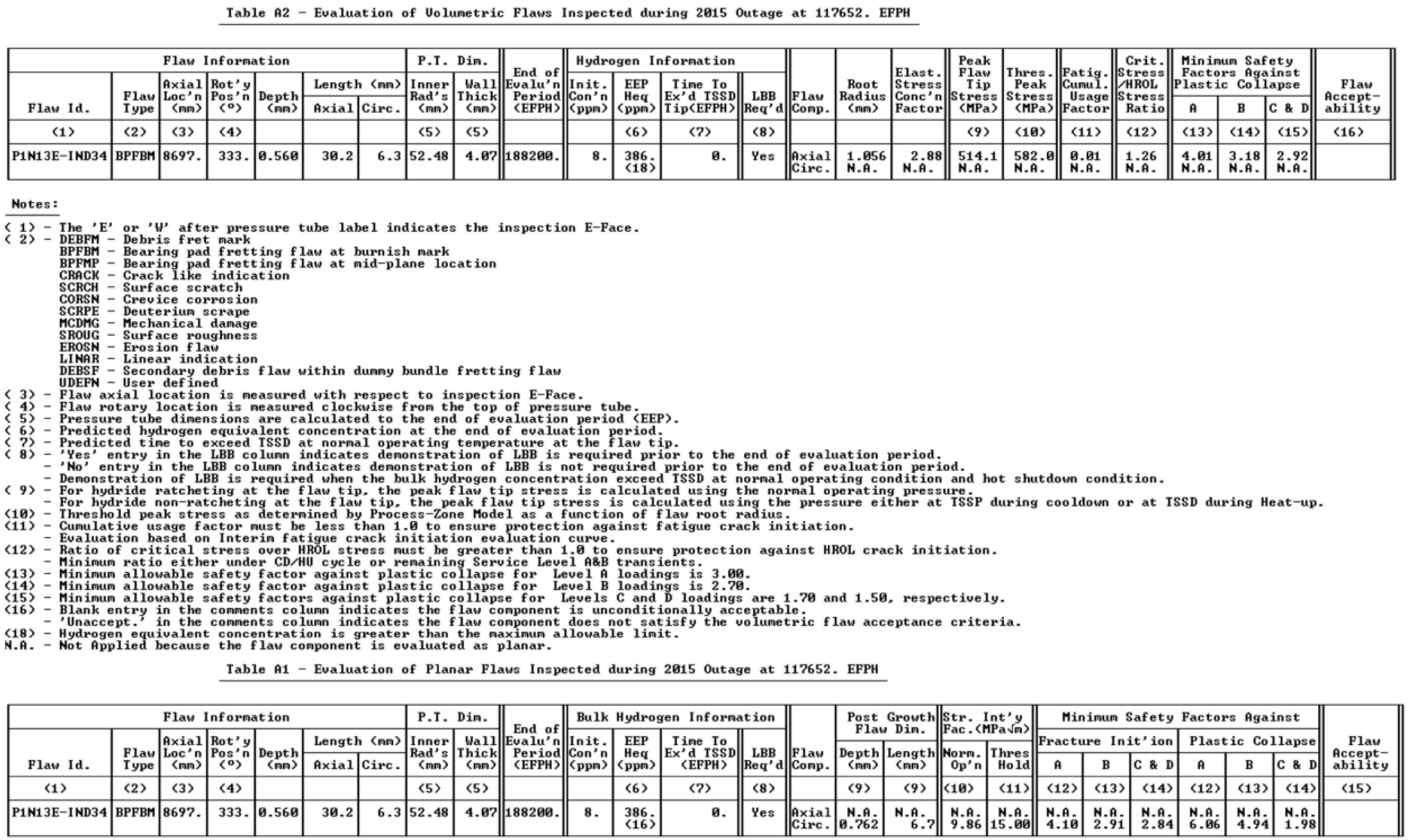

Table A2 - Evaluation of Volumetric Flaws Inspected during 2015 Outage at 117652. EFPH

Flaw Information							P.T. Dim.		End of Evalu'n Period (EFPH)	Hydrogen Information				Flaw Comp.	Root Radius (mm)	Elast. Stress Conc'n Factor	Peak Flaw Tip Stress (MPa)	Thres. Peak Stress (MPa)	Fatig. Cumul. Usage Factor	Crit. Stress /HROL Stress Ratio	Minimum Safety Factors Against Plastic Collapse			Flaw Accept-ability
Flaw Id.	Flaw Type	Axial Loc'n (mm)	Rot'y Pos'n (°)	Depth (mm)	Length (mm) Axial	Length (mm) Circ.	Inner Rad's (mm)	Wall Thick (mm)		Init. Con'n (ppm)	EEP Heq (ppm)	Time To Ex'd TSSD Tip(EFPH)	LBB Req'd								A	B	C & D	
(1)	(2)	(3)	(4)				(5)	(5)			(6)	(7)	(8)				(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
P1N13E-IND34	BPFBM	8697.	333.	0.560	30.2	6.3	52.48	4.07	188200.	8.	386. (18)	0.	Yes	Axial Circ.	1.056 N.A.	2.88 N.A.	514.1 N.A.	582.0 N.A.	0.01 N.A.	1.26 N.A.	4.01 N.A.	3.18 N.A.	2.92 N.A.	

Notes:

(1) - The 'E' or 'W' after pressure tube label indicates the inspection E-Face.
(2) - DEBFM - Debris fret mark
BPFBM - Bearing pad fretting flaw at burnish mark
BPFMP - Bearing pad fretting flaw at mid-plane location
CRACK - Crack like indication
SCRCH - Surface scratch
CORSN - Crevice corrosion
SCRPE - Deuterium scrape
MCDMG - Mechanical damage
SROUG - Surface roughness
EROSN - Erosion flaw
LINAR - Linear indication
DEBSF - Secondary debris flaw within dummy bundle fretting flaw
UDEFN - User defined
(3) - Flaw axial location is measured with respect to inspection E-Face.
(4) - Flaw rotary location is measured clockwise from the top of pressure tube.
(5) - Pressure tube dimensions are calculated to the end of evaluation period (EEP).
(6) - Predicted hydrogen equivalent concentration at the end of evaluation period.
(7) - Predicted time to exceed TSSD at normal operating temperature at the flaw tip.
(8) - 'Yes' entry in the LBB column indicates demonstration of LBB is required prior to the end of evaluation period.
- 'No' entry in the LBB column indicates demonstration of LBB is not required prior to the end of evaluation period.
- Demonstration of LBB is required when the bulk hydrogen concentration exceed TSSD at normal operating condition and hot shutdown condition.
(9) - For hydride ratcheting at the flaw tip, the peak flaw tip stress is calculated using the normal operating pressure.
- For hydride non-ratcheting at the flaw tip, the peak flaw tip stress is calculated using the pressure either at TSSP during cooldown or at TSSD during Heat-up.
(10) - Threshold peak stress as determined by Process-Zone Model as a function of flaw root radius.
(11) - Cumulative usage factor must be less than 1.0 to ensure protection against fatigue crack initiation.
- Evaluation based on Interim fatigue crack initiation evaluation curve.
(12) - Ratio of critical stress over HROL stress must be greater than 1.0 to ensure protection against HROL crack initiation.
- Minimum ratio either under CD/HU cycle or remaining Service Level A&B transients.
(13) - Minimum allowable safety factor against plastic collapse for Level A loadings is 3.00.
(14) - Minimum allowable safety factor against plastic collapse for Level B loadings is 2.70.
(15) - Minimum allowable safety factors against plastic collapse for Levels C and D loadings are 1.70 and 1.50, respectively.
(16) - Blank entry in the comments column indicates the flaw component is unconditionally acceptable.
- 'Unaccept.' in the comments column indicates the flaw component does not satisfy the volumetric flaw acceptance criteria.
(18) - Hydrogen equivalent concentration is greater than the maximum allowable limit.
N.A. - Not Applied because the flaw component is evaluated as planar.

Table A1 - Evaluation of Planar Flaws Inspected during 2015 Outage at 117652. EFPH

Flaw Information							P.T. Dim.		End of Evalu'n Period (EFPH)	Bulk Hydrogen Information				Flaw Comp.	Post Growth Flaw Dim.		Str. Int'y Fac.(MPa√m)		Minimum Safety Factors Against						Flaw Accept-ability
																			Fracture Init'ion			Plastic Collapse			
Flaw Id.	Flaw Type	Axial Loc'n (mm)	Rot'y Pos'n (°)	Depth (mm)	Length (mm) Axial	Length (mm) Circ.	Inner Rad's (mm)	Wall Thick (mm)		Init. Con'n (ppm)	EEP Heq (ppm)	Time To Ex'd TSSD (EFPH)	LBB Req'd		Depth (mm)	Length (mm)	Norm. Op'n	Thres Hold	A	B	C & D	A	B	C & D	
(1)	(2)	(3)	(4)				(5)	(5)			(6)	(7)	(8)		(9)	(9)	(10)	(11)	(12)	(13)	(14)	(12)	(13)	(14)	(15)
P1N13E-IND34	BPFBM	8697.	333.	0.560	30.2	6.3	52.48	4.07	188200.	8.	386. (16)	0.	Yes	Axial Circ.	N.A. 0.762	N.A. 6.7	N.A. 9.86	N.A. 15.00	N.A. 4.10	N.A. 2.91	N.A. 2.84	N.A. 6.06	N.A. 4.94	N.A. 1.98	

Table B1 – Evaluation of Planar Flaws Inspected during 2015 Outage at 117652. EFPH

Flaw Information							P.T. Dim.		End of Evalu'n Period (EFPH)	Bulk Hydrogen Information					Post Growth Flaw Dim.		Str. Int'y Fac.(MPa√m)		Minimum Safety Factors Against						Flaw Accept-ability
Flaw Id.	Flaw Type	Axial Loc'n (mm)	Rot'y Pos'n (°)	Depth (mm)	Length (mm)		Inner Rad's (mm)	Wall Thick (mm)		Init. Con'n (ppm)	EEP Heq (ppm)	Time To Ex'd TSSD (EFPH)	LBB Req'd	Flaw Comp.	Depth (mm)	Length (mm)	Norm. Op'n	Thres Hold	Fracture Init'ion			Plastic Collapse			
					Axial	Circ.													A	B	C & D	A	B	C & D	
(1)	(2)	(3)	(4)				(5)	(5)			(6)	(7)	(8)		(9)	(9)	(10)	(11)	(12)	(13)	(14)	(12)	(13)	(14)	(15)
P1N13E-IND33	DEBFM	8663.	335.	0.200	10.4	4.5	52.53	4.09	188200.	8.	362. (16)	0.	Yes	Axial Circ.	0.209 0.299	10.4 4.7	3.79 4.51	4.50 15.00	7.97 9.11	6.82 6.24	6.26 5.60	5.13 7.11	4.06 5.79	3.73 2.32	

Table A1 – Evaluation of Planar Flaws Inspected during 2017 Outage at 224091. EFPH

Flaw Information							P.T. Dim.		End of Evalu'n Period (EFPH)	Bulk Hydrogen Information					Post Growth Flaw Dim.		Str. Int'y Fac.(MPa√m)		Minimum Safety Factors Against						Flaw Accept-ability
Flaw Id.	Flaw Type	Axial Loc'n (mm)	Rot'y Pos'n (°)	Depth (mm)	Length (mm)		Inner Rad's (mm)	Wall Thick (mm)		Init. Con'n (ppm)	EEP Heq (ppm)	Time To Ex'd TSSD (EFPH)	LBB Req'd	Flaw Comp.	Depth (mm)	Length (mm)	Norm. Op'n	Thres Hold	Fracture Init'ion			Plastic Collapse			
					Axial	Circ.													A	B	C & D	A	B	C & D	
(1)	(2)	(3)	(4)				(5)	(5)			(6)	(7)	(8)		(9)	(9)	(10)	(11)	(12)	(13)	(14)	(12)	(13)	(14)	(15)
P5M07E-IND1	BPFMP	2462.	31.	0.160	28.2	4.4	52.53	4.02	293600.	4.	367. (16)	0.	Yes	Axial Circ.	0.162 0.162	28.2 4.4	3.98 3.05	4.50 15.00	6.84 10.84	6.84 8.90	6.63 6.93	5.00 6.11	4.54 4.35	4.03 2.21	

Table B1 – Evaluation of Planar Flaws Inspected during 2015 Outage at 209075. EFPH

Flaw Information							P.T. Dim.		End of Evalu'n Period (EFPH)	Bulk Hydrogen Information					Post Growth Flaw Dim.		Str. Int'y Fac.(MPa√m)		Minimum Safety Factors Against						Flaw Accept-ability
Flaw Id.	Flaw Type	Axial Loc'n (mm)	Rot'y Pos'n (°)	Depth (mm)	Length (mm)		Inner Rad's (mm)	Wall Thick (mm)		Init. Con'n (ppm)	EEP Heq (ppm)	Time To Ex'd TSSD (EFPH)	LBB Req'd	Flaw Comp.	Depth (mm)	Length (mm)	Norm. Op'n	Thres Hold	Fracture Init'ion			Plastic Collapse			
					Axial	Circ.													A	B	C & D	A	B	C & D	
(1)	(2)	(3)	(4)				(5)	(5)			(6)	(7)	(8)		(9)	(9)	(10)	(11)	(12)	(13)	(14)	(12)	(13)	(14)	(15)
P5Q05E-IND1	BPFMP	2462.	326.	0.180	27.6	3.6	52.60	4.07	293600.	7.	368. (16)	0.	Yes	Axial Circ.	0.182 0.183	27.6 3.6	3.54 2.56	4.50 15.00	7.69 12.93	7.68 10.20	7.22 7.37	4.94 6.07	4.47 4.32	3.97 2.20	

Table C1 – Evaluation of Planar Flaws Inspected during 1999 Outage at 107967. EFPH

Flaw Information							P.T. Dim.		End of Evalu'n Period (EFPH)	Bulk Hydrogen Information					Post Growth Flaw Dim.		Str. Int'y Fac.(MPa√m)		Minimum Safety Factors Against						Flaw Accept-ability
Flaw Id.	Flaw Type	Axial Loc'n (mm)	Rot'y Pos'n (°)	Depth (mm)	Length (mm)		Inner Rad's (mm)	Wall Thick (mm)		Init. Con'n (ppm)	EEP Heq (ppm)	Time To Ex'd TSSD (EFPH)	LBB Req'd	Flaw Comp.	Depth (mm)	Length (mm)	Norm. Op'n	Thres Hold	Fracture Init'ion			Plastic Collapse			
					Axial	Circ.													A	B	C & D	A	B	C & D	
(1)	(2)	(3)	(4)				(5)	(5)			(6)	(7)	(8)		(9)	(9)	(10)	(11)	(12)	(13)	(14)	(12)	(13)	(14)	(15)
P5O05E-IND1	DEBFM	2447.	206.	0.170	4.6	1.1	54.42	3.96	293600.	10.	373. (16)	0.	Yes	Axial Circ.	0.175 0.175	4.6 1.1	4.30 3.41	4.50 15.00	6.32 9.70	6.31 8.24	6.12 6.91	3.92 5.02	3.53 3.61	3.14 1.88	

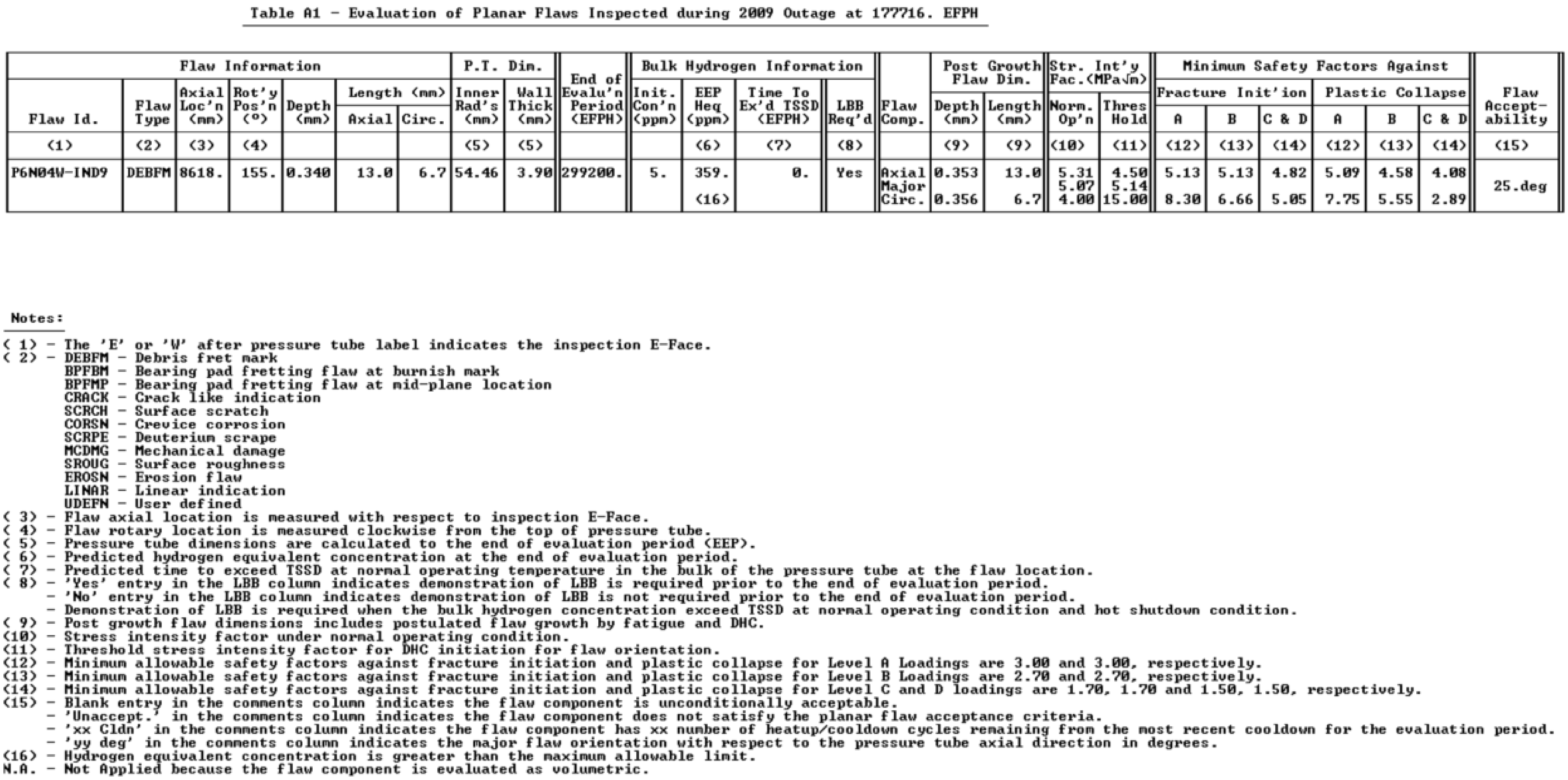

Table A1 – Evaluation of Planar Flaws Inspected during 2009 Outage at 177716. EFPH

Flaw Information							P.T. Dim.		End of Evalu'n Period (EFPH)	Bulk Hydrogen Information				Flaw Comp.	Post Growth Flaw Dim.		Str. Int'y Fac.(MPa√m)		Minimum Safety Factors Against						Flaw Accept-ability
Flaw Id.	Flaw Type	Axial Loc'n (mm)	Rot'y Pos'n (°)	Depth (mm)	Length (mm)		Inner Rad's (mm)	Wall Thick (mm)		Init. Con'n (ppm)	EEP Heq (ppm)	Time To Ex'd TSSD (EFPH)	LBB Req'd		Depth (mm)	Length (mm)	Norm. Op'n	Thres Hold	Fracture Init'ion			Plastic Collapse			
					Axial	Circ.													A	B	C & D	A	B	C & D	
(1)	(2)	(3)	(4)				(5)	(5)			(6)	(7)	(8)		(9)	(9)	(10)	(11)	(12)	(13)	(14)	(12)	(13)	(14)	(15)
P6N04W-IND9	DEBFM	8618.	155.	0.340	13.0	6.7	54.46	3.90	299200.	5.	359.	0.	Yes	Axial	0.353	13.0	5.31	4.50	5.13	5.13	4.82	5.09	4.58	4.08	25.deg
														Major			5.07	5.14							
											(16)			Circ.	0.356	6.7	4.00	15.00	8.30	6.66	5.05	7.75	5.55	2.89	

Notes:

(1) – The 'E' or 'W' after pressure tube label indicates the inspection E-Face.
(2) – DEBFM – Debris fret mark
BPFBM – Bearing pad fretting flaw at burnish mark
BPFMP – Bearing pad fretting flaw at mid-plane location
CRACK – Crack like indication
SCRCH – Surface scratch
CORSN – Crevice corrosion
SCRPE – Deuterium scrape
MCDMG – Mechanical damage
SROUG – Surface roughness
EROSN – Erosion flaw
LINAR – Linear indication
UDEFN – User defined
(3) – Flaw axial location is measured with respect to inspection E-Face.
(4) – Flaw rotary location is measured clockwise from the top of pressure tube.
(5) – Pressure tube dimensions are calculated to the end of evaluation period (EEP).
(6) – Predicted hydrogen equivalent concentration at the end of evaluation period.
(7) – Predicted time to exceed TSSD at normal operating temperature in the bulk of the pressure tube at the flaw location.
(8) – 'Yes' entry in the LBB column indicates demonstration of LBB is required prior to the end of evaluation period.
– 'No' entry in the LBB column indicates demonstration of LBB is not required prior to the end of evaluation period.
– Demonstration of LBB is required when the bulk hydrogen concentration exceed TSSD at normal operating condition and hot shutdown condition.
(9) – Post growth flaw dimensions includes postulated flaw growth by fatigue and DHC.
(10) – Stress intensity factor under normal operating condition.
(11) – Threshold stress intensity factor for DHC initiation for flaw orientation.
(12) – Minimum allowable safety factors against fracture initiation and plastic collapse for Level A Loadings are 3.00 and 3.00, respectively.
(13) – Minimum allowable safety factors against fracture initiation and plastic collapse for Level B Loadings are 2.70 and 2.70, respectively.
(14) – Minimum allowable safety factors against fracture initiation and plastic collapse for Level C and D loadings are 1.70, 1.70 and 1.50, 1.50, respectively.
(15) – Blank entry in the comments column indicates the flaw component is unconditionally acceptable.
– 'Unaccept.' in the comments column indicates the flaw component does not satisfy the planar flaw acceptance criteria.
– 'xx Cldn' in the comments column indicates the flaw component has xx number of heatup/cooldown cycles remaining from the most recent cooldown for the evaluation period.
– 'yy deg' in the comments column indicates the major flaw orientation with respect to the pressure tube axial direction in degrees.
(16) – Hydrogen equivalent concentration is greater than the maximum allowable limit.
N.A. – Not Applied because the flaw component is evaluated as volumetric.