Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

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ORIGINAL/ORIGINAL

CMD: 21-H11

Date signed/Signé le : 3 SEPTEMBER 2021

Review an Order

Réviser un ordre ou une ordonnance

CNSC staff assessment of the requests for restart submitted by Bruce Power and OPG pursuant to Orders issued due to hydrogen equivalent concentration discovery events at Bruce NGS A and B

Évaluation par le personnel de la CCSN des demandes de redémarrage soumises par Bruce Power et OPG conformément aux ordres délivrés en raison d'événements de découverte liés à la concentration d'hydrogène équivalent au centrales de Bruce A et B

Bruce Power and OPG

Bruce NGS A and B

Pickering NGS

Darlington NGS

Bruce Power et OPG

Centrale de Bruce A et B

Centrale de Pickering

Central de Darlington

One-Day Public Hearing

Audience publique d'une journée

Scheduled for:

September 10, 2021

Prévue pour :

10 septembre 2021

Submitted by:

CNSC Staff

Soumise par :

Le personnel de la CCSN

e-Doc 6621093(WORD)
e-Doc 6634528 (PDF)

Canada

Summary

The discovery of elevated hydrogen equivalent concentrations (Heq) at Bruce NGS A and B Units 3 and 6 put into question the predictive capability of the model for the Heq levels in operating reactors with pressure tubes in extended operation. In order to ensure that operating reactors remain in compliance with the licensing basis as established by the Commission, Designated Officer (DO) Orders were issued under paragraph 37(2)(f) and subsection 35(1) of the *Nuclear Safety and Control Act* (NSCA) to Bruce Power and Ontario Power Generation (OPG).

This CMD provides the Commission with:

- CNSC staff assessment criteria used to evaluate the requests for the blanket approval to restart the reactors from planned or unplanned outages impacted by the DO Orders.
- Conclusions and recommendations of CNSC staff's assessments of Bruce Power and OPG's requests for blanket restarts.
- Recommendations for the Commission regarding the Orders. The DO requests the Commission to confirm the Orders for Bruce Power and OPG Darlington, and to amend the Order for OPG Pickering.

Résumé

Bruce Power a signalé à la CCSN des concentrations d'hydrogène équivalent (Heq) élevées. Cette découverte aux tranches 3 et 6 des centrales de Bruce-A et Bruce-B a mis en question la capacité prédictive du modèle pour les niveaux de Heq dans les réacteurs en exploitation avec des tubes de force en exploitation prolongée. Afin de s'assurer que l'exploitation des réacteurs demeurent conformes au fondement d'autorisation établi par la Commission, des ordres ont été délivrés par un fonctionnaire désigné en vertu de l'alinéa 37(2)(f) et de paragraphe 35(1) de la *Loi sur la sûreté et la réglementation nucléaires* à Bruce Power et Ontario Power Generation (OPG).

Ce CMD présente à la Commission :

- Les critères d'évaluation établis par le personnel de la CCSN pour évaluer les demandes d'autorisation générales pour le redémarrage des réacteurs après tout arrêt prévu ou imprévu faisant l'objet des ordres délivrés par le fonctionnaire désigné
- Les conclusions et recommandations de l'évaluation par le personnel de la CCSN des demandes d'autorisation générales de redémarrage de Bruce Power et d'OPG
- Les recommandations à la Commission concernant les ordres. Le fonctionnaire désigné demande que la Commission confirme les ordres délivrés à Bruce Power et OPG pour les centrales de Bruce A et B et Darlington, et modifie l'ordre délivré à OPG pour la centrale de Pickering.

Signed/signé le

3 September 2021

Digitally signed by Viktorov, Alexandre
DN: C=CA, O=GC, OU=CNSC-CCSN, CN="Viktorov, Alexandre"
Reason: I am approving this document
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Date: 2021-09-03 13:31:39
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Alexandre Viktorov, PhD

Director General

Directorate of Power Reactor Regulation

Directeur général

Direction de la réglementation des centrales nucléaires

Jammal, Ramzi

Digitally signed by Jammal, Ramzi
DN: C=CA, O=GC, OU=CNSC-CCSN, CN="Jammal, Ramzi"
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Ramzi Jammal

Designated Officer – Fonctionnaire désigné

Executive Vice-President and Chief Regulatory Operations Officer

Regulatory Operations Branch

Premier vice-président et chef de la réglementation des opérations

Direction générale de la réglementation des opérations

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EXECUTIVE SUMMARY

In accordance with Licence Condition G.1 of Bruce Nuclear Generating Stations (NGS) A and B Power Reactor Operating Licence PROL 18.00/2028 and REGDOC-3.1.1, elevated hydrogen equivalent concentrations (Heq) were reported to the CNSC. This discovery at Bruce NGS A and B Units 3 and 6 respectively put into question the predictive capability of the model for the hydrogen equivalent concentration levels in operating reactors with pressure tubes in extended operation[1][1, 2]. In order to ensure that operating reactors remain in compliance with the licensing basis as established by the Commission, Designated Officer (DO) Orders were issued under paragraph 37(2)(f) and subsection 35(1) of the *Nuclear Safety and Control Act* (NSCA) to Bruce Power and Ontario Power Generation (OPG) on July 26, 2021 [3] and July 27, 2021 [4, 5], respectively. The DO Orders require that each licensee obtain an authorization from the Commission prior to the restart of any operating unit with pressure tubes that are in extended operation, following any outage that results in the cooldown of the heat transport system. Pursuant to subsection 37(6) of the NSCA, the DO referred the Order to the Commission for review.

This CMD provides the Commission with:

1. The assessment criteria developed by CNSC staff in order to evaluate the requests for the blanket approval to restart the reactors from planned or unplanned outages impacted by the DO Orders.
2. The conclusions and recommendations of CNSC staffs' assessments arising from the requests for the restarts as submitted by Bruce Power and OPG.
3. Recommendation for the Commission to confirm the Orders for Bruce Power and OPG Darlington. Recommendation for the Commission to amend the Order for OPG Pickering. In parallel, and by September 30, 2021, CNSC staff will strengthen compliance verification criteria in the Licence Conditions Handbook for each licensee to reflect the conditions of the Orders.

[1] Extended operation of pressure tubes refers to operation beyond 210,000 equivalent full power hours (EFPH).

1. PREAMBLE

In accordance with Licence Condition G.1 of Bruce Nuclear Generating Stations (NGS) A and B Power Reactor Operating Licence PROL 18.00/2028 and REGDOC-3.1.1, elevated hydrogen equivalent concentrations (Heq) were reported to the CNSC. This discovery at Bruce NGS A and B Units 3 and 6 respectively put into question the predictive capability of the model for the hydrogen equivalent concentration levels in operating reactors with pressure tubes in extended operation[2][1, 2]. In order to ensure that operating reactors remain in compliance with the licensing basis as established by the Commission, Designated Officer (DO) Orders were issued under paragraph 37(2)(f) and subsection 35(1) of the *Nuclear Safety and Control Act* (NSCA) to Bruce Power and Ontario Power Generation (OPG) on July 26, 2021 [3] and July 27, 2021 [4, 5], respectively. The DO Orders require that each licensee obtain an authorization from the Commission prior to the restart of any operating unit with pressure tubes that are in extended operation, following any outage that results in the cooldown of the heat transport system. Pursuant to subsection 37(6) of the NSCA, the DO referred the Order to the Commission for review. The DO is requesting confirmation of the orders to Bruce Power and OPG Darlington, and is requesting the Commission to amend the order to OPG Pickering.

2. PURPOSE

The purpose of this document is to provide the Commission with:

2 The assessment criteria developed by CNSC staff in order to evaluate the requests for the blanket approval to restart the reactors from planned or unplanned outages impacted by the DO Orders.
3 The conclusions and recommendations of CNSC staffs' assessments arising from the requests for the restarts as submitted by Bruce Power and OPG.
4 Recommendation for the Commission to confirm the Orders for Bruce Power and OPG Darlington. Recommendation for the Commission to amend the Order for OPG Pickering. In parallel, and by September 30, 2021, CNSC staff will strengthen compliance verification criteria in the Licence Conditions Handbook for each licensee to reflect the conditions of the Orders.

3. BACKGROUND

In early July 2021, Bruce Power made a discovery related to pressure tubes in Bruce NGS Units 3 and 6. Namely, the measured Heq near the outlet burnish mark of some

[2] Extended operation of pressure tubes refers to operation beyond 210,000 equivalent full power hours (EFPH).

pressure tubes exceeded the Power Reactor Operating Licence (PROL 18.01/2028) licence condition 15.3 limit of 120 parts per million by weight (ppm). Bruce Power reported that pressure tube B6S13 has an Heq measurement of 211 ppm at the burnish mark (BM) and 212 ppm at the BM plus 10 mm inboard [6]. The Heq value predicted by the model at the BM was 103 ppm. Bruce NGS A Unit 3 pressure tube inspections are ongoing and confirmed Heq values have not yet been submitted. However, the licensee reported that initial measurements from some pressure tubes in Bruce NGS A Unit 3 indicated the presence of Heq is in excess of 120 ppm near the BM. The approximate area of the pressure tube impacted by the measurements from the perspective of pressure tube fitness for service is illustrated in Figure 1.

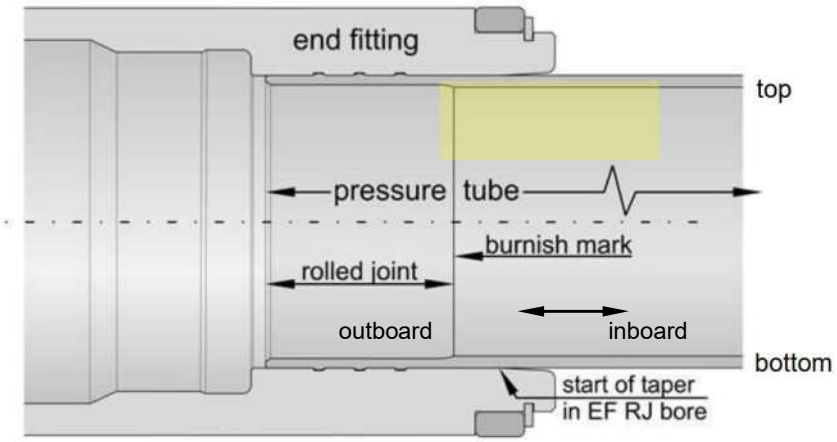

Figure 1 - Pressure tube at end fitting (the yellow shaded region represents the region of elevated Heq)

It is worth noting that the measurements from the Unit 6 pressure tube and the Unit 3 pressure tubes were obtained by different means. The Unit 6 tube was removed from the reactor at the start of the Unit 6 refurbishment outage and sent to a laboratory for testing. Detailed measurements could be obtained from this pressure tube at several axial and circumferential positions to bound the region of elevated Heq. The Heq measurements from the Unit 3 tubes were obtained from scrape samples removed from the inner diameter surface of Unit 3 pressure tubes during the current maintenance outage. Due to pressure tube geometry and tool limitations fewer scrape samples were obtained from these Unit 3 pressure tubes. More specifically, scrapes could not be obtained directly from or close to the burnish mark, which is the region interest for CNSC staff. Data from scrape samples obtained from both sides of the burnish mark were used to interpolate the Heq values at the burnish mark. According to traditional scraping procedures based on industry best practice, the first scrape location inboard of the burnish mark is about 60 to 70 mm away. Due to tooling improvements and the fact that Unit 3 is currently in an outage state, Bruce Power reported that they have obtained scrapes from some pressure tubes slightly closer to the burnish mark. The final results of the Unit 3 scrape campaign have not been fully validated nor have the results been formally submitted by the licensee

to the CNSC. At the time of writing of this CMD, CNSC staff did not review the final results of the Unit 3 scrape campaign.

The fuel bundles are located on the inboard side of the burnish mark during operation and the stresses in the pressure tube are tensile because of the primary heat transport system operating pressure. The pressure tube material on the outboard side of the burnish mark is attached to the end fitting and the stresses in the material are compressive because of the constraint provided by the end fitting. Elevated Heq is only a concern in the tensile region that is between the inlet and outlet burnish marks on the opposite ends of the pressure tube.

From the review of available information, it is important to take into account the following observations:

a. In-service inspections (based on scrape results obtained from pressure tubes in operation) at other Canadian NPPs do not include measurements from axial locations as close to the outlet burnish mark as the recent scrape measurements from the Bruce NGS A Unit 3.
b. Laboratory tests conducted or performed on the pressure tubes removed for surveillance are more refined than in-service scrapes since they can be measured closer to the burnish mark and samples can be obtained from multiple axial and circumferential locations.

These observations were factored into the actions taken by the DO in response to the Bruce Power discovery and as well as into the recommendations provided in this document. CNSC staff are unable to confirm at this time whether there are other pressure tubes that have Heq values in excess of 120 ppm based on observations from past scraping campaigns because those campaigns have not acquired samples from the same locations that were sampled in the Bruce Unit 3 and Unit 6 tubes.

CNSC staff informed the DO that estimation of the fracture toughness of the pressure tubes are called into question for the region of pressure tubes in extended operation near the outlet burnish mark for the following reasons:

1. Uncertainty associated with the model predictability for Heq uptake,
2. The high Heq measurements discovered at Bruce NGS A and B Units 3 and 6 exceed the validity range of the current fracture toughness model,
3. The absence of scrape sample measurements in the same areas in the pressure tubes of the operating units that are being operated beyond 210,000 equivalent full power hours (EFPH).

It is important to note that a single PT failure is assumed to be within a design basis accident for CANDU NPPs and there are safety systems in place to mitigate the consequences of a pressure tube failure.

3.1 Impact on Fitness for Service programs

Not being able to conservatively predict Heq uptakes in the PT is a limitation that CNSC staff determined will impact the Licensees' fitness for service evaluations, which address potential pressure tube failures from flaws that might be introduced through contact with fuel bundles. This was described in CMD 21-M4 [16]. For a crack to initiate in the pressure tube, there need to exist simultaneously a flaw, sufficient stress and the presence of hydrogen. If hydrogen or Heq is less than 120 ppm, the current models can be used to assess a flaw for crack initiation. If a crack initiates and grows through the wall of a PT, then valid knowledge of the Heq is necessary to determine whether the fracture toughness is sufficient to resist pressure tube failure. If the pressure tube fracture toughness at the location of the crack is not adequate, the pressure tube could fail. On the other hand, if fracture toughness is adequate, the crack would lead to a leak that could be detected by the reactor leak detection systems. This would permit the shutdown of the reactor before pressure tube failure.

CNSC staff note that if Heq modelling estimates are not representative of the actual condition, this may lead to an overestimation of the fracture toughness at temperatures below full power operating temperature. The fracture toughness is the ability of the pressure tube material to resist failure if a through-wall crack exists and is a function of Heq levels and material temperature. Laboratory testing has shown that fracture toughness is highest at normal full power operating temperatures and is not impacted by the material Heq uptakes. At temperatures associated with heatup and cooldown, the fracture toughness is lower and depends on the level of Heq. In summary, the inability to accurately predict Heq levels poses a concern primarily during the heatup and cooldown of pressure tubes since possible pressure transients occurring at lower temperatures (i.e., below normal operating temperatures) can challenge the pressure tube structural integrity if there is a crack present.

3.2 Designated Officer Orders

As mentioned above, the current licensing basis limits the Heq to 120 ppm, unless licensees can demonstrate, to the satisfaction of the Commission, that the fracture toughness of the pressure tubes will support the safety case for safe operation beyond 120 ppm. Criteria are included in the licensing bases[3] to define regulatory expectations for

[3] Bruce NGS A and B: PROL 18.01/2028, Licence Conditions 6.1 and 15.3, LCH-PR-18.01/2028-R002, Section 6.1 and 15.3, CSA N285.4-09 Update 2 and CSA N285.8-15 Update 1

this requirement. However, in response to the Bruce Power events and the uncertainty with Heq levels near the outlet burnish mark of pressure tubes in extended operation, the DO Orders to Bruce Power and OPG [3-5] established additional conditions, as described below, to prevent a licensee from restarting a reactor without authorization from the Commission, given the potential non-compliance with the existing licensing basis as established by the Commission. The Orders highlighted that the status quo compliance and verification measures needed to be re-evaluated. Pursuant to NSCA subsection 35(1) and paragraph 37(2)(f), the Orders included measures that the DO considered necessary to ensure compliance with the licensing basis.

The Orders, as written, apply to the following Canadian NPP reactors:

- Bruce NGS Units 3, 4, 5, 7 and 8;
- Pickering NGS Units 1, 4, 5, 6, 7 and 8; and
- Darlington NGS Units 1 and 4

Operating units excluded from the Orders are:

Bruce Power:

- Bruce NGS A Units 1, 2:
  Reason: units were recently refurbished and have not operated long enough to generate elevated levels of Heq in the region of interest.
- Bruce NGS B Unit 6:
  Reason: undergoing refurbishment which consists of full PT replacement.

Ontario Power Generation:

- OPG Darlington Unit 2:
  Reason: was recently refurbished (refurbishment completed on June 4, 2020)
- OPG Darlington Unit 3:
  Reason: in refurbishment outage which consists of full PT replacement.

New Brunswick Power:

- Point Lepreau NGS was recently refurbished and the unit has not operated long enough to generate elevated Heq in the region of interest.

Pickering NGS:	PROL 48.01/2028, Licence Conditions 6.1 and 15.3, LCH-PR-48.00/2028-R004, Section 6.1 and 15.3, CSA N285.4-05 and CSA N285.8-15
Darlington NGS:	PROL 13.02/2025, Licence Condition 6.1, and LCH-PR-13.01/2025-R004, Section 6.1, CSA N285.4-14 and CSA N285.8-15

4. APPROACH FOR DEVELOPMENT OF ASSESSMENT CRITERIA TO SATISFY THE CONDITIONS OF THE DO ORDERS

The Power Reactor Operating Licence requirements state that: "The licensee shall implement and maintain a fitness for service program" (Licence Condition 6.1). This is supplemented by Compliance Verification Criteria (CVC) in the Licence Conditions Handbook (LCH) that includes Canadian Standards Association (CSA) standards N285.4 *Periodic inspection of CANDU nuclear power plant components* and N285.8 *Technical requirements for in-service evaluation of zirconium alloy pressure tubes in CANDU reactors*.

Given the findings of elevated Heq by Bruce Power in Units 3 and 6 and the potential for transients during heatup and cooldown of pressure tubes, CNSC staff requires Bruce Power and OPG's pressure tube fitness for service program to be supplemented with additional quantitative analysis to support the case for restart after an outage.

Based on the review of available information, CNSC staff developed assessment criteria [13-15] to review requests for restart of any reactor arising from a planned or unplanned outage. When establishing the assessment criteria, CNSC staff considered the following:

1. The absence of the root cause of the elevated Heq observed in the Bruce NGS Units 3 and 6 pressure tubes;
    a. It is difficult to identify tubes which would have the highest likelihood of elevated Heq for targeted scraping campaigns;
    b. It is premature to conclude that the region of interest will remain constrained to the localized region defined by Bruce Power[3].
2. The models for crack initiation from flaws and fracture toughness have not been validated for the Heq values in excess of 120 ppm.
3. The location of scrape samples removed from in-service pressure tubes is subject to tooling limitations and physical constraints.
    a. Scrape samples cannot be obtained from the burnish mark location;
    b. The region of elevated Heq may not be symmetrical and may expand axially and circumferentially as Heq continues to accumulate with operation.
4. The scraping process used to obtain samples from in-service tubes produces flaws on the inner diameter surface of the tubes. These flaws cannot be analyzed (with the current models) to confirm that they would not initiate cracks in regions of Heq in excess of 120 ppm, given the constraint in item 2.
5. The region of interest should be defined as the first 75 mm inboard of the outlet burnish mark and the full circumference of the pressure tube.
6. The criteria are independent of outage type (planned or unplanned) since the risk of pressure tube failure would be similar in both scenarios.
7. The criteria are based upon information and scientific evidence currently available to CNSC staff. New information may justify revision of the restart criteria.

In the absence of the root cause for the elevated Heq and until the phenomenon is modelled, CNSC staff have conservatively extended the region of interest to 75 mm axially from the outlet burnish mark, encompassing the full circumference, to evaluate pressure tube fitness for service. This expanded region of interest will encompass the location of the first inboard scrapes taken using the current industry standard practice (nominally 60 to 70 mm from the BM) and will provide a margin for future expansion of the region of elevated Heq should that occur with continued operation.

The Orders and the assessment criteria established in References [13-15] provided the basis for these pressure tube fitness for service program enhancements.

4.1 Assessment Criteria for Order Option (a) [17]

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.

4.1.2 Rationale:

The licensee has to demonstrate that Heq in the region of interest remains below the 120 ppm limit established in the licensing basis. If the licensee is able to demonstrate that the current model conservatively predicts the Heq level, then the current model is acceptable by CNSC staff to be used to estimate pressure tube fracture toughness and carry out fitness for service evaluations. At the time of writing of this CMD, CNSC staff confidence in the Heq model predictions for the region of interest within the pressure tubes in extended operation is currently low and will require knowledge of the mechanism that impacted Bruce NGS A and B Unit 3 and Unit 6 pressure tubes.

Outside of the region of interest, CNSC staff are confident that Heq model predictions are valid for fitness for service evaluations.

4.2 Assessment Criteria for Order Option (b) [17]

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

2. *Corrective actions shall be implemented for tubes containing flaws greater than the specified depth.*

More specifically, in the short term (within 1 month), Bruce Power and OPG shall:

1.a. Provide a methodology to quantify the probability of flaws in the CNSC defined region of interest with elevated Heq; and
1.b. Submit unit specific evaluations to demonstrate that safety analysis assumptions related to the likelihood of pressure tube failures are not invalidated based on the results generated by 1.a.
2. Implement corrective actions for units that do not satisfy 1.a. and 1.b.

In order to remove the 0.15 mm flaw depth restriction, licensees need to perform additional crack initiation testing at elevated Heq (at levels based on Bruce Power observations) to demonstrate that the crack initiation models remain valid for flaw assessments.

4.2.1 Rationale:

CNSC staff consider that the reduction in fracture toughness combined with elevated Heq is not a safety concern if there are no flaws present that would lead to crack initiation. Therefore, if licensees can demonstrate that flaws that would lead to crack initiation are unlikely to exist in the region of elevated Heq (i.e. greater than 120 ppm), the restart of a reactor would remain within the overall safety case for the reactor. For precision on the decision making process, only the Commission can authorize the restart of reactors where the Heq is outside the licensing basis. CNSC staff reiterate the fact that the failure of a single pressure tube is a Design Basis Accident in the Safety Reports and that stations are equipped with safety systems to mitigate the consequences of a failure to add a layer of Defence-in-Depth to this rationale.

The specified allowable flaw depth of 0.15 mm is consistent with CSA standard N285.4-14 Clause 12.2.5.2.2 a) which states that for volumetric inspections, “The following conditions shall be considered acceptable:

a) Relevant indications that are not crack-like and that have a measured radial extent (relative to tube wall thickness) less than 0.15 mm”

Flaws less than 0.15 mm in depth are unlikely to generate stress concentrations that would lead to crack initiation. CSA N285.4-14 provides additional criteria permitting operation with deeper flaws based upon measurements of the axial and circumferential dimensions of the flaw, but this assumes the mechanism for crack initiation is well understood for given flaw dimensions and Heq levels. At this time, CNSC staff cannot recommend restart of a reactor with pressure tubes containing flaws deeper than 0.15 mm in the region of interest because existing crack initiation models have not been verified by testing of pressure tube material with Heq in the range observed in the Bruce NGS Units 3 and 6 pressure tubes. CNSC staff consider any flaw with a depth greater than 0.15 mm, within the region of interest, to be in a state that cannot be accurately analyzed with the currently accepted models.

Once Licensees have submitted their unit specific analyses that will quantify the probability of having a flaw in the region of interest with elevated Heq, then CNSC staff will be in a better position to consider risk arguments and, specifically, time at risk options. However, if such probability is high and invalidates the safety analysis assumptions, Licensees will have to enhance their fitness for service programs by performing additional volumetric inspections. Supplementary volumetric inspections would be performed in accordance with CSA standard N285.4 Clause 12.2 and in the CNSC defined region of interest to support the PT fitness for service case for safe operation beyond the next outage (planned or unplanned).

Licensees have the prime responsibility for safety and are directly responsible for managing regulated activities in a manner that protects health, safety, security and the environment. In line with risk informed decision making and performance based requirements, Bruce Power and OPG can propose an alternative justification for restart. If this information is accepted by CNSC staff, then staff may amend the assessment criteria described herein as new information becomes available.

The LCH is a CNSC tool for setting new requirements (CVC) and expectations (Guidance) arising from new findings or operating experience. CNSC staff will develop and introduce specific assessment criteria as Compliance Verification Criteria in the LCH by September 30, 2021.

5. CNSC STAFF'S REVIEW OF REQUESTS FOR RESTART

In response to the Orders issued to Bruce Power and OPG, the licensees provided requests for authorization to restart reactors in References 8-12. In the following section, this request will be referred to as "blanket" request, to differentiate it from any future or unit-specific requests for restart.

5.1 Review of Licensees' Submissions against Assessment Criteria

CNSC staff reviewed the licensees' requests for a blanket Commission authorization to restart Bruce NGS A and B Units 4, 5, 7 and 8 [8], Bruce NGS A Unit 3 [9], Pickering NGS Units 5-8 [11] and Darlington NGS Units 1 and 4 [12] against the assessment criteria presented in Section 4.0. The results are discussed below.

5.1.1 Option (a) - Heq Predictions

CNSC staff determined that the blanket requests to restart from an outage received from Bruce Power and OPG are based on a number of assumptions that are not supported by sufficient experimental or operational evidence, specifically:

- Licensees propose that these units will not experience elevated Heq near the outlet burnish mark, because the levels have not been observed in measurements from pressure tube scrapes or from samples taken from removed pressure tubes. CNSC staff point out that the same argument would have been made for Bruce NGS Units 3 and 6 pressure tubes prior to the recent measurements in these units. The majority of the data available to support this position was obtained from in-service scrapes that are not as close to the burnish mark as the measurements acquired from the Bruce Unit 3 and Unit 6 pressure tubes.
- The cause of the elevated Heq in the Bruce NGS Units 3 and 6 pressure tubes has not been determined. Without knowing the cause, it cannot be confirmed that previous scrape campaigns and tube removals have focused on tubes that are most likely to experience the same phenomenon.
- There is no evidence to assert that the region of interest of elevated Heq will remain constrained to a small region at the top of the pressure tubes as Heq increases with continued operation.

CNSC staff conclude that that the requests for a blanket authorization for restart [8-12] did not meet the conditions under Option (a) of the order for Bruce NGS A and B Units 4, 5, 7 and 8, Bruce NGS A Unit 3, Pickering NGS Units 5-8 and Darlington NGS Units 1 and 4. In order to demonstrate with a high degree of confidence that pressure tube Heq is within their licensing basis for these units, licensees would need to determine the cause of the elevated Heq in order to assess the resulting impact on crack initiation and fracture toughness [7].

With regard to Pickering NGS A Units 1 and 4 [10], CNSC staff conclude that Option (a) of the Order has been met, since the current pressure tube Heq levels in these units are low and the pressure tubes in these units are not in extended operation. There is substantial operating experience and data available to provide confidence that Heq at the outlet rolled joint will not exceed 120 ppm prior to the planned permanent shutdown of these units.

5.1.2 Option (b) - Presence of Flaws in the Regions of Elevated Heq

OPG and Bruce Power fitness for service cases made in References 8-12 rely on the assumption that flaws that will lead to crack initiation do not exist in the localized region defined by licensees as the top half of the pressure tubes and up to 50 mm from the outlet burnish mark. It should be noted that this localized region is smaller than the region of interest proposed by CNSC staff (i.e., full circumference of the pressure tube and up to 75

mm inboard of the outlet burnish mark). A summary of the licensees' findings is provided in the table below.

Licensee	Units	Summary of licensees' findings
Bruce Power	3, 4, 5, 7 and 8	• no flaws at the top of the pressure tube within 100 mm of the outlet burnish mark • three non-dispositionable flaws (flaws assessed not to crack given known flaw geometry and Heq levels) have been found at the bottom of tubes within 100 mm of the outlet burnish mark • provided qualitative arguments regarding confidence in the risk of dispositionable flaws in the region of interest
OPG – Pickering	5, 6, 7 and 8	• nine dispositionable flaws have been found at the top of the tube within 100 mm of the outlet burnish mark • did not provide information on whether there are any dispositionable flaws found in the bottom of the tubes within 100 mm of the outlet burnish mark
OPG – Darlington	1 and 4	• no flaws have been found at the top of the pressure tube within 100 mm of the outlet burnish mark • did not provide information on whether there are any dispositionable flaws found in the bottom of the tubes within 100 mm of the outlet burnish mark

For their assessments, the licensees have defined dispositionable flaws based on current criteria for pressure tube material with Heq less than 120 ppm. They have not provided confirmation that the same criteria can be applied to pressure tube material with Heq comparable to the values discovered in the Bruce Unit 3 and Unit 6 pressure tubes and have not provided detailed flaw geometry or location information for all of the flaws.

CNSC staff reviewed the submitted information and determined that the requests for a blanket Commission authorization to restart Bruce NGS Units 4, 5, 7 and 8 [8], Bruce NGS A Unit 3 [9], Pickering NGS Units 5-8 [11] and Darlington NGS Units 1 and 4 [12] are based on a qualitative assessment of historical inspection data that is not supported by quantitative risk evaluation. Specifically, the licensees credit the number of volumetric inspections for flaws, but did not actually quantify the likelihood of having a flaw in the region of interest based on the inspection sample size and findings for each unit. If the licensees are to take credit for the extent of volumetric inspections performed, it is CNSC staff's view that a unit-specific quantitative analysis is needed to determine the level of confidence that the assessment criteria can be met (low likelihood of flaws that are deeper than 0.15 mm in the CNSC defined region of interest). As a minimum, Bruce Power and

OPG should provide confirmation that the number of inspected tubes is sufficient to demonstrate that the likelihood of a flaw that would lead to crack initiation in the region of interest is bounded by the constraints established in the Safety Report. The safety case demonstrates that failure of a single pressure tube can be mitigated by safety systems and is based on the assumption that an initiating event comprised of multiple, simultaneous pressure tube failures is not credible.

For these reasons, CNSC staff conclude that the requests for a blanket authorization for restart [8-12] did not meet the conditions under Option (b) of the order for Bruce NGS B Units 4, 5, 7 and 8, Bruce NGS A Unit 3, Pickering NGS Units 5-8, and Darlington NGS Units 1 and 4. The licensees should provide unit specific evaluations to satisfy the restart criteria described in Section 4.

6. CONCLUSIONS

CNSC staff have reviewed the requests for blanket approvals for restart submitted by Bruce Power and OPG [8-12] against assessment criteria developed to assess whether the conditions of the order have been met to ensure compliance with the licensing basis as established by the Commission.

6.1 CNSC staff conclusion for OPG Pickering Units 1 and 4

With regard to Pickering NGS A Units 1 and 4 [10], CNSC staff conclude that Option (a) of the Order has been met, since the current pressure tube Heq levels in these units are relatively low. There is substantial operating experience and data available to provide confidence that Heq at the outlet rolled joint will not exceed 120 ppm prior to the planned permanent shutdown of these units. Pickering NGS A Units 1 and 4 are currently operating within the licensing basis.

Given this conclusion, CNSC staff concludes there should be no need for approval to be sought respecting restart of these units, and recommends amendment of the order issued to OPG respecting Pickering to this effect: see section 7 below.

6.2 CNSC staff conclusion for remaining OPG and Bruce Power units

However, CNSC staff find that Bruce Power and OPG have not provided, in their requests for blanket approvals for restart [8, 9, 11, 12], sufficient quantitative analysis to demonstrate that the conditions of the Orders have been met for other units listed in the Orders:

- Bruce NGS A and B, Units 3, 4, 5, 7 and 8
- Darlington NGS, Units 1 and 4
- Pickering NGS, Units 5, 6, 7 and 8.

Given the observed Heq measurements from Bruce NGS Units 3 and 6, CNSC staff conclude:

1. While there is no confirmed immediate threat to pressure tube safety, risk control measures should be implemented to support continued operation of pressure tubes in extended operation. The findings from the Bruce Unit 3 and Unit 6 pressure tubes have identified a localized region of pressure tubes where current methods of evaluating fitness for service may no longer apply.

2. Since the root cause of the elevated Heq in the Bruce Unit 3 and Unit 6 pressure tubes is unknown, predictions of Heq level in the region of interest for reactors in extended operation is questionable. Given the complexities involved, CNSC staff do not believe it likely that the understanding of the root cause will be available in the short term.

3. Continuing with scraping campaigns for pressure tubes needs to be re-evaluated to confirm pressure tube fitness for service.
    a. Without an understanding of the root cause, it is not possible to identify pressure tubes most at risk of experiencing the same phenomenon.
    b. Current scraping campaigns do not obtain samples close enough to the burnish mark in the region of interest.
    c. Scraping will potentially introduce flaws in regions of elevated Heq that cannot be currently analyzed to determine the likelihood of crack initiation.

4. To mitigate risks associated with reduced fracture toughness associated with elevated Heq, industry should demonstrate, with high confidence, that the potential for flaws (that will lead to crack initiation) to exist in the region of interest is low for pressure tubes in extended operation to support the case for safe operation beyond the next outage (planned or unplanned).
    a. Licensees have provided qualitative arguments suggesting that they have carried out inspections of a sufficient population of pressure tubes in each reactor to determine the potential for the presence of flaws, but should quantify the likelihood of flaws at risk of initiating cracks.
    b. Licensees should demonstrate that the likelihood of a flaw at risk of crack initiation in the region of crack initiation does not invalidate the assumptions of the deterministic safety analysis and probabilistic safety assessment.

5. The region of interest applicable to the evaluations described above should be expanded to 75 mm inboard of the outlet burnish mark and the full circumference of the pressure tubes until evidence is available to confirm that the region of interest is smaller, and will remain so, as Bruce Power has proposed.

As new information is acquired by Industry with respect to the cause of the region of elevated Heq in the Bruce Unit 3 and unit 6 pressure tubes and the material behavior in regions of elevated Heq, the conclusions presented by CNSC staff can be reassessed.

7. RECOMMENDATIONS

Based on the review of information provided by Bruce Power and OPG to date, CNSC staff recommend that the Commission:

7.1 Review of the Orders

7.1.1 Amend the Order to OPG Pickering (for Pickering NGS A Units 1 and 4)

CNSC staff conclude that the current pressure tube Heq levels in these units are relatively low and there is substantial operating experience and data available to provide confidence that Heq at the outlet rolled joint will not exceed 120 ppm prior to permanent shutdown of these units. CNSC staff confirm that there is a high degree of confidence that pressure tube Heq in Pickering NGS A Units 1 and 4 is within OPG's licensing basis and therefore Option (a) of the Order is met. CNSC staff request that the Commission amend the Order for OPG Pickering by removing Pickering Units 1 and 4.

7.1.2 Confirm the Orders to Bruce Power (Bruce NGS A and B) and OPG Darlington

7.2 Bruce Power and OPG Requests for Restart

7.2.1 In light of recommendation 7.1.1 for amendment, if the Commission agrees and amends, there is no need to approve restart of Pickering NGS A Units 1 or 4.

7.2.2 Request that Bruce Power and OPG provide supplemental quantitative analyses to support the requests for blanket approval for restart for Bruce NGS Units 4, 5, 7 and 8, Bruce NGS A Unit 3, Darlington NGS Units 1 and 4, and Pickering NGS Units 5, 6, 7 and 8

CNSC staff have assessed that, for Bruce NGS Units 3, 4, 5, 7 and 8, Darlington NGS Units 1 and 4, and Pickering NGS Units 5, 6, 7 and 8, Bruce Power and OPG have not yet demonstrated with a high degree of confidence that pressure tube Heq concentration are within their licensing basis, nor have the licensees demonstrated with a high degree of

confidence that no flaws are present in the region of interest. CNSC staff recommend that the Commission request that licensees provide additional quantitative analyses (as identified in Section 4.2) to support the case for restart of these units.

8. REFERENCES

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3. CNSC Letter, R. Jammal to M. Burton, "Designated Officer Order issued to Bruce Power", July 26, 2021, e-Doc 6612485.
4. CNSC Letter, R. Jammal to J. Franke, "Designated Officer Order issued to Ontario Power Generation", July 26, 2021, e-Doc 6612802.
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10. OPG Memorandum, "Fitness-for-Service Justification to Support Pickering Unit 1&4 Restart", August 7, 2021, NA44-CORR-31100-0940802, e-Doc 6619651.
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13. CNSC Letter, A. Viktorov to M. Burton, "Bruce A and B: CNSC Staff Assessment Criteria for Restart Requirements", August 12, 2021, e-Doc 6621711.

14. CNSC Letter, A. Viktorov to S. Gregoris, “Darlington NGS, Units 1 and 4 – CNSC Staff Assessment Criteria for Restart Requirements”, August 12, 2021, e-Doc 6621921.

15. CNSC Letter, A. Viktorov to J. Franke, “Pickering NGS – CNSC Staff Assessment Criteria for Restart Requirements”, August 12, 2021, e-Doc 6621914.

16. CNSC Commission Member Document, CMD 21-M4, “Status Update Condition of Pressure Tubes in Operating CANDU Reactors in Canada”, January 21, 2021, e-Doc 6367848.

17. CNSC Memorandum, B. Carroll and V. Tavasoli to A. Robert et al, “Review of Industry Responses to 12(2) Requests and Restart Authorization Requests Arising from the Bruce Unit 3 and Unit 6 Findings of Elevated Hydrogen Equivalent Concentration in Pressure Tubes”, August 20, 2021, e-Doc 6621963.