Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

CMD 21-M37.1

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Written submission from Bruce Power

Mémoire de Bruce Power

Hydrogen Equivalent Concentration in Pressure Tubes for Nuclear Power Plants

Responses of July 19 and 30, 2021 to request pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes

Concentration d'hydrogène équivalent dans les tubes de force pour les centrales nucléaires

Réponses des 19 et 30 juillet 2021 à la demande en vertu du paragraphe 12(2) du *Règlement général sur la sûreté et la réglementation nucléaires* : Enjeux concernant la mesure de la concentration d'hydrogène équivalent dans les tubes de force

Commission Meeting

Réunion de la Commission

September 3, 2021

Le 3 septembre 2021

Canada

CNSC Event Report

Bruce Power Inc., P.O. Box 1540, Tiverton, Ontario N0G 2T0

For preliminary event reports, the information is required as far as practicable and applicable. Each section should be reviewed; use "N/A" if "Not Applicable".

Report No.:	Event Title:
B-2021-98077 DR	Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement

☒ **REGDOC-3.1.1 Report:**

- ☐ Event is *Immediately* Reportable under Table A.1 – 1(b), 2, 5, 7, 11(a), 20, 26, 31, 32, 33 OR based on Safety Significance
- ☐ Event is Reportable within 5 business days under Table A.1 - 17 OR based on Safety Significance
- ☐ Event is Reportable within 7 calendar days under A.1 - 21 (action levels)
- ☒ Event is Reportable within 21 calendar days under Table A.1 – 8, 14(b)

☐ **REGDOC-3.1.1 Notification**

REGDOC-3.1.1 Report Type	Most applicable REGDOC-3.1.1 reporting provision:
☐ **Preliminary Report:** **Report Complete?** ☐ Yes ☐ No, *Detailed Report to follow.*	Table A1 – 14(b)
☒ **Detailed Report – Preliminary Report Reference:** N/A The information in this report supersedes the information provided in the Preliminary Report.	

Facility	Unit(s)	Event Date	Time of Event	Discovery Date	Reportable Date	Time of Discovery	Event Duration
Bruce B	6	February 01, 2021	00:00	June 30, 2021	June 30, 2021	16:40:00	N/A

Affected structures, systems, components:

System Name (USI, SCI or BSI and/or Equipment Code):

31100B – Fuel Channel Assemblies

Pressure Boundary	Design Flow Diagram	Design Pressure	Hydrostatic Test Pressure	Material Type and Code Classification
	N/A	N/A	N/A	N/A

Magnitude, size or quantification of degradation/fault (if applicable):
(e.g., approximate size, length, depth or leak rates, deviation from set point)

N/A

Event Description

Condition of site, prior, during and after event, and operating condition of affected units, including reactor power:

Unit 6 has been shut down for Major Component Replacement (MCR) since January 2020 (B2061 outage)

Description of occurrence, circumstances and consequences of the situation, including any research or analysis that led to awareness of the problem or potential problem, the nature of any non-compliance with a licence condition, and any secondary of coincidental events of regulatory interest:

Hydrogen/Deuterium measurements were obtained from B6S13 pressure tube as planned during the Unit 6 MCR. This tube was selected as part of an industry-supported surveillance program for analysis. Results from the analysis demonstrated elevated hydrogen equivalent concentration (Heq) measurements in the outlet Rolled Joint (RJ) which are above the generic predictions for the locations inboard and outboard of the burnish mark (BM). This is similar to recent observations of scrape results in a limited number of Unit 3 pressure tubes obtained from the A2131 outage scrape campaign, that were reported in REGDOC 3.1.1 Event Report B-2021-93819 on June 30, 2021. The observation is limited in both axial and circumferential extent.

Safety and control functions affected, including a summary of any impairment of a special safety system or safety-related system:

N/A

Cause(s), including a summary of any analysis completed and evaluation of any design, operating and or training deficiencies and conclusions:

Potential causes include:
- circumferential variability in Heq from top of the tube to bottom of the tube.
- the elevated results are extremely limited in both axial and circumferential extent

Code(s), standard(s) or methodology used to assess the significance of the degradation (if applicable):

The Hydrogen Isotope Concentrations (HIC) measurements in B6S13 potentially exceeded the parameters of the fracture toughness model as per CSA N285.8-2015 Update 1, Clause D.13.2.3.1.2 (a), hence, potentially not meeting Clause 4.5.1.3. This is being evaluated in consideration of future assessments and those that have been performed previously to satisfy the requirements of Clauses 7.2 to 7.4.

Extent of condition or any review of comparable situations or events

Bruce Units 4, 5, 7 and 8 are monitored through scrape sampling in recent outages and have not had observations of elevated D-uptake behaviour. Units 4 and 8 were sampled in 2020 and Unit 5 and 7 in 2019.
As Bruce Units 1 and 2 are refurbished Units, the HIC measurements are lower.
Additional surveillance activities analysis and outage inspections are planned to further investigate the Heq observations in these tubes and determine extent of condition.

Measured or estimated doses to plant personnel and public as a consequence of the situation or event:

N/A

Resulting impact on the environment. Include name of the nuclear/hazardous substance, the estimated or measured quantity/rate and manner of release:

N/A

Other municipal, provincial and federal authorities that were notified of the situation or event:

☐ TSSA ☐ MECP ☐ MOL ☐ Environment Canada ☐ Other ( )

Actions and/or remedial actions taken or proposed to be taken to correct or prevent recurrence of event, including, where applicable, actions identified and taken to restore the effectiveness of the radiation or environmental protection programs:
***Note: for immediately reportable events include notification details (CNSC Contact Name, Date and Time)**

- Industry experts from external organizations were contacted for assistance in assessing the outage RJ region results and to support a fitness-for-service evaluation.
- Share the results with the industry.
- Additional Circumferential Wet Scrape Tool (CWEST) and Advanced Non-Destructive Evaluation scope is to continue in the A2131 outage.
- Additional Destructive Evaluation scope has been recommended for the B6 Surveillance Pressure Tubes.
- A Technical Operability Evaluation was initiated for Units 4, 5, 7 and 8.

Designated representative of licensee:

Name: JGoldberg cn=Jason L. Goldberg, o=Bruce Power LP, ou=DM, Reactor Safety Engineering, email=jason.goldberg@brucepower.com, c=CA 2021.07.05 15:39:11 -04'00' **Title:** Department Manager, NSAS **Date:** July 5, 2021

INSTRUCTIONS FOR SUBMISSION

Initiating Line: **i)** Review and email the completed preliminary report form as follows:
For Bruce A facility, email completed report to BA Prelim Reports
For Bruce B facility, email completed report to BB Prelim Reports
For CoS facility, email completed report to CoS Prelim Reports

Duty Manager: **i)** Review and forward to Licensing if report is final or was reported immediately to the CNSC; if report is not final, submit as Designated Licensing Authority (DLA).

DLA: **i)** Review and follow-up as required.
ii) Ensure surface contamination is reported in Bq/cm^2.
iii) PDF and Distribute completed preliminary report to CNSC via email as follows:
to: luc.sigouin2@canada.ca
cc: alexis.gallant@canada.ca; julie.poirier2@canada.ca; Designated Licence Authority; clerical;
plus any other internal distribution as required

CNSC Event Report

Bruce Power Inc., P.O. Box 1540, Tiverton, Ontario N0G 2T0

For preliminary event reports, the information is required as far as practicable and applicable. Each section should be reviewed; use "N/A" if "Not Applicable".

Report No.:	Event Title:
B-2021-93819 DR	A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements

☒ **REGDOC-3.1.1 Report:**

- ☐ Event is *Immediately* Reportable under Table A.1 – 1(b), 2, 5, 7, 11(a), 20, 26, 31, 32, 33 OR based on Safety Significance
- ☐ Event is Reportable within 5 business days under Table A.1 - 17 OR based on Safety Significance
- ☐ Event is Reportable within 7 calendar days under A.1 - 21 (action levels)
- ☒ Event is Reportable within 21 calendar days under Table A.1 – 8, 14(b)

☐ **REGDOC-3.1.1 Notification**

REGDOC-3.1.1 Report Type	Most applicable REGDOC-3.1.1 reporting provision:
☐ **Preliminary Report:** **Report Complete?** ☐ Yes ☐ No, *Detailed Report to follow.*	Table A1 – 14(b)
☒ **Detailed Report – Preliminary Report Reference:** N/A The information in this report supersedes the information provided in the Preliminary Report.	

Facility	Unit(s)	Event Date	Time of Event	Discovery Date	Reportable Date	Time of Discovery	Event Duration
Bruce A	3	May 20, 2021	09:15	June 15, 2021	June 15, 2021	09:20:26	N/A

Affected structures, systems, components:

System Name (USI, SCI or BSI and/or Equipment Code):

31100A – Fuel Channel Assemblies

Pressure Boundary	Design Flow Diagram	Design Pressure	Hydrostatic Test Pressure	Material Type and Code Classification
	N/A	N/A	N/A	N/A

Magnitude, size or quantification of degradation/fault (if applicable):
(e.g., approximate size, length, depth or leak rates, deviation from set point)

N/A

Event Description

Condition of site, prior, during and after event, and operating condition of affected units, including reactor power:

Unit 3 was shut down for a scheduled inspection and maintenance outage since March 2021 (A2131).

Description of occurrence, circumstances and consequences of the situation, including any research or analysis that led to awareness of the problem or potential problem, the nature of any non-compliance with a licence condition, and any secondary of coincidental events of regulatory interest:

Measurements obtained from the A2131 outage Circumferential Wet Scrape Tool (CWEST) scrape campaign showed elevated Hydrogen equivalent concentration (Heq) measurements found near the top of the pressure tube in the outlet Rolled Joint (RJ) region for three channels with front end outlet (FEO) orientation (B3C11, B3F16 and B3L11), which may be above the generic predictions for the locations outboard of the burnish mark. Based on additional scrape scope in A2131, B3F16 has a measured scrape sample inboard of the rolled joint burnish mark that is >120 ppm.

Safety and control functions affected, including a summary of any impairment of a special safety system or safety-related system:

N/A

Cause(s), including a summary of any analysis completed and evaluation of any design, operating and or training deficiencies and conclusions:

Potential causes include:
- FEO orientation vs Back End Outlet (BEO) orientation tubes,
- circumferential variability in Heq from top of the tube to bottom of the tube.

Code(s), standard(s) or methodology used to assess the significance of the degradation (if applicable):

The Hydrogen Isotope Concentrations (HIC) measurements in the first few scraped channels potentially exceed the parameters of the fracture toughness model for the front end as per CSA N285.8-2015 Update 1, Clause D.13.2.3.1.2 (a), hence, potentially not meeting Clause 4.5.1.3 and invalidating the assessments that have been performed previously to satisfy the requirements of Clauses 7.2 to 7.4.

Extent of condition or any review of comparable situations or events

Bruce Unit 3 has a unique FEO installed configuration in half of the core (i.e. 240 channels) unlike Bruce Units 4 to 8 which have BEO installed configuration. Since the 2018 Unit 3 outage (A1831) and continuing into the A2131 outage, scrape samples have been taken at the east face to facilitate collection of scrape data from tubes with FEO orientation.
Bruce Units 1 and 2 have FEO installed configuration; however, as they are refurbished Units, the HIC measurements are lower.
Additional inspection activities and analysis are being carried out to further investigate the Heq observations in these tubes.

Measured or estimated doses to plant personnel and public as a consequence of the situation or event:

N/A

Resulting impact on the environment. Include name of the nuclear/hazardous substance, the estimated or measured quantity/rate and manner of release:

N/A

Other municipal, provincial and federal authorities that were notified of the situation or event:

☐ TSSA ☐ MECP ☐ MOL ☐ Environment Canada ☐ Other ( )

Actions and/or remedial actions taken or proposed to be taken to correct or prevent recurrence of event, including, where applicable, actions identified and taken to restore the effectiveness of the radiation or environmental protection programs:
***Note: for immediately reportable events include notification details (CNSC Contact Name, Date and Time)**

- A review of CWEST and Canadian Nuclear Laboratories scrape processes was undertaken to ensure that no potential sources of error could have impacted these scrape results.
- An independent review of the data by Kinectrics was initiated.
- Industry experts from external organizations have been contacted for assistance in assessing the A2131 outage RJ region scrape results and to support a fitness-for-service.
- Additional CWEST and Advanced Non-Destructive Evaluation scope has been recommended to the A2131 outage.

Designated representative of licensee:

Name: _____ **Title:** Department Manager, NSAS **Date:** 08JUL2021

INSTRUCTIONS FOR SUBMISSION

Initiating Line: **i)** Review and email the completed preliminary report form as follows:
For Bruce A facility, email completed report to BA Prelim Reports
For Bruce B facility, email completed report to BB Prelim Reports
For CoS facility, email completed report to CoS Prelim Reports

Duty Manager: **i)** Review and forward to Licensing if report is final or was reported immediately to the CNSC; if report is not final, submit as Designated Licensing Authority (DLA).

DLA:
i) Review and follow-up as required.
ii) Ensure surface contamination is reported in Bq/cm^2.
iii) PDF and Distribute completed preliminary report to CNSC via email as follows:
to: luc.sigouin2@canada.ca
cc: alexis.gallant@canada.ca; julie.poirier2@canada.ca; Designated Licence Authority; clerical;
plus any other internal distribution as required

July 15, 2021

BP-CORR-00531-01853

Mr. L. Sigouin
Director, Bruce Regulatory Program Division
Canadian Nuclear Safety Commission
P.O. Box 1046
280 Slater Street
Ottawa, Ontario
K1P 5S9

Dear Mr. Sigouin:

Action Item 2021-07-23406:
CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR

The purpose of this letter is to respond to Reference 1 and provide the information requested by CNSC staff in response to their review of Reference 2.

During testing of a surveillance pressure tube removed from Unit 6, the hydrogen equivalent concentration in the outlet rolled joint region measured at 12 o'clock was discovered to be in excess of the generic predictions outboard and inboard of the burnish mark (BM). The position (12 o'clock very close to the BM) at the outlet rolled joint had not been measured as a part of prior scrape campaigns due to limitations inherent to the scrape tooling; however, the high measured concentration is consistent with recent results recorded during the current Unit 3 outage (i.e. a newly observed high degree of circumferential variation). Note that the results are limited to a small area of interest on the upper portion of the fuel channel near the outlet rolled joint.

A summary of the Unit 6 predicted and measured hydrogen equivalent values, requested by CNSC staff in Reference 1, is provided in Attachment A.

In responding to the findings, Bruce Power has maintained a paramount commitment to safety and reverence for the licensing basis by immediately assembling a multi-disciplinary team, in accordance with Reference 3, to examine the findings, while proactively sharing information with CNSC staff and other CANDU operators.

As CNSC staff are aware, the Power Reactor Operating Licence (PROL 18.01/2028) Condition 15.3 requires that:

Licence Condition 15.3:

> **Before hydrogen equivalent concentrations exceed 120 ppm, the licensee shall demonstrate that pressure tube fracture toughness will be sufficient for safe operation beyond 120 ppm.**

Bruce Power Maury Burton, Chief Regulatory Officer
P.O. Box 1540 B10 2nd Floor E, Tiverton ON N0G 2T0
Telephone 519-361-5291
maury.burton@brucepower.com

As presented in the Introduction to the Licence Conditions Handbook (LCH-PR-18.01/2028-R002), "*the general purpose of the Licence Conditions Handbook (LCH) is to identify and clarify the relevant parts of the licensing basis for each licence condition."*

Within the Licence Condition Handbook, Compliance Verification Criteria (CVC) are established within each section to serve, "*as the criteria used by CNSC staff to verify and oversee compliance with* [a licence condition]."

The Compliance Verification Criteria for Section 15.3 establish clear criteria to measure Bruce Power's compliance with Licence Condition 15.3:

Compliance Verification Criteria:

1. For continued operation of units containing pressure tubes with a [H_{eq}] exceeding 120 ppm between the inlet and outlet burnish marks:
   a. Bruce Power shall obtain approval from the Commission before operating any pressure tube with a measured [H_{eq}] greater than 120 ppm, or beyond the time any pressure tube is predicted to have a [H_{eq}] greater than 120 ppm,
      i. Predictions of maximum [H_{eq}] shall be determined utilizing the hydrogen prediction model applied to the unit in the most recent report submitted to the CNSC under CSA N285.4, Clause 12.3.6.2. Revisions to the hydrogen prediction model used in the most recent report shall be accepted by the CNSC.
   b. Bruce Power shall submit annual reports by July 1 of each year indicating when each unit is predicted to reach a maximum [H_{eq}] of 120 ppm.

As applied to Units 1 and 2, which have only been in operation for a limited number of hot hours following refurbishment, pressure tube hydrogen equivalent concentrations remain lower than the other units. As such, the operation of Unit 1 and Unit 2 remains in accordance with the established compliance verification criteria and the licensing basis.

As applied to Units 4, 5, 7, and 8, which are currently operating, as no operating pressure tube has been predicted (Reference 3) or measured to be in excess of 120 ppm, operation remains in accordance with the established compliance verification criteria and the licensing basis. Units 4, 5, 7, and 8 were returned to service following planned maintenance outages in accordance with the processes required by Licence Condition 6.1 and Section 6.1 of the Licence Conditions Handbook, and as supported by fitness-for-service assessments which were accepted by CNSC staff in accordance with CSA N285.8. The fitness for service evaluation process utilizes models developed using extensive data which has been accumulated over many years.

Given the result from the Unit 6 surveillance tube, Bruce Power immediately initiated a Technical Operability Evaluation (Reference 3) to evaluate the ability of all operating pressure tubes to carry out their safety-related functions. The completed Technical Operability Evaluation is provided as Enclosure 1.

A summary of the results of the Technical Operability Evaluation and additional information requested by CNSC staff with respect to Units 1, 2, 4, 5, 7, and 8, in Reference 1, is provided in Attachment B.

The Technical Operability Evaluation concludes that the entire length of all pressure tubes in units 1, 2, 4, 5, 7, and 8 are considered operable based upon the lack of flaws observed in the region of interest and the bounding of measurements by predictions outside of the region of interest.

Bruce Power is planning for scrape campaigns to determine the applicability of the [Heq] uptake behaviour observed in Unit 6 to the remaining units as part of planned outages. To this end, Bruce Power has already undertaken modifications to the circumferential wet scrape tool (CWEST) to facilitate the acquisition of more representative scrape measurements closer to the burnish mark region and at some other positions around the pressure tube circumference (e.g. 12 o'clock and 7-9 o'clock positions). This will allow the limited circumferential extent of the region of interest to be clearly defined.

In accordance with the Compliance Verification Criteria of Section 15.3, Bruce Power understands that, should any pressure tube in Units 1, 2, 4, 5, 7, or 8, be measured to be in excess of 120 ppm, Commission approval would need to be obtained. Note that Units 1, 2, 4, 5, 7, and 8 were returned to service in accordance with the processes required by Licence Condition 6.1 and Section 6.1 of the Licence Conditions Handbook, supported by fitness-for-service assessments accepted by CNSC staff in accordance with N285.8.

For clarity, Bruce Power maintains that elevated [Heq] is not a factor which impacts the safe, on-going, operation of Units 1, 2, 4, 5, 7, and 8 due to the upper shelf behavior exhibited during high temperature operation of the pressure tubes. As documented within Bruce Power's Technical Operability Evaluation (Enclosure 1), there is adequate assurance that margins of safety remain in support of the continued, unconditional, operation of pressure tubes within the operating units.

With respect to the Reference 5, Bruce Power's forth coming response will provide additional information regarding both the actions taken and on-going work identified following the completion of the recent Technical Operability Evaluation provided as Enclosure 1.

If you require further information or have any questions regarding this submission, please contact Mr. Maury Burton, Chief Regulatory Officer, Corporate Affairs & Operational Services, at (519) 361-2673 extension 15291, or at maury.burton@brucepower.com.

Yours truly,

Maury Burton
Chief Regulatory Officer
Bruce Power

cc: CNSC Bruce Site Office

Attach.

NOTE: Enclosure 1 contains CONFIDENTIAL information and has not been included in this document.

Enclosure:

1. Technical Operability Evaluation “Pressure Tube Measured Hydride Concentration” July 13, 2021, NK29-TOE-31100-00001.

References:

1. Letter, L. Sigouin to M. Burton, “Bruce A and B: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR on Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement – New Action Item 2021-07-23406”, July 8, 2021, e-Doc 6600766, BP-CORR-00531-01849.
2. REGDOC-3.1.1 Unscheduled Report, “Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement”, July 5, 2021, B-2021-98077 DR.
3. Bruce Power procedure, “Technical Operability Evaluation”, BP-PROC-00014, Revision 10.
4. Letter, M. Burton to L. Sigouin, “Bruce A and B: 2021 Annual Update on Deterministic Hydrogen Equivalent Predictions”, June 22, 2021, BP-CORR-00531-01669.
5. Letter, A. Viktorov to M. Burton, “Bruce A and B: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes”, July 13, 2021, e-Doc 6603948, BP-CORR-00531-01868.

Attachment A

Unit 6 Predicted and Measured Hydrogen Equivalence Values

Attachment A:
Unit 6 Predicted and Measured Hydrogen Equivalence Values

In Reference A1, CNSC staff requested:

a) *the predicted [Heq] values for Unit 6 at the time of shutdown for MCR in January 2020; and*
b) *the [Heq] measurements from the Unit 6 S13 surveillance pressure tube.*

In accordance with the Power Reactor Operating Licence, PROL 18.01/2028, Condition 15.3 and the Compliance Verification Criteria established in the associated Licence Condition Handbook, LCH-PR-18.01/2028-R002, Section 15.3, Item 1, b. Bruce Power has been required to provide:

> *"… annual reports by July 1 of each year indicating when each unit is predicted to reach a maximum [Heq] of 120 ppm."*

Prior to the Unit 6 shutdown for Major Component Replacement in January 2020, predicted [Heq] values were submitted to CNSC staff in Reference A2, based on the corresponding upper bound of the deterministic generic rolled joint [Heq] predictions for Units 1 through 8. The predictions previously provided in Reference A2, specific to Unit 6, are reproduced in Table A1.

Table A1 – Deterministic [Heq] Predictions at Outlet RJ for Unit 6 (March 2019)

Unit	Channel	Zone	Max [H]initial	Time to reach 120 ppm (HH)	Time to reach 120 ppm (kEFPH)	Time to reach 120 ppm (Date)
6	B6P09	IZ	18.3	294,687	264.2	> MCR in 2020
6	B6A17	OZ	17.3	316,806	284.1	> MCR in 2020

These predictions correspond to the burnish mark locations for the channel with the maximum [H]initial in each respective Unit, as it would be predicted to first reach the 120 ppm limit.

The deterministic generic [Heq] predictions were based on bounding operating conditions in each corresponding Unit, and were not channel specific operating conditions. The upper bound (97.5% percentile) of the corresponding body of tube model was used for waterside corrosion contribution (as discussed in Reference A2) coupled with the upperbound of the corresponding Rolled Joint (RJ) model.

Following the Unit 6 shutdown for Major Component Replacement in January 2020, Bruce Power confirmed within the 2020 annual deterministic hydrogen equivalent prediction update (Reference A3) that the predicted times for each Unit to reach a [Heq] concentration of 120 ppm remained unchanged from the predictions previously submitted in Reference A2. Again the predictions were made for the outlet rolled joint, at the burnish mark location.

Most recently, in June 2020, Bruce Power submitted the 2021 annual deterministic hydrogen equivalent prediction update (Reference A4), based on the corresponding upper bound of the deterministic generic rolled joint [Heq] predictions for Units 1 through 8. The predictions provided in Reference A4 specific to Unit 6 were unchanged from those originally provided in 2019 (Reference A2).

As stated in Reference A2, Bruce Power continuously evaluates and updates these models based on OPEX and inspection results from each Unit. These predictions were based on the industry and regulatory understanding at the time of submission.

As Unit 6 was shut down after 271,729 hot hours (243,773 Effective Full Power Hours), each of these submissions reflect Bruce Power's prediction that [Heq] values for Unit 6 pressure tubes at the time of shutdown in January 2020 were less than 120 ppm.

Specific to CNSC staff's request (Reference A1), the predicted [Heq] values for Unit 6 at the time of shutdown for MCR in January 2020 are provided in Table A2 for the outlet rolled joints for B6S13, and the bounding inner zone (IZ) and outer zone (OZ) channels, which were selected based on Hinitial. Table A3 provides interpolated generic deterministic predictions for every 1 mm from 0 to 150 mm.

Beyond the predictions provided annually, within each planned outage, Bruce Power obtains scrape measurements to determine the level of [Heq] in sampled pressure tubes. The measurements serve as a comparison to model predictions and allow Bruce Power to compare to the validity limit of the fracture toughness model. Prior to the recent results, scrape results from planned outages were consistent with model predictions and the validity limit of the fracture toughness model developed by industry, and accepted for use by CNSC staff, had not been exceeded.

The results of the [Heq] measurements taken from the Unit 6 surveillance tube (B6S13), provided in Table A2 and plotted circumferentially in Figures A1 and A2, reveal circumferential variation of [Heq] (i.e. the measured results had not been predicted).

Figure A1 is at the burnish mark and Figure A2 is at the burnish mark + 20mm. The burnish mark + 20mm position is significant because the postulated flaw length for fracture protection evaluations is 20mm and (given the rolled joint region is under compressive stress), the tip of a 20mm long flaw inboard from the burnish mark is where the corresponding [Heq] is used for evaluation. Based on a conservative balance of flaw stability (minimized at longer flaw length) and [Heq] (maximized at shorter flaw lengths) the 20mm assessment is cited as the standard calculation input per CSA N285.

A comparison of generic predictions and the measured results from the Unit 6 surveillance tube is provided in Table A3.

Table A2 – Hydrogen and Deuterium Concentration Measurements from Through-Wall Punches Obtained from the Outlet Rolled Joint Region of B6S13.

Axial Location (mm)	Circumferential Location (clock)*	[H] (mg/kg)	[D] (mg/kg)	[Heq] (mg/kg)
8	12	55 ± 3	520 ± 30	315
13	12	55 ± 3	530 ± 20	320
28	12	57 ± 3	520 ± 30	317
44	12	51 ± 3	450 ± 20	276
59	12	44 ± 2	360 ± 20	224
69 (burnish mark)	12	46 ± 2	330 ± 20	211
	3	13 ± 1	94 ± 5	60
	6	12.0 ± 0.9	93 ± 5	59
	9	13 ± 1	95 ± 5	61
79	12	42 ± 2	340 ± 20	212
89/90 (burnish mark + 20mm)	12	22 ± 1	152 ± 8	98
	3	11.8 ± 0.9	89 ± 4	56
	6	12.5 ± 0.9	88 ± 4	57
	9	12.2 ± 0.9	87 ± 4	56
145	12	17 ± 1	109 ± 5	72

Bruce Power noted that the predictions provided in Reference A4 had not accounted for the results exhibiting a high degree of circumferential variation reported in References A5 and A6. The recent results are asymmetrically distributed around the channel circumference with higher values found at (or near) the 12 o'clock position of the tubes.

Figure A1 – Hydrogen Equivalent Concentration of B6S13 at Outlet Burnish Mark (69 mm)

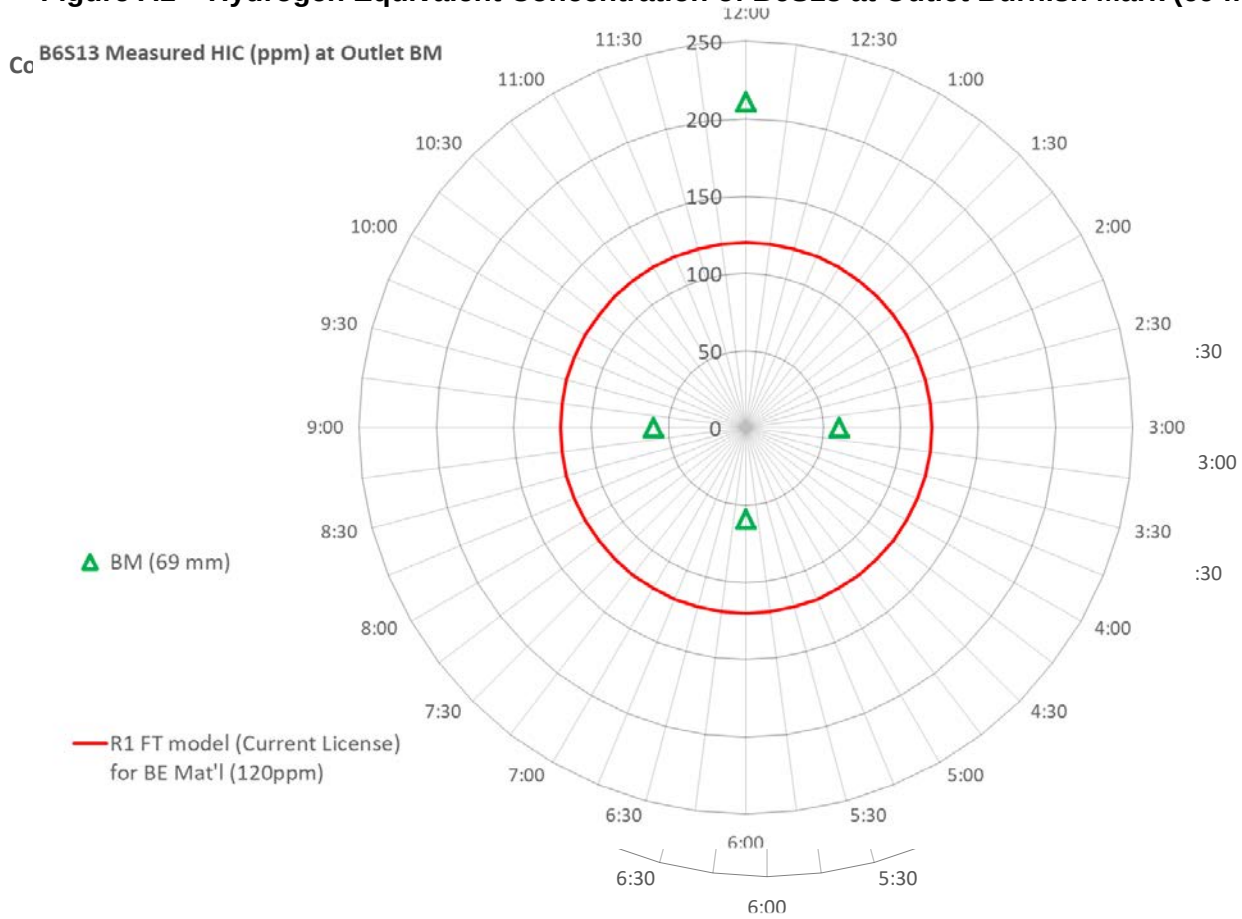


Figure A2 – Hydrogen Equivalent Concentration B6S13 at Outlet Burnish Mark+20mm (89 mm)

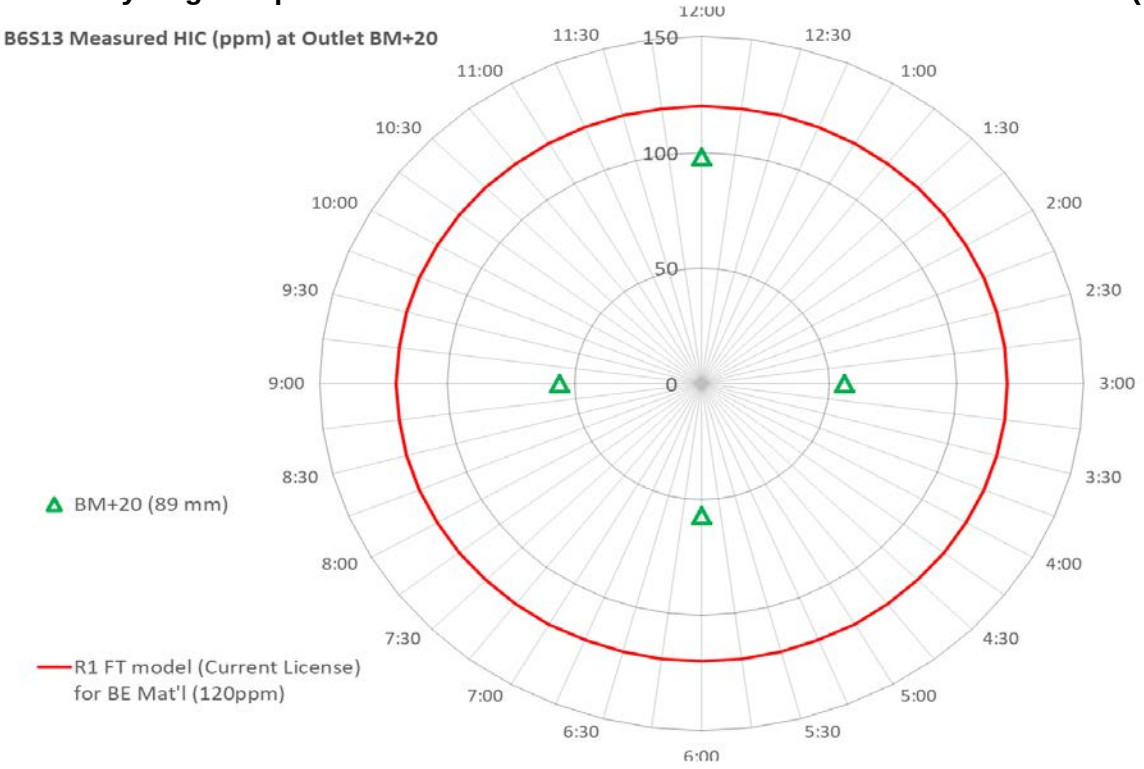
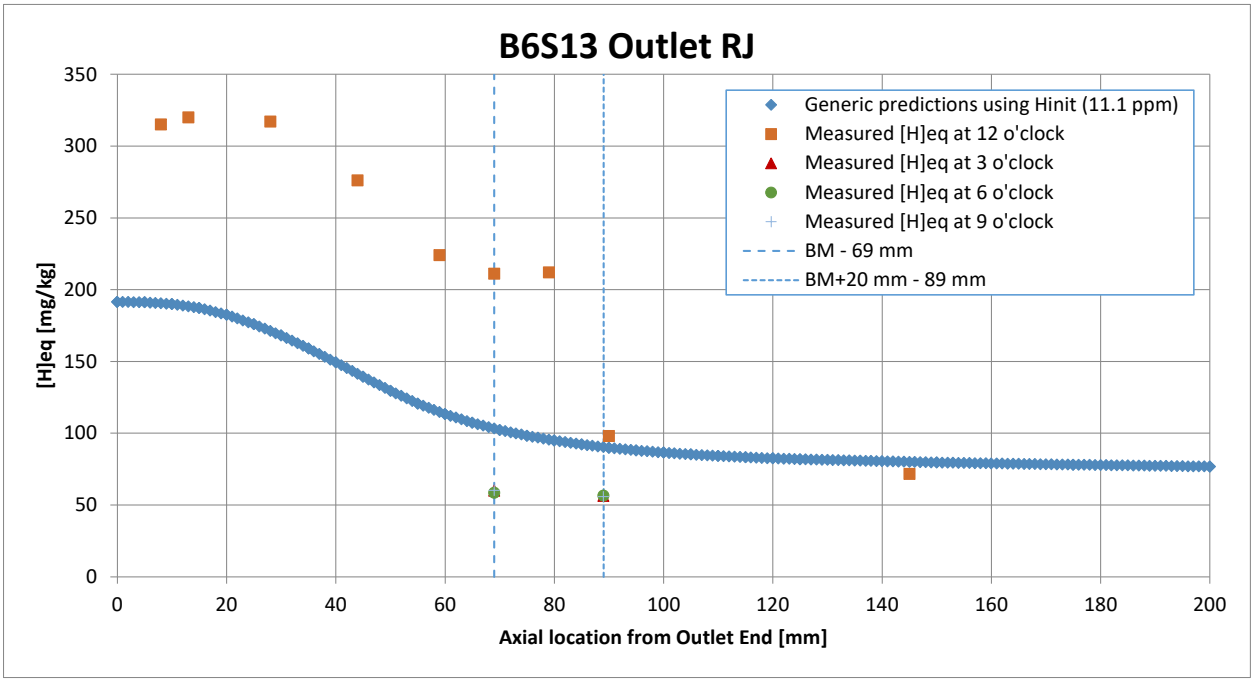


Figure A3 – Generic Prediction and Measured Hydrogen Equivalent Concentrations from the Unit 6 surveillance tube (B6S13)



To further understand the fuel channel hydrogen uptake behaviour, Bruce Power has undertaken modifications to the circumferential wet scrape tool (CWEST) to facilitate the acquisition of more representative scrape measurements closer to the burnish mark region and at some other positions around the pressure tube circumference (e.g. 12 o'clock and 7-9 o'clock positions). The modified tool is to be used during forthcoming outages starting with the Unit 3 planned outage which is currently underway.

Note that for the balance of the pressure tube (i.e. everything outside of the limited area of interest) the predictions remain bounding.

Table A3: Generic Deterministic Heq predictions at MCR for Bruce Unit 6

Location wrt PT outlet (mm)	Generic Deterministic [H]eq predictions (ppm) at MCR (B6)		
	B6S13	B6P09 (bounding unscraped IZ)	B6A17 (bounding unscraped OZ)
0	191.4	221.6	224.7
1	191.3	221.5	224.6
2	191.2	221.4	224.5
3	191.2	221.3	224.5
4	191.1	221.3	224.4
5	191.1	221.2	224.3
6	190.8	220.9	224.0
7	190.6	220.5	223.6
8	190.3	220.2	223.3
9	190.1	219.9	222.9

Location wrt PT outlet (mm)	Generic Deterministic [H]eq predictions (ppm) at MCR (B6)		
	B6S13	B6P09 (bounding unscraped IZ)	B6A17 (bounding unscraped OZ)
10	189.8	219.6	222.6
11	189.3	218.9	221.8
12	188.8	218.1	221.1
13	188.2	217.4	220.3
14	187.7	216.7	219.6
15	187.1	216.0	218.8
16	186.2	214.7	217.5
17	185.2	213.5	216.2
18	184.3	212.3	214.8
19	183.3	211.1	213.5
20	182.4	209.9	212.2
21	181.1	208.2	210.4
22	179.8	206.6	208.6
23	178.5	204.9	206.8
24	177.1	203.3	205.1
25	175.8	201.6	203.3
26	174.3	199.6	201.1
27	172.7	197.6	198.9
28	171.1	195.6	196.7
29	169.5	193.5	194.5
30	167.9	191.5	192.3
31	166.1	189.2	189.8
32	164.3	186.9	187.3
33	162.5	184.6	184.8
34	160.7	182.4	182.3
35	158.9	180.1	179.8
36	157.0	177.6	177.2
37	155.0	175.2	174.6
38	153.1	172.8	171.9
39	151.2	170.3	169.3
40	149.2	167.9	166.6
41	147.2	165.4	163.9
42	145.2	163.0	161.2
43	143.2	160.5	158.5
44	141.3	158.1	155.8
45	139.3	155.6	153.1
46	137.3	153.2	150.5
47	135.3	150.8	147.9
48	133.4	148.4	145.3
49	131.4	146.0	142.7
50	129.5	143.6	140.0
51	127.7	141.4	137.7
52	125.9	139.2	135.3
53	124.1	137.1	133.0
54	122.3	134.9	130.6
55	120.6	132.7	128.2
56	119.1	131.0	126.3
57	117.6	129.2	124.4
58	116.1	127.4	122.5
59	114.7	125.6	120.6

Location wrt PT outlet (mm)	Generic Deterministic [H]eq predictions (ppm) at MCR (B6)		
	B6S13	B6P09 (bounding unscraped IZ)	B6A17 (bounding unscraped OZ)
60	113.2	123.9	118.7
61	112.0	122.4	117.1
62	110.8	120.9	115.6
63	109.6	119.5	114.0
64	108.4	118.0	112.5
65	107.2	116.6	110.9
66	106.2	115.4	109.7
67	105.2	114.2	108.4
68	104.2	113.0	107.2
69* location of the burnish mark	103.2	111.8	105.9
70	102.2	110.6	104.7
71	101.4	109.7	103.7
72	100.6	108.7	102.7
73	99.8	107.7	101.7
74	98.9	106.8	100.7
75	98.1	105.8	99.7
76	97.5	105.0	98.8
77	96.8	104.2	98.0
78	96.1	103.4	97.2
79	95.5	102.6	96.4
80	94.8	101.8	95.6
81	94.2	101.2	94.9
82	93.7	100.5	94.2
83	93.1	99.9	93.6
84	92.6	99.2	92.9
85	92.0	98.6	92.2
86	91.6	98.0	91.7
87	91.1	97.5	91.2
88	90.7	97.0	90.6
89	90.2	96.4	90.1
90	89.8	95.9	89.6
91	89.4	95.5	89.1
92	89.0	95.0	88.7
93	88.7	94.6	88.3
94	88.3	94.2	87.8
95	87.9	93.7	87.4
96	87.6	93.4	87.0
97	87.3	93.0	86.7
98	87.0	92.7	86.3
99	86.7	92.3	86.0
100	86.4	92.0	85.6
101	86.1	91.7	85.3
102	85.9	91.4	85.0
103	85.6	91.1	84.8
104	85.4	90.8	84.5
105	85.1	90.5	84.2
106	84.9	90.3	83.9
107	84.7	90.0	83.7

Location wrt PT outlet (mm)	Generic Deterministic [H]eq predictions (ppm) at MCR (B6)		
	B6S13	B6P09 (bounding unscraped IZ)	B6A17 (bounding unscraped OZ)
108	84.5	89.8	83.5
109	84.3	89.5	83.2
110	84.0	89.3	83.0
111	83.9	89.1	82.8
112	83.7	88.9	82.6
113	83.5	88.7	82.4
114	83.3	88.5	82.2
115	83.2	88.3	82.0
116	83.0	88.1	81.9
117	82.9	88.0	81.7
118	82.7	87.8	81.6
119	82.6	87.6	81.4
120	82.4	87.5	81.2
121	82.3	87.3	81.1
122	82.1	87.2	81.0
123	82.0	87.1	80.8
124	81.9	86.9	80.7
125	81.8	86.8	80.6
126	81.7	86.7	80.5
127	81.6	86.6	80.4
128	81.5	86.5	80.3
129	81.4	86.4	80.2
130	81.3	86.3	80.1
131	81.2	86.2	80.0
132	81.1	86.1	80.0
133	81.0	86.0	79.9
134	81.0	85.9	79.8
135	80.9	85.9	79.7
136	80.8	85.8	79.6
137	80.7	85.7	79.5
138	80.6	85.6	79.4
139	80.5	85.5	79.3
140	80.4	85.4	79.3
141	80.3	85.3	79.2
142	80.2	85.2	79.1
143	80.1	85.1	79.0
144	80.1	85.0	78.9
145	80.0	84.9	78.8
146	79.9	84.8	78.7
147	79.8	84.7	78.7
148	79.7	84.7	78.6
149	79.6	84.6	78.5
150	79.5	84.5	78.4

References:

A1. Letter, L. Sigouin to M. Burton, “Bruce A and B: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR on Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement – New Action Item 2021-07-23406”, July 8, 2021, e-Doc 6600766, BP-CORR-00531-01849.

A2. Letter, M. Burton to L. Sigouin, “Bruce A and B: Annual Update on Deterministic Hydrogen Equivalent Predictions”, March 7, 2019, NK21-CORR-00531-14968 / NK29-CORR-00531-15731.

A3. Letter, M. Burton to L. Sigouin, “Bruce A and B: Annual Update on Deterministic Hydrogen Equivalent Predictions”, June 9, 2020, BP-CORR-00531-00581.

A4. Letter, M. Burton to L. Sigouin, “Bruce A and B: 2021 Annual Update on Deterministic Hydrogen Equivalent Predictions”, June 22, 2021, BP-CORR-00531-01669.

A5. REGDOC-3.1.1 Unscheduled Report, “A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements”, June 29, 2021, B-2021-93819 DR.

A6. REGDOC-3.1.1 Unscheduled Report, “Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement”, July 5, 2021, B-2021-98077 DR.

Attachment B

Unit 6 Measured Hydrogen Equivalent Values Impact on Operating Units

Attachment B:
Unit 6 Measured Hydrogen Equivalent Values Impact on Operating Units

Background:

The operability of fuel channels in a CANDU reactor is repeatedly evaluated by examining the fitness-for-service of the pressure tubes using industry standard models, accepted for use by CNSC staff, and through the assessment of measurements taken during periodic planned outages.

Prior to the return to service of any unit from a planned outage, fitness-for-service evaluations are undertaken in accordance with the Power Reactor Operating Licence (PROL 18.01/2028), Condition 6.1, the Licence Conditions Handbook (LCH-PR-18.01/2028-R002), Section 6.1, and the requirements of CSA N285.8-10, "Technical requirements for in-service evaluation of zirconium alloy pressure tubes in CANDU reactors."

The objective of the fitness-for-service evaluations is to demonstrate that pressure tubes:

a) have resistance to crack initiation;
b) are not impacted by pressure tube to calandria tube contact if the predicted [Heq] exceeds blister formation threshold (BFT);
c) continue to demonstrate leak-before-break (LBB) to a high level of confidence; and,
d) are protected from fracture as a result of a postulated, non-detected, through-wall flaw.

Each of these elements relate to pressure tube integrity and must be demonstrated along both the length and circumference where fitness-for-service evaluation are performed, as prescribed within the licensing basis.

Licensing Basis for Operation Units

In Reference B1, CNSC staff requested that Bruce Power,

> "*… provide assurance that the operating Bruce A and B units (Units 1, 2, 4, 5, 7, and 8) continue to meet the Licensing Basis in PROL18.01/2028, Licence Conditions 6.1 and 15.3.*"

As presented in the covering letter, Units 1, 2, 4, 5, 7, and 8 are currently operating and, as no operating pressure tube has been predicted, or measured, to be in excess of 120 ppm, operation remains in accordance with the established compliance verification criteria and the licensing basis established within Condition 15.3.

Units 1, 2, 4, 5, 7, and 8 were returned to service in accordance with the processes required by Licence Condition 6.1 and Section 6.1 of the Licence Conditions Handbook, supported by fitness-for-service assessments accepted by CNSC staff in accordance with N285.8-10. As such, operation remains in accordance with the established compliance verification criteria and the licensing basis established within Condition 6.1.

Technical Operability Evaluation Summary

In accordance with Bruce Power's on-going commitment to safety, upon receipt of the elevated hydrogen equivalent measurements from the Unit 6 surveillance tube, a Technical Operability Evaluation was initiated. The objective of the technical operability evaluations is to systematically determine whether a structure, system, component, or tool is capable of delivering its credited safety

functions. Fundamentally, technical operability evaluations are used to assess whether it is safe to continue operating the stations.

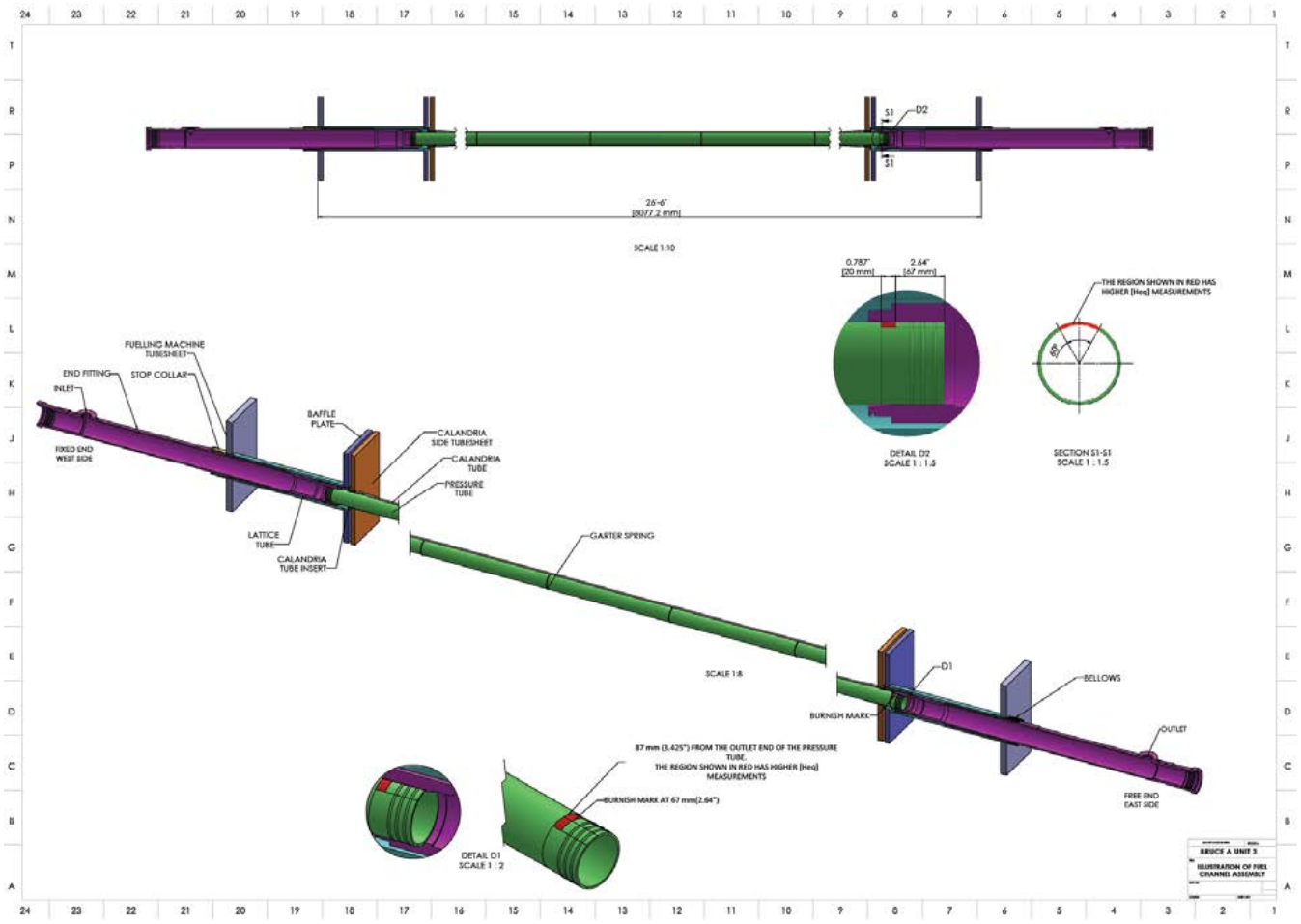
The technical operability evaluation undertaken as a result of the elevated hydrogen equivalent measurements taken from the Unit 6 surveillance tube is provided as Enclosure 1.

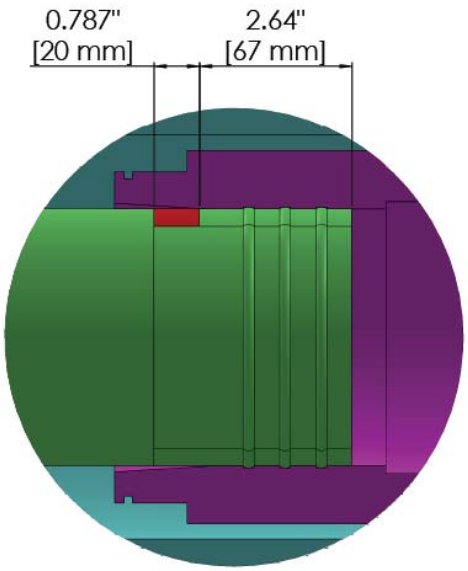
The technical operability evaluation examined the impact on all portions of the pressure tube, including:

a) the lower pressure tube (i.e. that which supports the fuel string and normally experiences contact with the fuel bundles);
b) the upper tube region near the outlet rolled joints (i.e. the region of interest where elevated levels of hydrogen equivalent concentration measurements were observed in Unit 6 and where fuel bundle contact does not normally occur); and
c) the remaining portions of fuel channel not near the outlet burnish mark (i.e. the body of tube for the remainder of the fuel channels length up to the inlet burnish mark, full circumference).

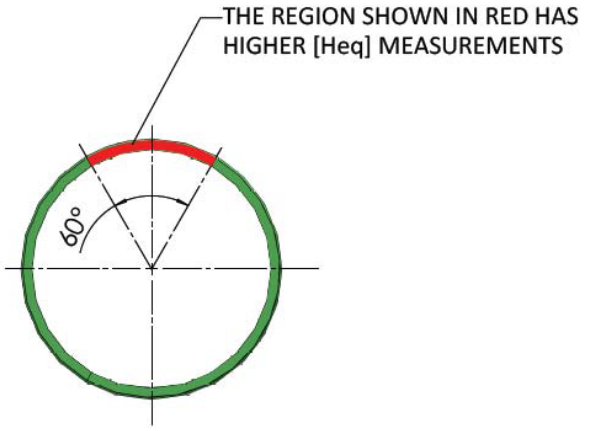
Figure B1 highlights the area of interest, where higher levels of hydrogen equivalent concentrations were measured in the Unit 6 surveillance tube.

Figure B1 – Illustration of the Area of Interest identified by the Unit 6 Surveillance Tube





DETAIL D2
SCALE 1 : 1.5



SECTION S1-S1
SCALE 1 : 1.5

Key points from the evaluation are summarized here for convenience.

For all areas of operating pressure tubes:

- Consistent with established Fitness for Service requirements established within the licensing basis, Bruce Power continues to conduct Pressure Tube (PT) fitness for service assessments using a combination of conservative models, measurements from inspections and tested material properties (such as pressure tube fracture toughness) consistent with the verification criteria in CSA N285.4 and CSA N285.8.
- Owing to their limited time in operation, for Units 1 and 2, all areas of the pressure tube are unconditionally operable.
- For Units 4, 5, 7, and 8, the entire length of the pressure tubes is unconditionally operable based upon the lack of flaws observed in the region of interest, and the bounding of measurements by predictions outside of the region of interest. Confirmation of expert judgment of acceptable PFP and PCA results will be completed as a TOE corrective action.

For the lower region and the balance of operating pressure tubes:

- The use of the higher concentration from the upper quadrants of the tube in the modelling continues to ensure the bounding nature of the predictive models for hydrogen isotope concentration in the lower region of the pressure tube.
- This is the portion of the pressure tube where the fuel bundles are in contact and where flaws are most likely to be created during reactor operation.
- All measured values to date are bounded by the model predictions in these regions. As such, there is no operability concern for the pressure tube outside of the region of interest. The existing fitness for service evaluations remain valid and all analyses supported by Revision 1 of the fracture toughness model remain bounding to the operating condition of Units 1, 2, 4, 5, 7, and 8.
- Given the results are consistent with past predictions, the failure modes effect outside of the region of interest is unchanged from previous submissions (e.g. safety report and existing fitness-for-service assessments).

For the area of interest:

- Only areas of the channel circumference close to the burnish mark and at or near the 12 o'clock position are revealing elevated levels of measured hydrogen equivalent concentration.
- The main concern stemming from the potential for higher levels of hydrogen equivalent concentration is reduced fracture toughness due to the presence of brittle hydrides that are highly influential in determining pressure tube fracture toughness in the lower-shelf and transition temperature regimes. Reduced fracture toughness can impact the stability of postulated cracks should they be initiated; however, crack initiation has been shown through experimental modelling to be insensitive to increases in [Heq] levels under hydride ratcheting conditions.
- Given that there are no flaws requiring disposition in the outlet rolled joint region, there is no anticipated effect of this circumferential variation of [Heq] on flaw disposition.
- The limited extent to the area of interest, the lack of observed flaws in that location, and the reduced stresses in the rolled joint due to creep-induced relaxation of residual stresses all contribute to the expectation that there no anticipated significant effects on the probabilistic core assessment (PCA), including the leak-before-break analysis.
- Due to the temperature-effects on pressure tube toughness, operation at high temperature (i.e. equal to and above 250ºC) is unaffected by the increased concentration of hydrogen. In the

'upper shelf' region hydrogen concentration is not used in the model to predict the upper shelf fracture toughness

- A fracture protection evaluation has been completed for the normal set of bounding operating states (heat-up, cool-down, and cold overpressure transient) in order to provide assurance of safety within all acceptable operating bounds.
- Engineering evaluations as to the anticipated impact of increased hydrogen equivalent concentrations on the fitness-for-service evaluations for the operating units are summarized below.
- Further investigation and analysis must continue such that the cause and impact of the observations can be understood. In support of resolving the recent findings and in accordance with CSA N285.8-15 section 8, Bruce Power is in the process of advancing this as an industry matter and is increasing testing with accelerated timetables. The additional measurements are needed to provide both the industry and the CNSC with the opportunity to consider, in the future, an approach to incorporate these finding in revisions/approaches to Revision 2 of the Cohesive Zone Fracture Toughness Model and associated regulatory or licensing elements.

Impact of Measured Hydrogen Equivalent Values

The predictive capability of industry models to anticipate the hydrogen equivalent [Heq] concentrations in the body of tube (BOT) remain bounding; however, the recent hydrogen equivalent [Heq] values measured in the outlet rolled joint region of pressure tubes from Units 3 and 6, requires the predictive capability of the models in the outlet rolled joint region to be reviewed to account for the circumferential variation in Heq.

The impacts of the recently measured results on each of the pressure tube fitness-for-service elements, required by CSA N285.8-10, are examined below.

Pressure Tube Flaw Dispositions

As the elevated [Heq] measurements are confined to the top of the pressure tube in the outlet rolled joint region, and no dispositionable flaws have been detected at the top of the pressure tube in the outlet rolled joint region, the recent elevated levels of hydrogen equivalent concentrations do not impact existing flaw dispositions submitted by Bruce Power for Units 1, 2, 4, 5, 7, or 8, nor their acceptance by CNSC staff.

Pressure Tube to Calandria Tube Contact Dispositions

As no physical contact between pressure tubes and calandria tubes is possible at the outlet rolled joint region, the recent elevated levels of hydrogen equivalent concentration do not impact the the existing pressure-tube-to-calandria-tube contact dispositions, submitted by Bruce Power for Units 4, 5, 7, or 8, nor their acceptance by CNSC staff.

As spacers are repositioned to prevent contact, especially for the outlet half of the pressure tubes, any change in the predicted level of hydrogen equivalent concentrations would not impact the adequacy of the accepted pressure-tube-to-calandria-tube contact disposition results.

Demonstration of Leak-Before-Break (LBB)

Bruce Power probabilistically evaluates Leak-Before-Break as part of probabilistic core assessments (PCA).

An increase in hydrogen equivalent concentration [Heq] would result in reduced fracture toughness, and a consequential increase in predicted pressure tube ruptures within the probabilistic core

assessment; however, as the accepted probabilistic core assessments show significant margin to the allowable rupture frequency as per CSA N285.8-15, the conclusions of the probabilistic core assessments (i.e. all units meet the acceptance criteria of pressure tube failure and LBB) remain unchanged.

The probabilistic core assessment code is to be updated to implement Revision 2 of the fracture toughness model and probabilistic evaluations will be re-performed for the bounding units.

Demonstration of Fracture Protection

For demonstration of fracture protection, Bruce Power postulates a 20 mm through-wall flaw (or less when justified) and fracture protection is evaluated for the entire length of the pressure tube, starting at the burnish mark from one end of the tube to the burnish mark at the other end of the tube.

Any postulated 20 mm through-wall flaw would be anticipated to occur at the bottom of the pressure tube as the bottom of the pressure tube is where there is potential for flaws to form due to the interaction between the fuel bearing pads and the internal surface of the pressure tube. As discussed in Pressure Tube Flaw Disposition section (above), based on all available volumetric ultrasonic inspection data collected, there have never been dispositionable flaws detected in the outlet rolled joint area.

The only location, where a fracture protection evaluation could be impacted by a higher than anticipated hydrogen equivalent measurement, is 20 mm inboard of the burnish mark at the outlet end. This corresponds to the location of the inboard tip of the postulated crack. The recent [Heq] measurements obtained from pressure tubes in Unit 3 near the outlet burnish mark region show that the Heq at the bottom of the tube at a location of 20 mm inboard of the burnish mark remains below 120 ppm. This observation is also confirmed by the [Heq] measurements obtained at the bottom of surveillance tube B6S13 at 20 mm inboard of the burnish mark. Based on the measurements obtained, Heq decreases substantially further inboard into the tube from the burnish mark. Therefore, the current fracture protection evaluations are unaffected by the recent results.

Conclusion

As evaluated above, the fitness-for-service of pressure tubes in all the operating Bruce Power units is maintained. The continued operation of Units 1, 2, and 4, at Bruce A and Units 5, 7, and 8 at Bruce B continues in accordance with the requirements of the Power Reactor Operating Licence (PROL 18.01/2028), Conditions 6.1 and 15.3, which require that Bruce Power both, "*…implement and maintain a fitness-for-service program*" and that "*[b]efore hydrogen equivalent concentrations exceed 120 ppm,* [Bruce Power] *shall demonstrate that pressure tube fracture toughness will be sufficient for safe operation beyond 120 ppm.*"

July 16, 2021

BP-CORR-00531-01863

Mr. L. Sigouin
Director, Bruce Regulatory Program Division
Canadian Nuclear Safety Commission
P.O. Box 1046
280 Slater Street
Ottawa, Ontario
K1P 5S9

Dear Mr. Sigouin:

Action Item 2021-07-23424:
CNSC Review of REGDOC-3.1.1 Event Report B-2021-93819

The purpose of this letter is to respond to Reference 1 and provide the information requested by CNSC staff in response to their review of Reference 2.

As reported in Reference 2, measurements obtained from the current Unit 3 outage (A2131) Circumferential Wet Scrape Tool (CWEST) scrape campaign showed elevated hydrogen equivalent concentration (Heq) measurements. Measurements near the top of the pressure tube in the outlet Rolled Joint (RJ) region in some pressure tubes were in excess of the generic predictions for the locations outboard of the burnish mark. Note that the subject results are limited to a small area of interest on the upper portion of the fuel channel near the outlet rolled joint. The newly observed high degree of circumferential variation was also the subject of References 3 and 4.

A summary of the Unit 3 predicted Heq and measured hydrogen equivalent values, requested by CNSC staff in Reference 1, is provided in Attachment A.

These measurements were taken from Unit 3 and the Unit is not currently operating. All operating Units on the site have had their pressure tubes inspected during recent outage campaigns and were deemed to be both safe and within the licensing basis.

Bruce Power continues to maintain a paramount commitment to safety and reverence for the licensing basis by assembling a multi-disciplinary team to examine the findings, while proactively sharing information with CNSC staff and other CANDU operators.

With respect to the Reference 5, Bruce Power's forth coming response will provide additional information regarding both the actions taken and on-going work informed by the completion of the recent Technical Operability Evaluation (Enclosure 1 to Reference 4).

Bruce Power Maury Burton, Chief Regulatory Officer
P.O. Box 1540 B10 2nd Floor E, Tiverton ON N0G 2T0
Telephone 519-361-5291
maury.burton@brucepower.com

As CNSC staff are aware, the Power Reactor Operating Licence (PROL 18.01/2028) Condition 15.3 requires that:

Licence Condition 15.3:

Before hydrogen equivalent concentrations exceed 120 ppm, the licensee shall demonstrate that pressure tube fracture toughness will be sufficient for safe operation beyond 120 ppm.

As presented in the Introduction to the Licence Conditions Handbook (LCH-PR-18.01/2028-R002), "*the general purpose of the Licence Conditions Handbook (LCH) is to identify and clarify the relevant parts of the licensing basis for each licence condition."*

Within the Licence Condition Handbook, Compliance Verification Criteria (CVC) are established within each section to serve, "*as the criteria used by CNSC staff to verify and oversee compliance with* [a licence condition]."

The Compliance Verification Criteria for Section 15.3 establish clear criteria to measure Bruce Power's compliance with Licence Condition 15.3:

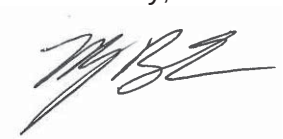
Compliance Verification Criteria:

1. For continued operation of units containing pressure tubes with a [H_{eq}] exceeding 120 ppm between the inlet and outlet burnish marks:
   a. Bruce Power shall obtain approval from the Commission before operating any pressure tube with a measured [H_{eq}] greater than 120 ppm, or beyond the time any pressure tube is predicted to have a [H_{eq}] greater than 120 ppm,
      i. Predictions of maximum [H_{eq}] shall be determined utilizing the hydrogen prediction model applied to the unit in the most recent report submitted to the CNSC under CSA N285.4, Clause 12.3.6.2. Revisions to the hydrogen prediction model used in the most recent report shall be accepted by the CNSC.
   b. Bruce Power shall submit annual reports by July 1 of each year indicating when each unit is predicted to reach a maximum [H_{eq}] of 120 ppm.

Bruce Power understands that the operation of any pressure tube with a measured hydrogen equivalent concentration in excess of 120 ppm must be addressed, in accordance with the requirements of Licence Conditions 6.1 and 15.3. As Unit 3 is currently offline for a planned maintenance outage, compliance with the licensing basis is maintained.

If you require further information or have any questions regarding this submission, please contact Mr. Maury Burton, Chief Regulatory Officer, Corporate Affairs & Operational Services, at (519) 361-2673 extension 15291, or maury.burton@brucepower.com.

Yours truly,



Maury Burton
Chief Regulatory Officer,
Bruce Power
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Maury Burton
Chief Regulatory Officer
Bruce Power

cc: CNSC Bruce Site Office

Attach.

References:

1. Letter, L. Sigouin to M. Burton, “Bruce A: CNSC Review of REGDOC-3.1.1 Event Report B-2021-93819 on A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements – New Action Item 2021-07-23424”, July 9, 2021, e-Doc 6603183, BP-CORR-00531-01855.
2. REGDOC-3.1.1 Unscheduled Report, “A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements”, June 29, 2021, B-2021-93819 DR.
3. Letter, L. Sigouin to M. Burton, “Bruce A and B: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR on Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement – New Action Item 2021-07-23406”, July 8, 2021, e-Doc 6600766, BP-CORR-00531-01849.
4. Letter, M. Burton to L. Sigouin, “Action Item 2021-07-23406: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR”, July 15, 2021, BP-CORR-00531-01853.
5. Letter, A. Viktorov to M. Burton, “Bruce A and B: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes”, July 13, 2021, e-Doc 6603948, BP-CORR-00531-01868.

Attachment A

Unit 3 Predicted and Measured Hydrogen Equivalence Values

Attachment A:
Unit 3 Predicted and Measured Hydrogen Equivalence Values

In Reference A1, CNSC staff requested:

a) *The predicted Heq values for Unit 3 at the time of shutdown for the A2131 planned outage; and,*
b) *The Heq measurements from the Unit 3 F16 pressure tube.*

As stated in Reference A2, Bruce Power continuously evaluates and updates predictive models based on operating experience and inspection results from each unit's planned outages. During planned outages, Bruce Power obtains scrape measurements to determine the level of hydrogen equivalent concentration in sampled pressure tubes. The measurements serve as a comparison to model predictions and allow Bruce Power to compare to the validity limit of the fracture toughness model. All predictions are based on the industry and regulatory understanding at the time of submission.

Specific to CNSC staff's request (Reference A1), the interpolated, generic, deterministic predictions of hydrogen equivalent concentration for B3F16 and the bounding inner zone (IZ) and outer zone (OZ) channels are provided in Table A1 for every 1 mm from 0 to 150 mm. The predictions correspond to the time at which Unit 3 was shutdown for its planned maintenance outage. At the time of shutdown, Unit 3 had operated for 271,326 hot hours (231,964 Effective Full Power Hours). Hydrogen equivalent values were expected to be less than 120 ppm for all areas of the pressure tube inboard of the burnish marks.

Table A1: Generic Deterministic Heq predictions at A2131 outage for Bruce Unit 3

Location wrt PT outlet (mm)	Generic Deterministic [H]eq predictions at A2131 (ppm)		
	B3F16	B3H06 (bounding unscraped IZ)	B3X09 (bounding unscraped OZ)
0	272.7	290.9	265.0
1	272.6	290.7	264.9
2	272.5	290.6	264.7
3	272.3	290.5	264.6
4	272.2	290.4	264.5
5	272.1	290.2	264.4
6	271.5	289.7	263.9
7	271.0	289.2	263.3
8	270.5	288.6	262.8
9	269.9	288.1	262.3
10	269.4	287.6	261.8
11	268.2	286.3	260.6
12	267.0	285.1	259.5
13	265.8	283.9	258.3
14	264.6	282.7	257.1
15	263.4	281.4	256.0

Location wrt PT outlet (mm)	Generic Deterministic [H]eq predictions at A2131 (ppm)		
	B3F16	B3H06 (bounding unscraped IZ)	B3X09 (bounding unscraped OZ)
16	261.3	279.3	254.1
17	259.3	277.1	252.1
18	257.2	275.0	250.2
19	255.1	272.8	248.3
20	253.0	270.7	246.3
21	250.2	267.7	243.7
22	247.3	264.7	241.1
23	244.4	261.7	238.4
24	241.6	258.6	235.8
25	238.7	255.6	233.2
26	235.2	252.0	230.0
27	231.7	248.4	226.8
28	228.3	244.8	223.6
29	224.8	241.2	220.4
30	221.3	237.6	217.2
31	217.4	233.4	213.6
32	213.5	229.3	210.0
33	209.6	225.1	206.4
34	205.7	221.0	202.8
35	201.8	216.8	199.2
36	197.7	212.4	195.4
37	193.6	208.0	191.6
38	189.5	203.6	187.9
39	185.4	199.1	184.1
40	181.3	194.7	180.3
41	177.2	190.3	176.6
42	173.2	185.9	172.9
43	169.2	181.5	169.2
44	165.1	177.1	165.4
45	161.1	172.7	161.7
46	157.3	168.5	158.2
47	153.5	164.4	154.7
48	149.7	160.2	151.2
49	145.9	156.1	147.7
50	142.1	151.9	144.2
51	138.9	148.4	141.2
52	135.6	144.8	138.1
53	132.4	141.2	135.1
54	129.2	137.6	132.1

Location wrt PT outlet (mm)	Generic Deterministic [H]eq predictions at A2131 (ppm)		
	B3F16	B3H06 (bounding unscraped IZ)	B3X09 (bounding unscraped OZ)
55	125.9	134.1	129.1
56	123.4	131.3	126.7
57	120.9	128.6	124.3
58	118.4	125.8	121.9
59	115.9	123.0	119.6
60	113.3	120.3	117.2
61	111.4	118.1	115.3
62	109.5	116.0	113.5
63	107.5	113.8	111.6
64	105.6	111.7	109.7
65	103.6	109.5	107.9
66	102.1	107.9	106.4
67 *Location of the burnish mark for B3F16.	100.6	106.2	104.9
68	99.0	104.5	103.5
69	97.5	102.8	102.0
70	96.0	101.2	100.6
71	94.8	99.9	99.4
72	93.6	98.6	98.2
73	92.5	97.2	97.1
74	91.3	95.9	95.9
75	90.1	94.6	94.8
76	89.2	93.6	93.9
77	88.2	92.6	92.9
78	87.3	91.6	92.0
79	86.4	90.5	91.1
80	85.5	89.5	90.2
81	84.7	88.7	89.5
82	84.0	87.9	88.7
83	83.3	87.1	88.0
84	82.5	86.3	87.3
85	81.8	85.5	86.6
86	81.2	84.8	86.0
87	80.7	84.2	85.4
88	80.1	83.6	84.8
89	79.5	82.9	84.2
90	78.9	82.3	83.7

Location wrt PT outlet (mm)	Generic Deterministic [H]eq predictions at A2131 (ppm)		
	B3F16	B3H06 (bounding unscraped IZ)	B3X09 (bounding unscraped OZ)
91	78.5	81.8	83.2
92	78.0	81.3	82.7
93	77.6	80.8	82.3
94	77.1	80.3	81.8
95	76.6	79.8	81.3
96	76.3	79.4	81.0
97	75.9	79.0	80.6
98	75.5	78.6	80.2
99	75.2	78.2	79.9
100	74.8	77.8	79.5
101	74.5	77.4	79.2
102	74.2	77.1	78.9
103	73.9	76.8	78.6
104	73.6	76.5	78.3
105	73.3	76.2	78.0
106	73.1	75.9	77.7
107	72.9	75.6	77.5
108	72.6	75.4	77.3
109	72.4	75.1	77.0
110	72.2	74.9	76.8
111	72.0	74.7	76.6
112	71.8	74.5	76.4
113	71.6	74.3	76.2
114	71.4	74.0	76.0
115	71.2	73.8	75.8
116	71.1	73.7	75.6
117	70.9	73.5	75.4
118	70.7	73.3	75.3
119	70.6	73.2	75.1
120	70.4	73.0	74.9
121	70.3	72.9	74.8
122	70.2	72.7	74.7
123	70.0	72.6	74.5
124	69.9	72.4	74.4
125	69.8	72.3	74.3
126	69.7	72.2	74.2
127	69.6	72.1	74.1
128	69.5	72.1	74.0
129	69.4	72.0	73.9

Location wrt PT outlet (mm)	Generic Deterministic [H]eq predictions at A2131 (ppm)		
	B3F16	B3H06 (bounding unscraped IZ)	B3X09 (bounding unscraped OZ)
130	69.4	71.9	73.8
131	69.3	71.8	73.7
132	69.2	71.7	73.6
133	69.1	71.6	73.5
134	69.0	71.5	73.5
135	68.9	71.4	73.4
136	68.8	71.4	73.3
137	68.8	71.3	73.2
138	68.7	71.2	73.1
139	68.6	71.1	73.0
140	68.5	71.0	72.9
141	68.4	70.9	72.8
142	68.3	70.8	72.7
143	68.2	70.7	72.6
144	68.2	70.7	72.6
145	68.1	70.6	72.5
146	68.0	70.5	72.4
147	67.9	70.4	72.3
148	67.8	70.3	72.2
149	67.7	70.2	72.1
150	67.6	70.1	72.0

As requested in Reference A1, the results of the hydrogen equivalent concentration measurements taken from Unit 3 channel F16 (B3F16) are provided in Table A2 for the outlet rolled joint region. The measurements reveal circumferential variation of hydrogen equivalent concentrations which were the subject of Reference A3 and A4. A comparison of predicted and the measured results is provided in Figure A1.

Prior to the recent findings, scrape results from planned outages were consistent with model predictions and the validity limit of the fracture toughness model developed by industry, and accepted for use by CNSC staff, had not been exceeded. Note that for the balance of the pressure tube (i.e. everything outside of the limited area of interest) the predictions remain bounding.

To further understand the fuel channel hydrogen uptake behaviour, Bruce Power has undertaken modifications to the circumferential wet scrape tool (CWEST) to facilitate the acquisition of more representative scrape measurements closer to the burnish mark region and at some other positions around the pressure tube circumference (e.g. 12 o'clock and 7-9 o'clock positions). The modified tool is to be used during forthcoming outages starting with the Unit 3 planned outage, already underway.

Table A2 – Hydrogen and Deuterium Concentration Measurements Obtained from Scrapes in the Outlet RJ of B3F16

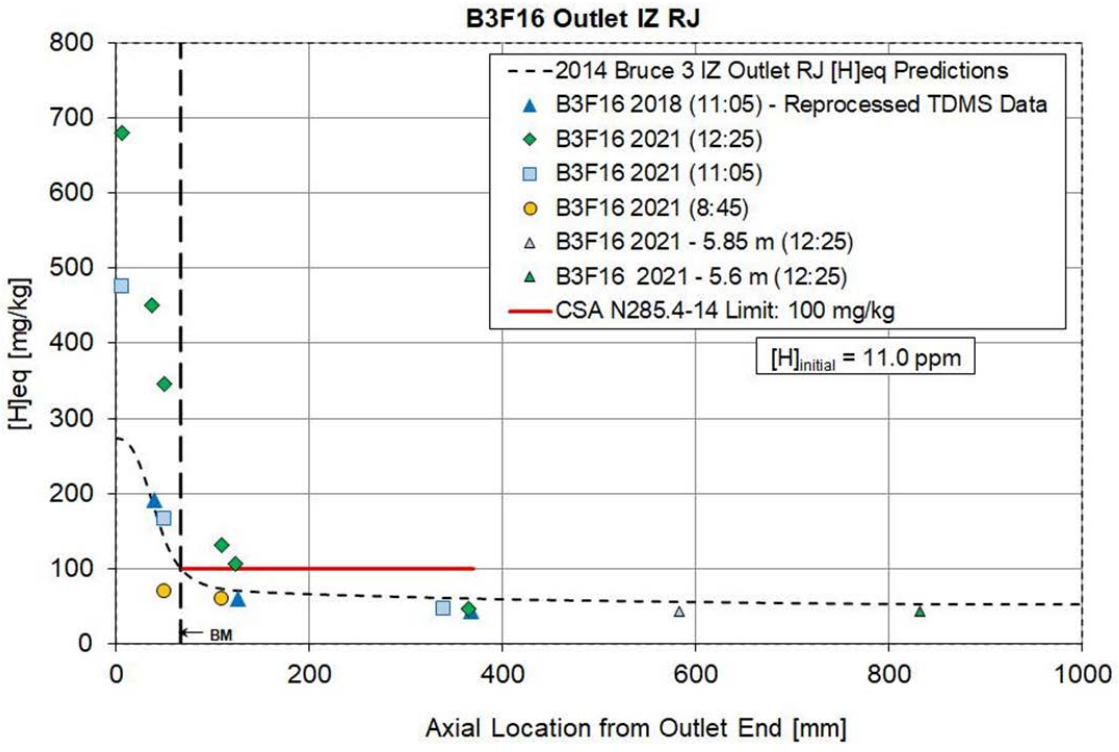
Unit & Channel	Location wrt PT outlet (mm)	Rotary Position (o'clock)	Measured [H] (ppm)	Measured [D] (ppm)	[H]eq (ppm)	Hot Hours
B3F16	9	12:25	111	1340	681	271,330
B3F16	9	11:05	80	930	476	271,330
B3F16	40	12:25	79	880	451	271,330
B3F16	54	12:25	67	670	346	271,330
B3F16	54	11:05	29	310	166	271,330
B3F16	54	8:45	15	115	68.5	271,330
B3F16	113	12:25	31	240	131	271,330
B3F16	113	8:45	16	96	59	271,330
B3F16	127	12:25	29	190	106	271,330
B3F16	368	12:25	22	71	46.5	271,330
B3F16	343	11:05	20	69	45.5	271,330
B3F16*	40	11:05	43.5	360.1	191.05	255,050
B3F16*	127	11:05	27	96.2	59.1	255,050
B3F16*	368	11:05	20.8	62.2	42.1	255,050

Unit 3 planned outage in 2018 (A1831) certified results.

Note: For B3F16 in both tables, [H]eq is calculated using [H]initial + 0.5 *measured [D].

Note: The difference in [H]eq between the yellow highlighted row and the green highlighted row is indicative of the high degree of circumferential variation.

Figure A1 – Generic Prediction and Measured Hydrogen Equivalent Concentrations from B3F16



References:

A1. Letter, L. Sigouin to M. Burton, “Bruce A and B: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR on Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement – New Action Item 2021-07-23406”, July 8, 2021, e-Doc 6600766, BP-CORR-00531-01849.

A2. Letter, M. Burton to L. Sigouin, “Bruce A and B: 2021 Annual Update on Deterministic Hydrogen Equivalent Predictions”, June 22, 2021, BP-CORR-00531-01669.

A3. Letter, L. Sigouin to M. Burton, “Bruce A and B: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR on Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement – New Action Item 2021-07-23406”, July 8, 2021, e-Doc 6600766, BP-CORR-00531-01849.

A4. Letter, M. Burton to L. Sigouin, “Action Item 2021-07-23406: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR”, July 15, 2021, BP-CORR-00531-01853.

A5. REGDOC-3.1.1 Unscheduled Report, “A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements”, June 29, 2021, B-2021-93819 DR.

A6. REGDOC-3.1.1 Unscheduled Report, “Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement”, July 5, 2021, B-2021-98077 DR.

July 25, 2021

BP-CORR-00531-01883

Mr. L. Sigouin
Director, Bruce Regulatory Program Division
Canadian Nuclear Safety Commission
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Ottawa, Ontario
K1P 5S9

Dear Mr. Sigouin:

Action Item 2021-07-23406: Bruce A and B:
Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements

The purpose of this letter is to provide notification, pursuant to PROL 18.01/2028, Licence Condition G.2, and the associated Licence Conditions Handbook, Section G.2, regarding the approach Bruce Power intends to follow should Units 4, 5, 7 or 8 be taken offline before their respective planned maintenance outages.

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

While Bruce Power has planned outages scheduled for all these Units and additional activities underway as noted previously, this correspondence demonstrates the measures being put in place proactively to improve margins of safety and the additional measures that would be undertaken by Bruce Power if a Unit is removed from service in an unplanned manner.

Compliance with Licensing Basis

Bruce Power maintains a paramount commitment to safety and reverence for the licensing basis. In Reference 1, Bruce Power provided information regarding the current operation of Units 1, 2, 4, 5, 7 and 8 in light of recent measurements from a surveillance pressure tube harvested from Unit 6. This included results from a Technical Operability Evaluation (TOE) of all operating pressure tubes at Bruce A and Bruce B to assess their ability to carry out their safety-related functions. The TOE concluded the pressure tubes are unconditionally operable and no operating pressure tube has been predicted or measured to be in excess of 120 ppm, and as such the Units remains in accordance with the established compliance verification criteria under Licence Condition 15.3.

The approach herein is consistent with the outcomes of our TOE ensuring continued safety of operation, consistency with the Licensing Basis and includes additional measures Bruce Power is undertaking.

Bruce Power Maury Burton, Chief Regulatory Officer
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The TOE also confirmed the entire length of all pressure tubes in operating units remain safe to operate based upon the lack of flaws observed in the region of interest and the bounding of measurements by predictions outside of the region of interest. It is important to note that consistent data from inspections of channels demonstrating a lack of flaws in the region of interest is a critical safety consideration related to the integrity of the tubes.

The units are safe to operate in any mode such as startup, shutdown and power operation; these changing conditions will not damage the pressure tubes given the lack of flaws in the region of interest as demonstrated through fitness for service assessments.

Pressure Tube Integrity

Over the previous 18-months, pressure tubes within all operating units on site were inspected during outage campaigns. These inspections confirmed the pressure tubes were fit-for-service and within the licensing basis. All units were returned to service in accordance with the processes required by Licence Condition 6.1 and Section 6.1 of the Licence Conditions Handbook, and as supported by fitness-for-service assessments which were accepted by CNSC staff in accordance with CSA N285.8.

All Pressure Tube inspections for Hydrogen Equivalent concentrations in the noted Units, over the last 18-months, were within 120 ppm and in compliance with Section 15.3

When pressure tubes are burst tested as part of industry surveillance activities it is important to note that with Hydrogen concentration increased alone, they do not fracture. In order to support testing in a laboratory environment significant flaws are added to the tubes to enable this result. These are flaws added in a laboratory environment have never been observed in a Bruce Power pressure tube.

In fact, Bruce Power has performed ~480 unique channel inspections (including the first 100mm inboard of the outlet burnish mark) for the life of Bruce Units 4,5,6,7 & 8. No flaws have ever been detected in the region of interest (top of tube) and there have been no dispositionable flaws detected for all axial positions in this portion of the pressure tubes.

In particular, as applied to Units 1 and 2, the TOE concluded that, due to operation for a limited number of hot hours following refurbishment, the pressure tube hydrogen equivalent concentrations in Units 1 and 2 remain lower than the other units. As such, the proposed approach for an unplanned outage applies only to Units 4, 5, 7 and 8.

The TOE confirmed the entire length of all pressure tubes in operating units remain safe to operate based upon the lack of flaws observed in the region of interest and the bounding of measurements by predictions outside of the region of interest. It is important to note that consistent data from inspections of channels demonstrating a lack of flaws in the region of interest is a critical safety consideration related to the integrity of the tubes and there is ample evidence in all Units on this front.

Safety Margin Enhancements

Following the submission of Reference 1, which focused on sustained reactor operation under hot conditions, Bruce Power examined beyond steady-state operation to determine what mitigating actions could be taken if there is a desire or need to cool down a unit or if a unit is removed from service in an unplanned manner before its planned maintenance outage to build additional safety margin.

A shutdown and return-to-service strategy has been developed to provide additional assurances that Units 4, 5, 7 and 8 can continue to operate safely and incompliance with the Licensing Basis through to the planned maintenance outages. Safety margin has also been improved by putting in place additional measures should a unit be removed from service in an unplanned manner prior to the planned outage date.

In particular, Bruce Power will be putting in place both plant configuration and design enhancements in addition to procedural changes and operator training as concrete steps to strengthen safety margin during the interim period prior to planned outages. Pursuant to Licence Condition G.2, a summary and rationale for the proposed changes to the shutdown and return-to-service of Units 4, 5, 7 and 8 is provided in Attachment A.

The approach improves margins of safety by applying several proactive and post shutdown measures that systematically prevent reactor states to further reduce risk and provide assurance of safety before returning a unit to service.

The proposed return to service approach would remain in place on lead-up to the planned outages. Upcoming planned outages have been included in Attachment B.

Planned Outages

As noted, Bruce Power has planned maintenance and inspection outages scheduled for Units 4, 5, 7 and 8 over the course of the next 18-months and will be carrying-out routine and enhanced fuel channel inspection activities as part of the scope for these outages.

Bruce Power will utilize enhancements to tooling currently underway, updated modeling data and recent learnings specifically related to circumferential observations. In addition the knowledge and experience gained through A2131 and the Unit 6 surveillance tube will be used to further refine the methods and approaches to be taken for pressure tube inspections during future outage campaigns.

As an example, prior to and during A2131, Bruce Power had already undertaken modifications to the circumferential wet scrape tool (CWEST) to facilitate the acquisition of scrape measurements closer to the burnish mark region and at some other positions around the pressure tube circumference (e.g. 12 o’clock and 7-9 o’clock positions). In addition, Bruce Power is expanding the A2131 CWEST inspection scope on a larger population of channels.

This data will be used in both Bruce Power’s Unit 3 return to service case (which will be communicated in a separate submission) and, given the orientation and location of the expanded channel population will be applied to broader considerations in demonstrating fuel channel hydrogen uptake behavior.

Summary

The proposed approach in Attachment A is consistent with the licensing basis and continues to ensure high levels of safety for the health, safety or security of Canadians or the environment. At its core, Units 4, 5, 7 and 8 remain capable of carrying out their safety-related functions combined with the integrity of key plant components.

The units were returned to service following their previous planned outage in accordance with Licence Condition 6.1, Section 6.1 of the Licence Conditions Handbook and supported by fitness-for-service assessments accepted by CNSC staff in accordance with CSA N285.8, Technical Requirements for In-Service Evaluation of Zirconium Alloy Pressure Tubes in CANDU Reactors.

Bruce Power will continue to share operating experience with industry peers regarding fuel channel hydrogen uptake, other inspection results which have demonstrated strong integrity and lack of flaws; inspection findings, mitigation strategies, procedures and training materials as well as design changes to ensure on-going industry learning and safety improvements.

In closing, discovered [H]eq behaviour of concentrations in the small upper region of some channels does not increase the probability of an occurrence (e.g. cold-overpressure transient), nor does it (based on the TOE) create anything not bounded by the approved accident analysis.

If you require further information or have any questions regarding this submission, please contact Mr. Maury Burton, Chief Regulatory Officer, Corporate Affairs & Operational Services, at (519) 361-2673 extension 15291, or maury.burton@brucepower.com.

Yours truly,

Maury Burton
Chief Regulatory Officer,
Bruce Power
2021.07.25 12:51:21 -04'00'

Maury Burton
Chief Regulatory Officer
Bruce Power

cc: CNSC Bruce Site Office

Attach. Note: Attachment B contains CONFIDENTIAL information and has not been included in this document.

Reference:

1. Letter, M. Burton to L. Sigouin, “Action Item 2021-07-23406: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR”, July 15, 2021, BP-CORR-00531-01853.

Attachment A

Shutdown and Return-to-Service of Units 4, 5, 7 and 8

Attachment A: Shutdown and Return-to-Service of Units 4, 5, 7 and 8

This attachment outlines the approach that Bruce Power intends to follow should there be a desire or need to cool down a unit in advance of its planned maintenance outage. This strategy applies to Forced Outages where the Unit is required to cool down. For any Forced Outage where the Reactor remains at Zero Power Hot (ZPH), the current approach remains valid and applicable. This strategy applies to Forced Outages in Units 4, 5, 7, and 8. Units 1 & 2 have recently been refurbished.

As described in the Technical Operability Evaluation, provided as Enclosure 1 to Reference A1, there is low risk of pressure tube rupture under cold overpressure transient (COPT) conditions, as there would need to be a through-wall flaw in a pressure tube which remained undetected by the persistent monitoring of the Annulus Gas system. Notwithstanding the low risk, cold overpressure transients, form a design basis challenge to pressure tube integrity which is appropriate to evaluate as Bruce Power has done through its process given additional information.

A cold over pressure transient (COPT) is when there is a loss of HT pressure control causing the HTS to pressurize at a cold PHT temperature. For example, a failure of pressure controllers in solid mode with the heat transport system full and cold could cause a COPT. While these are low probability as part of Bruce Power's rigorous process to continue to secure safety margin this was reviewed.

Reactor states which present an opportunity for a COPT to occur include any time that:

1. the unit is in a high level drained state and Unit-33320-RV16 not in place.
2. the unit is full, cold (<~140C) and Unit-33320-RV16 is not in place.
3. the unit is not in normal mode when the pressurizer remains connected providing a steam cushion.

Bruce Power has developed a strategy to mitigate the risk of this (rare/unlikely) event through the implementation of a proposed strategy that encompasses several proactive and post shutdown measures.

Proactive measures underway to build safety margin include:

1. Outage Planning and execution improvements
2. Revision of the Pressure/Temperature profile for heat-ups and cooldown
3. Permanent design changes and an enhancement to mitigate the magnitude and frequency of the COPT
4. Future inspections

The post shutdown measures are to review and evaluate the outage specific cooldown profile and confirmation if the Unit experienced an unplanned transient and in particular a Cold Over Pressure Transient.

Proactive Measures Underway:

1. **Outage Planning and execution improvements to lower risk of COPT**
   These activities are intended to minimize the time at risk or completely mitigate COPT likelihood during outages. Some activities that Bruce is considering have been broken down into three main categories. The first category is the Heat Transport System operating states (e.g. maximizing time with boilers open and reducing the time at risk by cooling down and heating up the PHT with the Feed and Bleed system in Normal Mode). The second is limiting time at risk configurations (e.g. reviewing lead out SSTs to reduce exposure time to COPTs). Finally,

ensuring the Operational documentation is updated and the crew receives additional training to decrease the response time for operator intervention should the pressure increase.

2. **Revise the Pressure/Temperature profile for heatups and cooldowns**
   Bruce Power is evaluating the feasibility of adjusting the Temperature and Pressure profile for heatups and cooldowns to provide additional margin for fracture protection. The changes will be performed in accordance with the Engineering Change Control Process (ECC) at both Bruce A and Bruce B. The target completion is approximately two months.

3. **Design Changes in relation to COPT**
   Bruce Power is also pursuing permanent design change and a separate enhancement action to recover available margin in the fracture protection assessments. The intent of the enhancement action is to supplement the COPT risk mitigation efforts in parallel with the implementation of the permanent design change. Each of these changes are being completed through the Engineering Change Control Process (ECC) to ensure the appropriate level of rigor is applied with respect to the change and to confirm its applicability.

   The enhancement action being investigated is a DCC software update which will provide automatic Heat Transport Feed Pump trip by the DCC on rapid increase of Heat Transport pressure. This update is currently underway and the target completion is approximately two months in order to complete the ECC process.

   In parallel, Bruce Power will implement a permanent modification which will mitigate the likelihood of a Cold Over Pressure Transient. This design change will be to install an alternate conditioned Liquid Relief Valve (LRV) setpoint to enhance overpressure protection to mitigate the consequence of a COPT. The design is in progress with a target completion of no later than Q1 2022 as this change will require system registration with the TSSA for all affected Units.

   Given that the cold over pressure transient is an already rare event, Bruce Power is taking these actions to further reduce the risk of a COPT.

4. **Future Inspections**
   To further understand the fuel channel hydrogen uptake behavior, Bruce Power has undertaken modifications to the circumferential wet scrape tool (CWEST) to facilitate the acquisition of scrape measurements closer to the burnish mark region and at some other positions around the pressure tube circumference (e.g. 12 o'clock and 7-9 o'clock positions). The modified tool is to be used during forthcoming outages starting with the Unit 3 planned outage which is currently underway. The next outage is scheduled in the fall of 2021 in unit 7. Bruce Power is currently evaluating the quantity of CWEST inspections in the next planned outage in Unit 7.

Post Shutdown Measures:

Review and Evaluate the outage specific cooldown Profile
Bruce Power has comprehensive operating manual procedures that apply operating pressure tube constraints for cooldown and heatup transients. These procedures are intended to maintain the Primary Heat Transport System (PHTS) within temperature, pressure, and duration profiles during the transient. The profiles minimize the risk of crack initiation from service-induced flaws in pressure tubes.

In general, the pressure tube operating procedures during heat-up and cool-down transients are developed to achieve the following objectives.

1. Heat-up and cool-down cycles in compliance with the operating procedures can minimize the risk of crack initiation from flaws in the pressure tubes due to Delayed Hydride Cracking (DHC), overload or fatigue.
2. Heat-up and cool-down cycles in compliance with the operating procedures will result in precipitating bulk hydrides which are less deleterious to fracture toughness.

The pressure, temperature, and duration steps in the operating procedures are generally governed by the operating envelope that is based on fracture protection, consideration of the pressure tubes using the fracture toughness versus temperature curve, or the flaw stability lines, in accordance with the CSA Standard N285.8. The time durations at various temperature ranges are generally established based on the consideration of DHC initiation avoidance.

Following any unit transient, the exact PHTS conditions during the transient are reviewed to assess whether the assumed operating conditions used in the assessments of pressure tube flaws remain bounding and therefore the acceptability of further operation. Bruce Power will specifically confirm and document that the preventative measures have been effective at avoiding a cold over pressure transient should a unit be removed from service requiring transition to a cold / depressurized state.

July 19, 2021

BP-CORR-00531-01875

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Dear Mr. Leblanc and Dr. Viktorov:

Bruce A and B: Response to
Subsection 12(2) of the General Nuclear Safety and Control Regulations:
Measurement of Hydrogen Equivalent Concentration in Pressure Tubes

The purpose of this letter is to confirm that Bruce Power will carry out the request made in Reference 1 and continue to provide information related to the measurement of hydrogen equivalent concentrations in pressure tubes at the earliest opportunity, but in every case, no later than July 30, 2021, as required by Reference 1.

The information required in accordance with the requirements of Subsection 12 (2) of the General Nuclear Safety and Control Regulations is provided in Attachment A.

In response to the findings, Bruce Power has maintained a paramount commitment to safety and reverence for the licensing basis by assembling a multi-disciplinary team to examine the findings, while proactively sharing information with CNSC staff and other CANDU operators. A Technical Operability Evaluation completed by the team was submitted to CNSC staff and shared with industry peers.

As noted in previous communications, measurements obtained from both the current Unit 3 outage (A2131) Circumferential Wet Scrape Tool (CWEST) scrape campaign and an industry surveillance tube removed from Unit 6 showed elevated hydrogen equivalent concentration (Heq) measurements in very specific locations of the channels. Upon further analysis of these measurements, it is clear they are limited to a small area of interest, which does not include the fuel string supporting section, commonly referred to as the working part, of the pressure tube. While this is positive from a safety and integrity perspective, Bruce Power will make future submissions for CNSC's consideration with respect to updating the licensing basis in this regard.

These measurements were taken from pressure tubes in Units not currently in operation. All operating Units on site have had their pressure tubes inspected during recent outage campaigns and were found to be both safe and within the licensing basis. At the time Bruce Power requested renewal of the operating licence from the CNSC, the submission was based on the best available information and testing to date. As industry

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developments, inspection and testing continue to advance, and as noted to the Commission at the time, Bruce Power has always intended to provide updates as additional results and inspections become available, and testing is completed as part of an industry-wide program.

Consistent with this, in May 2021 Bruce Power submitted to CNSC an updated Fracture Toughness Model (Revision 2) for review and consideration. The inputs from this model reflect the additional knowledge gained since licence renewal in 2018 and as such, it is more capable of accurately modelling pressure tube toughness.

In addition to the submission of information to the Commission, no later than July 30, 2021, as required by Reference 1, Bruce Power intends to provide the CNSC a subsequent submission, in the short term, that forms a strong technical basis for the Return to Service of Unit 3, which could be applied to future Unit planned outages, that builds on the outcome of the Technical Operability Evaluation and its follow up activities.

The integrity of pressure tubes is of the upmost importance to Bruce Power. The knowledge and experience obtained may be used to establish a framework to allow the return to service of Unit 3, which in turn, could be applied to future inspections planned on Units 7, 5, 4 and 8 as they enter upcoming planned maintenance outages over the next 18 months. These inspections are planned in order to safely manage the Fitness for Service of pressure tubes to their Major Component Replacement (MCR) outages where they will be fully replaced.

Bruce Power will establish a Regulatory Communication Plan, which is referred to at the CNSC as an administrative protocol, to outline communications and submissions required in accordance with regulatory processes. During this period, Bruce Power will continue to be fully transparent with the public using our Public Information Program to ensure appropriate information and context is available on these matters as it's our commitment to build both knowledge and confidence in safety as a licensee.

In addition to applying strong internal processes, industry collaboration through inspection and testing, and vendor partner support, Bruce Power will also secure experts ranging in backgrounds that will support the development, review and eventual submissions to the CNSC in support of a Commission decision for Return to Service of Unit 3 and updates to the licensing basis. While securing outside expertise is not new and is widely used in this area, Bruce Power believes this additional element is appropriate and will also form part of our Public Information Program activities.

Bruce Power looks forward to communicating with CNSC staff to ensure information provided in regulatory submissions meets CNSC staff needs on items that require short-term Staff and/or Commission consideration.

If you require further information or have any questions regarding this submission, please contact Mr. Maury Burton, Chief Regulatory Officer, Corporate Affairs & Operational Services, at (519) 361-2673 extension 15291, or maury.burton@brucepower.com.

Yours truly,

Maury Burton
Chief Regulatory Officer,
Bruce Power
2021.07.19 13:07:33 -04'00'

Maury Burton
Chief Regulatory Officer
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cc: CNSC Bruce Site Office
Luc Sigouin, CNSC Ottawa

Attach.

Reference:

1. Letter, A. Viktorov to M. Burton, “Bruce A and B: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes”, July 13, 2021, e-Doc 6603948, BP-CORR-00531-01868.

Attachment A

Report of Planned Compliance pursuant to Subsection 12 (2) of the General Nuclear Safety and Control Regulations related to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes

Attachment A:
Report of Planned Compliance pursuant to Subsection 12(2)
of the General Nuclear Safety and Control Regulations
related to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes

The information required to be filed with the Commission by July 19, 2021, as a result of the request made pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations (Reference A1) is provided herein.

a) confirmation that the request will or will not be carried out or will be carried out in part.

Bruce Power intends to carry out the requests of Reference A1, and file a report to the Commission, no later than July 30, 2021, with respect to the following actions:

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

In addition, Bruce Power intends to complete the following analyses and make a report to the Commission at the earliest opportunity and in advance of the timelines as required by Reference A1 with respect to:

5. Analysis of the hydrogen uptake model validity, reflecting new information.

b) any action Bruce Power has taken to carry out the request or any part of it.

Following the identification of elevated hydrogen equivalent concentrations reported in References A2 and A3, Bruce Power immediately initiated a Technical Operability Evaluation to evaluate the ability of all operating pressure tubes to carry out their safety-related functions. The completed Technical Operability Evaluation was provided as Enclosure 1 to Reference A4.

c) any reasons why the request or any part of it will not be carried out.

Bruce Power's intention is to carry out the request in full.

d) any proposed alternative means to achieve the objectives of the request.

Alternative means to achieve the objectives of the request are not expected to be necessary.

e) any proposed alternative period within which Bruce Power proposes to carry out the request.

While Bruce Power's intention is to carry out the request in full by July 30, 2021, the completion of corrective actions identified by the recently completed Technical Operability Evaluation (Enclosure 1 to Reference 4) extend throughout the remainder of 2021.

References:

A1. Letter, A. Viktorov to M. Burton, “Bruce A and B: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes”, July 13, 2021, e-Doc 6603948, BP-CORR-00531-01868.

A2. REGDOC-3.1.1 Unscheduled Report, “A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements”, June 29, 2021, B-2021-93819 DR.

A3. REGDOC-3.1.1 Unscheduled Report, “Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement”, July 5, 2021, B-2021-98077 DR.

A4. Letter, M. Burton to L. Sigouin, “Action Item 2021-07-23406: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR”, July 15, 2021, BP-CORR-00531-01853.

July 30, 2021

BP-CORR-00531-01884

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Dear Mr. Leblanc and Dr. Viktorov:

Bruce A and B: Response to
Subsection 12(2) of the General Nuclear Safety and Control Regulations:
Measurement of Hydrogen Equivalent Concentration in Pressure Tubes

The purpose of this letter is to respond to Reference 1 and the formal request pursuant to subsection 12(2) of the *General Nuclear Safety and Control Regulations,* as committed in Reference 2. Bruce Power's report regarding operational pressure tube fitness for service and the licensing basis is provided as Attachment A.

The report provides the requested information related to Bruce Power's recent findings in a limited number of pressure tubes. This is regarding the measurement of elevated levels of hydrogen equivalent concentration within limited and very specific region of interest. These findings represent a small number of pressure tubes from a larger overall inspection campaign.

Compliance with Licensing Basis

Since 2019, pressure tubes within all operating units on site have been inspected during unit planned outages. These inspections confirmed the pressure tubes remain fit-for-service and within the licensing basis. All units were returned to service in accordance with the processes required by Licence Condition 6.1 and Section 6.1 of the Licence Conditions Handbook, and as supported by fitness-for-service assessments, which were accepted by CNSC staff in accordance with CSA N285.8. Accordingly, all pressure tube inspections in the Units 1, 2, 4, 5, 7 and 8 have measured and predicted hydrogen equivalent concentrations within 120 ppm and in compliance with Section 15.3 of the Licence Conditions Handbook, LCH-PR-18.01/2028-R002.

Note that, on the observed subset of pressure tubes from Unit 3 and Unit 6, the volume of the region of interest, where elevated levels of hydrogen equivalent concentration was measured, is less than 0.5% of the total pressure tube volume. Furthermore, the existing predictive model continues to provide bounding predictions for all pressure tubes outside this small region of interest.

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Pressure Tube Integrity

Over the operating life of all pressure tubes, Bruce Power has also performed full length volumetric inspections to detect pressure tube flaws (including inspections of the region of interest). These inspections for flaws use a modern tool setup known as Advanced Non-Destructive Evaluation (ANDE) that carries out extensive imaging of pressure tubes. They also include a significant database of historical Channel Inspection and Gauging Apparatus for Reactors (CIGAR) inspections. The results of the ANDE and CIGAR inspections have demonstrated, and continue to demonstrate, in concert with data from a large population of pressure tubes, that there is no evidence of flaws in the region of interest.

In isolation, elevated levels of equivalent hydrogen concentration do not challenge pressure tube fitness for service. For fitness for service to be challenged, a pressure tube would also need a flaw of significant dimensions introduced to an area with adequate hydrogen concentration to promote Delayed Hydride Cracking initiation, propagate to a through-wall condition and then a failure of the Annulus Gas system to detect the dew point rate of rise.

Additionally, as discussed in References 3 and 4, Bruce Power determined that the continued operation of Units 1, 2, 4, 5, 7, and 8, is safe, in accordance with the licensing basis, and does not negatively impact the health, safety, or security of Canadians or the environment as in-service pressure tubes remain capable of carrying out their safety related functions. The units are safe to operate in any mode, including startup, shutdown and power operation. Also, Bruce A Units 1 and 2 pressure tubes were refurbished in 2012 and have not operated long enough to exhibit pressure tubes with elevated [Heq].

Planned Outages

Bruce Power has planned maintenance and inspection outages scheduled for Units 4, 5, 7 and 8 over the course of the next 18-months and will be carrying-out routine pressure tube inspection activities. However, based upon the current observations from Units 3 and 6, Bruce Power plans to refine the scope of inspections to further the understanding of the circumferential distribution of hydrogen isotopes within the region of interest. Bruce Power will utilize scrape tool enhancements developed as part of the Unit 3 extent of condition effort and updated modeling to further understand this hydrogen isotope circumferential bias in the region of interest.

In accordance with Reference 5, Bruce Power will seek authorization from the Commission prior to the restart of Unit 3, which is currently shut down for a planned maintenance outage. While in the outage, all Unit 3 pressure tubes remain depressurized. Any request for authorization would be accompanied by supporting fitness for service assessments in accordance with the licensing basis.

Bruce Power will continue to share operating experience with industry peers regarding pressure tube hydrogen isotope surveillance results, and inspection findings within the region of interest, mitigation strategies, procedures and training materials, as well as design changes, to ensure on-going industry learning and safety enhancements.

If you require further information or have any questions regarding this submission, please contact Mr. Maury Burton, Chief Regulatory Officer, Corporate Affairs & Operational Services, at (519) 361-2673 extension 15291, or maury.burton@brucepower.com.

Yours truly,

Maury Burton
Chief Regulatory Officer
Bruce Power

cc: CNSC Bruce Site Office
Luc Sigouin, CNSC Ottawa

Attach.

References:

1. Letter, A. Viktorov to M. Burton, "Bruce A and B: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes", July 13, 2021, e-Doc 6603948, BP-CORR-00531-01868.
2. Letter, M. Burton to M. Leblanc and A. Viktorov, "Bruce A and B: Response to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Measurement of Hydrogen Equivalent Concentration in Pressure Tubes", July 19, 2021, BP-CORR-00531-01875.
3. Letter, M. Burton to L. Sigouin, "Action Item 2021-07-23406: CNSC Review REGDOC-3.1.1 Event Report B-2021-98077 DR", July 15, 2021, BP-CORR-00531-01853.
4. Letter, M. Burton to L. Sigoiun, "Action Item 2021-07-23406: Bruce A and B: Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements", July 25, 2021, BP-CORR-00531-01883.
5. Letter, R. Jammal to M. Burton, "Designated Officer Order issued to Bruce Power", July 26, 2021, BP-CORR-00531-01904.

Attachment A

Report of Bruce Power Analysis and Review regarding Pressure Tube Fitness for Service pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations related to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes

Attachment A:
Report of Bruce Power Analysis and Review regarding Pressure Tube Fitness for Service pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations related to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes

Pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations, Reference A1 requested a report by July 30, 2021, regarding Bruce Power's analysis and review of pressure tube fitness for service, in respect of the following actions:

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

The report, which expands upon the Bruce Power's original response (Reference A2), is provided below. Bruce Power will provide an additional report with respect to Item 5 by January 13, 2022, as required by Reference A1.

1. Impact on the Demonstration of Pressure Tube Fitness for Service

Bruce Power maintains a paramount commitment to safety and reverence for the licensing basis.

Following the identification of hydrogen equivalent concentrations in excess of the generic predictions near the outlet burnish mark of Unit 3 pressure tubes and a surveillance pressure tube removed from Unit 6, Bruce Power assembled a multi-disciplinary team to examine the findings, while proactively sharing information with CNSC staff and other CANDU operators. The detailed Technical Operability Evaluation, completed within a week of initiation by the team, was submitted to CNSC staff, in Reference A3, and shared with industry peers.

The Technical Operability Evaluation examined all operating pressure tubes at Bruce A and Bruce B to assess their ability to carry-out their safety related functions. The evaluation confirmed the pressure tubes are unconditionally operable and that no operating pressure tube has been predicted or measured to be in excess of 120 ppm. As such, the operating units remain in accordance with established compliance verification criteria under Licence Condition 15.3.

Specifically, having only operated for a limited number of hours, the recently replaced pressure tubes in Units 1 and 2 have not operated long enough to be impacted by elevated hydrogen equivalent concentrations. The pressure tubes in Units 4, 5, 7 and 8 remain operable along their entire length as there is assurance that margins of safety remain in support of the continued, unconditional, operation of pressure tubes within the operating units.

More recently, as described in Reference A4, Bruce Power concluded that changes to operating conditions, including power operations, start-up and cooldown will not challenge the pressure tubes fitness for service, given the lack of flaws in the region of interest.

Note that, when pressure tube burst tests are carried out in the laboratory (as part of industry surveillance activities) with elevated hydrogen equivalent concentrations alone and without an artificially introduced starter notch, its fracture would not be expected. In order to support testing in a laboratory environment, a significant artificial flaw is added to the tube to enable the fracture toughness test to be

completed. This confirms that the presence of flaws is a prerequisite for challenges to pressure tube fitness for service.

Bruce Power has performed ~480 unique pressure tube inspections (including the region of interest) for the life of Bruce Units 3, 4, 5, 6, 7 and 8. No flaws have ever been detected in the region of interest and there have been no dispositionable flaws detected for all axial and circumferential positions in this portion of the pressure tubes.

The elevated hydrogen equivalent concentrations in Units 3 and 6 were from a limited region of interest in a small number of pressure tubes. This area of the pressure tube does not come into contact with fuel bundle bearing pads and therefore is not subject to the formation of flaws while in service. The absence of flaws within the region of interest, the behavior of pressure tubes in the high temperature region, and the concurrence between predictive and measured values outside the region of interest all support Bruce Power's assessment of continued pressure tube fitness for service.

The Technical Operability Evaluation confirmed the entire length of all pressure tubes in operating units remain safe to operate based upon the lack of flaws observed in the region of interest and the bounding of measurements by predictions outside of the region of interest. It is important to note that consistent data from inspections of pressure tubes demonstrating a lack of flaws in the region of interest is a critical safety consideration related to the integrity of the tubes and there is ample evidence in all units on this front.

Units 3 and 6 are currently offline and, as such, there is no safety concern resulting from the elevated measurements of hydrogen equivalent concentration in their pressure tubes. In fact, the Unit 6 pressure tube removal has been completed as part of the Major Component Replacement currently underway. New pressure tubes will be installed prior to return to service in 2023.

The discovered hydrogen equivalent concentration behaviour limited to the small upper region of some pressure tubes does not increase the probability of station transient (e.g. cold overpressure transient), nor does it (based on the results of the Technical Operability Evaluation) lead to scenarios that are not bounded by the approved accident analysis

2. Verify Operation of All Reactors Remains within the Licensing Basis

Bruce Power's Power Reactor Operating Licence (PROL 18.01/2028) imposes two conditions related to the operability of pressure tubes. Licence Condition 6.1 requires that Bruce Power, "*...implement and maintain a fitness for service program"* and Licence Condition 15.3 requires that, "[b]*efore hydrogen equivalent concentrations exceed 120 ppm, [Bruce Power must] demonstrate that pressure tube fracture toughness will be sufficient for safe operation beyond 120 ppm."*

As presented in the Introduction to the Licence Conditions Handbook (LCH-PR-18.01/2028-R002), *"the general purpose of the Licence Conditions Handbook (LCH) is to identify and clarify the relevant parts of the licensing basis for each licence condition*." Within the Licence Conditions Handbook, Compliance Verification Criteria (CVC) are established within each section to serve, "*as the criteria used by CNSC staff to verify and oversee compliance with* [a licence condition]."

The Compliance Verification Criteria within Section 6.1 of the Licence Conditions Handbook requires that Bruce Power implement and maintain a pressure tube fitness for service program which satisfies the requirements of CSA N285.8, *Technical requirements for in-service evaluation of zirconium alloy pressure tubes in CANDU reactors.* In accordance with the standard, prior to the return to service of any reactor from a planned maintenance outage, Bruce Power submits pressure tube fitness for service assessments for CNSC staff acceptance. The assessments use a combination of conservative models, measurements from inspections and tested material properties (such as pressure tube fracture toughness) consistent with the verification criteria in CSA N285.8. Additionally, the standard requires

that Bruce Power periodically demonstrate that fracture protection and Leak-Before-Break assessments of pressure tubes (using predicted Fracture Toughness) satisfy CSA N285.8 acceptance criteria.

Since 2019, pressure tubes within all operating units on site were inspected during outage campaigns. These inspections confirmed the pressure tubes were fit-for-service and within the licensing basis. All units were returned to service in accordance with the processes required by Licence Condition 6.1 and Section 6.1 of the Licence Conditions Handbook, and as supported by fitness-for-service assessments, accepted by CNSC staff in accordance with CSA N285.8.

As each of the operating units have satisfied these requirements prior to their most recent return to service from their respective planned outages, Bruce Power confirms that the operating units remains in compliance with the licensing basis required by Licence Condition 6.1.

The Compliance Verification Criteria within Section 15.3 of the Licence Conditions Handbook requires that Bruce Power "*…obtain approval from the Commission before operating any pressure tube with a measured [H_{eq}] greater than 120 ppm, or beyond the time any pressure tube is predicted to have a [H_{eq}] greater than 120 ppm."* The Compliance Verification Criteria further limit the validity of predictions to those which are "*… determined utilizing the hydrogen prediction model applied to the unit in the most recent report submitted to the CNSC under CSA N285.4, Clause 12.3.6.2"* and notes that "[r]*evisions to the hydrogen predictions model used in the most recent report shall be accepted by the CNSC."*

All pressure tube inspections for hydrogen equivalent concentrations in Units 1, 2, 4, 5, 7, and 8, over the last outage cycle, were within 120 ppm and in compliance with Section 15.3.

In accordance with the Compliance Verification Criteria of Section 15.3, Bruce Power understands that, should any pressure tube in Units 1, 2, 4, 5, 7, or 8, be measured to be in excess of 120 ppm, Commission approval would need to be obtained; however, as no operating pressure tube has been predicted or measured to be in excess of 120 ppm, operation remains in accordance with the established compliance verification criteria and the licensing basis required by Licence Condition 15.3.

3. Other Measures taken in Response

Shutdown and Return-to-Service Safety Margin Enhancements

Following the submission of Reference A3, which focused on sustained reactor operation under hot conditions, Bruce Power examined beyond steady-state operation to determine what mitigating actions could be taken if there is a desire or need to cooldown a unit or if a unit is removed from service in an unplanned manner before its planned maintenance outage to build additional safety margin. A shutdown and return-to-service strategy was developed, and submitted to CNSC staff in Reference A4, to provide additional assurance that Units 4, 5, 7 and 8 can continue to operate safely and in compliance with the licensing basis through to the planned maintenance outages by demonstrating the measures being put in place proactively to improve margins of safety and the additional measures that would be undertaken by Bruce Power if a Unit is removed from service in an unplanned manner.

In particular, Bruce Power sought to establish both plant configuration and design enhancements, in addition to procedural changes and operator training, as concrete steps to strengthen safety margin during the interim period prior to planned outages.

In order to minimize the time at risk or completely mitigate the risk of a unit being exposed to a cold overpressure transient, where pressure tubes minimum required margins can be challenged, Bruce Power has considered a number of enhancements within three main categories. The first being an examination of the Heat Transport System operating states (e.g. maximizing time with boilers open and reducing the time at risk by cooling down and heating up the Primary Heat Transport with the Feed and Bleed system in Normal Mode). The second category looked to limit time at risk configurations (e.g.

reviewing lead out safety system tests to further reduce the potential for cold overpressure transients). Finally, Bruce Power has examined operational documentation with an aim to ensure it is updated and the crew receives additional training to decrease the response time for operator intervention should heat transport pressure increase.

Design Improvements

a) Revise the Pressure/Temperature profile for heat-ups and cooldowns

Bruce Power is evaluating the feasibility of adjusting the temperature and pressure profile for heat-ups and cooldowns to provide additional margin for fracture protection. The changes, if implemented, would be performed in accordance with the Engineering Change Control Process (ECC) at both Bruce A and Bruce B.

b) Design Changes in relation to Cold Overpressure Transient (COPT)

Bruce Power is also examining the benefits of a permanent design change and a separate enhancement action to bolster available margin in fracture protection assessments. The enhancement action considers a Digital Control Computer (DCC) software update which is expected to provide automatic Heat Transport Feed Pump trip by the DCC on rapid increase of Heat Transport pressure.

The intent of the enhancement action would be to supplement any COPT risk mitigation efforts. Each of these changes would be completed through the Engineering Change Control Process (ECC) to ensure the appropriate level of rigor is applied with respect to the change and to confirm its applicability.

In parallel, Bruce Power is exploring the feasibility of a permanent modification which would install alternate conditioned Liquid Relief Valve (LRV) setpoint(s) to enhance overpressure protection with the aim to further mitigate the consequence of a COPT. This change will require system registration with the TSSA for the new LRV setpoints.

All changes will be performed in accordance with the Engineering Change Control (ECC) process at both Bruce A and Bruce B as required by the Licence Condition 5.1.

In accordance with Reference A5, Bruce Power will seek authorization from the Commission prior to the restart of any of Units 3, 4, 5, 7 or 8 following any outage that results in the cooldown of the heat transport system.

Bruce Power's approach improves margins of safety by applying several proactive and post-shutdown measures that systematically prevent reactor states to further reduce risk and provide assurance of safety before returning a unit to service.

Planned Outage Enhancements

As noted, Bruce Power has planned maintenance and inspection outages scheduled for Units 4, 5, 7 and 8 over the course of the next 18-months and will be carrying-out routine and enhanced pressure tube inspection activities as part of the scope for these outages.

Bruce Power will utilize enhancements to tooling currently underway, updated modeling data and recent learnings specifically related to circumferential observations. In addition, the knowledge and experience gained through the current Unit 3 planned outage (A2131) and the Unit 6 surveillance tube will be used to further refine the methods and approaches to be taken for pressure tube inspections during future outage campaigns.

As an example, prior to and during A2131, Bruce Power had already undertaken modifications to the circumferential wet scrape tool (CWEST) to facilitate the acquisition of scrape measurements closer to the burnish mark region and at some other positions around the pressure tube circumference (e.g. 12 o'clock and 7-9 o'clock positions). In addition, Bruce Power is expanding the A2131 CWEST inspection scope on a larger population of pressure tubes. This data will be used in both Bruce Power's Unit 3 return to service case (which will be communicated in a separate submission) and, will be applied to evaluating and modelling pressure tube hydrogen uptake behavior.

Operating Experience

Bruce Power will continue to share operating experience with industry peers regarding pressure tube hydrogen uptake, other inspection findings, mitigation strategies, procedures and training materials as well as design changes to ensure on-going industry learning and safety improvements.

4. Impact on Unit 3 Return to Service

In accordance with Reference A5, Bruce Power will seek authorization from the Commission prior to the restart of Unit 3, which is currently shut down for a planned maintenance outage, as a result of the measurements taken during the outage. While in outage, all Unit 3 pressure tubes remain depressurized.

During A2131 outage, hydrogen equivalent measurements [Heq] obtained from several pressure tubes in the outlet rolled joint region measured higher than expected. The results from three pressure tubes, F16, C11, and L11 had elevated [Heq] in the compressive region at the outlet rolled joint, and F16 also had elevated [Heq] inboard of the Burnish Mark (BM). These results were reported to CNSC in a timely manner under REGDOC-3.1.1 (References A7 and A8).

Note that, on the observed subset of pressure tubes from Unit 3, the volume of the region of interest, where elevated levels of hydrogen equivalent concentration was measured, is < 0.5% of the total pressure tube volume. Further, the existing deuterium pickup model continues to provide bounding predictions for the all pressure tubes outside this small region of interest.

Based on the results, additional pressure tubes were added to outage scope for the Circumferential Wet Scrape Tool (CWEST) and Advanced non-Destructive Evaluation (ANDE) inspections of the outlet region. In addition, several of the pressure tubes targeted by the original scope were also revisited to scrape as close as possible to the BM as well as at different clock positions to understand the extent of measured circumferential variation.

From the results of this scrape campaign, large circumferential variation in [Heq] was observed in the rolled joint region in the compressive region in the upper portion of the tube outboard of the BM and a small distance inboard of the BM (i.e. the region of interest) including one confirmed measurement of 131 ppm for F16 inboard of the burnish mark. Notably, the results of the ANDE inspections of these pressure tubes confirmed that there are no flaws in the outlet rolled joint regions of these pressure tubes that require disposition in accordance with CSA N285.4.

Given the findings in the region of interest, Bruce Power will complete additional activities to ensure all Unit 3 pressure tubes will only be returned to service when fitness for service evaluations can be completed, in accordance with the licensing basis, and the CNSC order, received in Reference A5.

To this end, Bruce Power is examining impacts to existing assessments, and the activities required to support a return to service from the current Unit 3 planned outage (A2131) to demonstrate continued fitness for service for Unit 3 to its planned MCR outage.

The activities being pursued include the following:

Support to Increase [Heq] Level

1. Mechanistic understanding/model and d-uptake predictive model

In light of the [Heq] measurements and circumferential variation in the region of interest the predictive capability for [Heq] for the region of interest and for the rest of the tube is being re-evaluated.

Development of a predictive model accounting for elevated [Heq] and circumferential variation of [Heq] observed in the outlet rolled joint region is in progress. For the region of interest, the scrape data collected during A2131 may serve as a basis for such a model. Alternative methods to model and predict the observations, including the use of other software such as H3DMAP, will also be pursued to conservatively predict [Heq] at end of life (EOL).

For the balance of the tube, the existing rolled-joint model is sufficiently conservative for predicting [Heq] at EOL.

2. Justification of extending fracture toughness model validity limits

Due to the potential for [Heq] levels greater than 120 ppm measured in the region of interest, the use of the Rev. 2 fracture toughness model may benefit this region. For the balance of the tube, the Rev. 1 model remains appropriate and applicable. Currently, the Rev. 2 fracture toughness model has a validity limit of 100 ppm up to 1.5m from the front end of the tube and 140 ppm for the rest of the tube. While a justification for extending the validity limit to 120 ppm for the front end has already been developed, a justification for 160 ppm or higher for the front and back end is being considered for use in FFS assessments.

A burst test specimen hydrided to 160 ppm [Heq] is being prepared on the front end section of B6N07 for testing. The test temperature has been selected as 65ºC as this is the temperature where the margin between the allowable pressure profile and the heat-up and cooldown transient is the least in fracture protection evaluation. The burst test results could be used to validate the prediction of the Rev. 2 Cohesive-Zone fracture toughness model up to at least that concentration, for both front end outlet (FEO) and back end outlet (BEO) configurations.

Impact to Relevant Assessments

a) Flaw disposition.

The existing flaw disposition for Bruce Unit 3 (Reference A9) remains valid and is not impacted by elevated [Heq] in the region of interest because there are no flaws detected in the region of interest that require disposition. As per established process, an updated flaw disposition for all inspected flaws would be submitted to CNSC for acceptance prior to the return to service from A2131 and would account for [Heq] findings, as required.

b) Pressure Tube to Calandria Tube (PT/CT) contact disposition.

The existing PT/CT contact dispositions for Bruce Unit 3 (Reference A10) remains valid and is not impacted by elevated [Heq] in the region of interest because no PT/CT contact in the region of interest is physically possible. Given the existing PT/CT contact dispositions expired at the time of the current

A2131 outage, new dispositions based on completed inspection and maintenance scope would be submitted to CNSC for acceptance prior to restart from A2131 accounting for [Heq] findings, as required.

c) Fracture protection evaluation.

The existing probabilistic fracture protection (PFP) assessment for Bruce Unit 3 (Reference A11) remains valid for portions of pressure tube outside the region of interest because [Heq] is below the limits of the Rev. 1 fracture toughness model.

For the region of interest, demonstration of fracture protection for elevated [Heq] would need to be evaluated for all Service Levels.

For heat-up and cooldown transients a deterministic fracture protection evaluation could be performed, potentially with a modified transient, with the objective of maintaining a safety factor of 1.3 as required by CSA N285.8.

Any modifications to the heat-up and cooldown profile in the operating units would be evaluated in parallel via the Engineering Change Control (ECC) process as further discussed in the Design Improvement section in part 3 above.

Similarly, for Level C transients, deterministic fracture protection evaluations could be performed to maintain a safety factor of 1.0 as required by CSA Standard N285.8 by potentially crediting a change to the HTS pressure during a cold over pressure transient (COPT). The pressure setpoint, if modified, would be confirmed in parallel via the ECC process as further discussed in part 3.

d) Evaluation of uninspected pressure tubes in Bruce Unit 3.

A Probabilistic Core Assessment (PCA) may be considered in the longer term to evaluate the impact of elevated [Heq] on the predicted pressure tube rupture frequencies, assuming the elevated [Heq] measurements are also applicable to uninspected pressure tubes. In order to perform the PCA, it may be beneficial to first incorporate the Rev. 2 fracture toughness model into the code. Based on past experience, it is expected that the impact of elevated [Heq] in the narrow region of interest on the predicted pressure tube rupture frequencies would not be significant.

5. Additional Development Initiatives and Hydrogen Uptake Model Update

Bruce Power believes that the diffusion of hydrogen isotopes to the region of interest at the top of the outlet end of pressure tubes is driven by a temperature gradient from the top to the bottom of the pressure tube. This behavior is being investigated via finite element modeling,

As documented in the Technical Operability Evaluation, submitted in Reference A3, Bruce Power has initiated a number of corrective actions in response to the newly observed uptake behaviour. Bruce Power expects, by the end of the year, to:

1) Use the measurement results from the current Unit 3 outage (A2131) and the Unit 6 surveillance pressure tube to evaluate and determine the hydrogen equivalent concentrations appropriate to evaluate fracture protection (FP) and probabilistic core assessments (PCA);
2) Complete fracture toughness burst tests at 160ppm hydrogen concentration. Confirm results are within acceptable range to confirm model behaviour

3) Complete fracture protection (FP) assessment for the bounding units to confirm results are within acceptance criteria;
4) Complete probabilistic core assessment (PCA) for the bounding unit and confirm results are within acceptance criteria; and,

With this in mind, in the coming months Bruce Power, in partnership with industry, will ensure the completion of further burst testing. The goal is to test samples with a target hydrogen isotope concentration of 160 ppm to further confirm the validity of the previously developed Revision 2 Fracture Toughness model which was previously submitted to CNSC staff in Reference A6.

In parallel, Bruce Power will seek to advance CNSC staff acceptance of Revision 2 of the fracture toughness model previously submitted. Revision 2 of the model was developed to predict the fracture toughness of pressure tubes in the lower-shelf and transition temperature regimes for higher levels of hydrogen equivalent concentration. The revised model, which is based on significantly more results from rising pressure burst tests on hydrided irradiated specimens than the Revision 1 model, is valid beyond the current limits of the Revision 1 model and enacts other enhancements.

Bruce Power will provide an additional report with respect to the analysis of the hydrogen uptake model validity, reflecting new information prior to January 13, 2022, as required by Reference A1.

References:

A1. Letter, A. Viktorov to M. Burton, “Bruce A and B: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes”, July 13, 2021, e-Doc 6603948, BP-CORR-00531-01868.

A2. Letter, M. Burton to M. Leblanc and A. Viktorov, “Bruce A and B: Response to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Measurement of Hydrogen Equivalent Concentration in Pressure Tubes”, July 19, 2021, BP-CORR-00531-01875.

A3. Letter, M. Burton to L. Sigouin, “Action Item 2021-07-23406: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR”, July 15, 2021, BP-CORR-00531-01853.

A4. Letter, M. Burton to L. Sigoiun, “Action Item 2021-07-23406: Bruce A and B: Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements”, July 25, 2021, BP-CORR-00531-01883.

A5. Letter, R. Jammal to M. Burton, “Designated Officer Order issued to Bruce Power”, July 26, 2021, BP-CORR-00531-01904.

A6. Letter, M. Burton to L. Sigouin, “Bruce A and B: Technical Basis for Revision 2 of Cohesive-Zone Based Fracture Toughness Model”, May 19, 2021, BP-CORR-00531-01570.

A7. REGDOC-3.1.1 Unscheduled Report, “A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements”, June 29, 2021, B-2021-93819 DR.

A8. REGDOC-3.1.1 Unscheduled Report, “Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement”, July 5, 2021, B-2021-98077 DR.

A9. Letter, M. Burton to L. Sigouin, “Bruce A Unit 3 2018/2019: Pressure Tube Flaw Component Disposition”, March 1, 2019, NK21-CORR-00531-14892.

A10. Letter, M. Burton to L. Sigouin, “Bruce A Unit 3: Component Disposition of Pressure Tube to Calandria Tube Contact”, November 20, 2020, BP-CORR-00531-00955.

A11. Letter, M. Burton to L. Sigouin, “Bruce A Unit 3: Probabilistic Fracture Protection Assessment”, October 20, 2020, BP-CORR-00531-00901.