March 11, 2022

BP-CORR-00531-02589

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:

Bruce A and B: Defense-in-Depth Approach for Addressing
<u>Elevated Hydrogen Equivalent Concentration ($[H]_{eq}$) in the Inlet Rolled Joint</u>

The purpose of this letter is to provide CNSC staff with supplementary information on Bruce Power's defense-in-depth approach to ensure the overall risk of a tube rupture due to elevated hydrogen equivalent concentration ($[H]_{eq}$) in the inlet rolled joint region of pressure tube remains low. The defense-in-depth approach was communicated to the CNSC in Reference 1.

Bruce Power recognizes that ongoing technical work is required to further understand the longer-term considerations and mechanisms related to elevated $[H]_{eq}$ in the inlet rolled joint region of ex-service pressure tubes from both Bruce Power and OPG through a joint industry program.

While this longer-term work is underway, Bruce Power has established a defense-in-depth approach to evaluate the overall risk of pressure tube integrity to demonstrate safety, consisting of two key elements:

1) a risk-informed fracture protection evaluation of a postulated through-wall flaw in the inlet rolled joint region with elevated $[H]_{eq}$ (Enclosure 1 in Reference 1); and

2) a Probabilistic Safety Analysis (PSA) to evaluate the impact of pressure tube leak and rupture on the overall severe core damage and large release frequency (Attachment A in this letter).

For the first element of the defense-in-depth– the risk-informed fracture protection evaluation, there are several key foundational elements which are specifically designed to ensure protection against pressure tube rupture. These are based on conservative assumptions that are bounding from a fracture protection perspective including:

1) postulation of a flaw at the top 180 degrees in the inlet rolled joint region where $[H]_{eq}$ is elevated regardless of the fact that no flaw has ever been detected in that portion of pressure tube in Bruce reactors. Furthermore, the conclusions of the risk-informed fracture protection evaluation apply to any circumferential positions in the inlet rolled joint region, regardless of how the region of interest is defined circumferentially;

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2) postulation of a flaw that is severe enough to have initiated and grown through wall without being detected by the Annulus Gas System (AGS), which is specifically designed to detect any moisture ingress from pressure tubes (including any from a flaw that has grown through wall);

3) Evaluation of this postulated through-wall flaw located within an area where $[H]_{eq}$ could be up to 120 ppm at 20 mm inboard of the burnish mark (whereas the measured $[H]_{eq}$ was only at 40 ppm in B6S13 inlet rolled joint).

4) As an extra conservative measure, sensitivity cases to evaluate fracture protection with $[H]_{eq}$ up to 200 ppm at 20 mm inboard of the burnish mark (Attachment B in Reference 1).

The risk-informed fracture protection evaluation has demonstrated that the required safety factors for all service level transients as per CSA N285.8-15 were met for $[H]_{eq}$ up to 120 ppm. A sensitivity assessment was performed to demonstrate that the safety factors are at least 1.0 for all service level transients for $[H]_{eq}$ up to 200 ppm.

Using the Bruce Power's internal processes within the Management System, Bruce Power also performed an engineering evaluation for continued operation of Bruce Power pressure tubes with elevated inlet rolled joint region $[H]_{eq}$ (provided as Enclosure 1 in Reference 2). The engineering evaluation demonstrated operability of Bruce Power pressure tubes and is further supported by the risk-informed fracture protection evaluation in Reference 1 and the supplementary information provided in this letter.

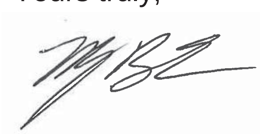
Bruce Power acknowledges that the Rev. 2 Cohesive-Zone (CZ) based fracture toughness model is still under review by the CNSC staff, and the model currently has a limit of 100 ppm for the front end of pressure tube. Since the submission of the technical basis document for the model to the CNSC in Reference 3, more burst tests on ex-service pressure tube sections hydrided to various level of $[H]_{eq}$ were performed and the results were communicated to the CNSC in Reference 4. The results of the most recent burst tests completed since Reference 4 are provided in Attachment A in this letter. Based on the new burst test results, justification can be made to extend the validity limit of the Rev. 2 model to elevated levels of $[H]_{eq}$, and the justification of 120 ppm limit for the front end of pressure tube has been established and provided in Enclosure 1. This work supports the use of Rev. 2 CZ fracture toughness model at 120 ppm in the aforementioned risk-informed evaluation of fracture protection.

For the second element of the defense-in-depth, insights from the current the PSA are provided in Attachment A. The PSA confirms that it is highly unlikely that a spontaneous pressure tube leak will progress to Severe Core Damage (SCD) or to a Large Release (LR) since the low Conditional Core Damage Probability (CCDP) and Conditional Large Release Probability (CLRP) are in the range of 6.50E-05 to 1.30E-07. Results indicate that the detection via annulus gas and the credited mitigating system are highly reliable. It is also concluded that an independent concurrent failure of two pressure tubes would have a frequency of 3E-09 which is a very unlikely event, orders of magnitude below the SCD frequency. Therefore, the frequency of two independent, concurrent pressure tube(PT) failures is shown to be very low. Since the submission in Reference 1, Bruce Power has assembled additional supplementary information to further bolster the defense-in-depth approach (Attachment A). The supplementary information addresses the implications of a scenario where the current assumptions and understanding in the current assessments are incorrect and also re-emphasizes the validity of the fracture toughness model for elevated levels of $[H]_{eq}$. The supplementary information also includes the results of the elevated $[H]_{eq}$ Delayed Hydride Cracking (DHC) initiation tests completed to-date as well as a high level plan of Finite Element Analysis (FEA) to investigate hydrogen diffusion and the interaction of elevated $[H]_{eq}$ and a postulated flaw in the inlet rolled joint region.

Based on the conclusions of the defense-in-depth approach and the supplementary information provided in this letter, Bruce Power has thoroughly demonstrated that the risk of pressure tube rupture due to elevated $[H]_{eq}$ in the inlet rolled joint is low, and therefore, safe continued operation of Bruce reactors is assured while the industry is working to gain improved understanding of the behaviour and develop predictive capability through modeling.

If you require further information or have any questions regarding this submission, please contact Mr. Jason Goldberg, Department Manager, Nuclear Safety Analysis and Support, at (416) 867-2927 extension 4310, or jason.goldberg@brucepower.com.

Yours truly,



Maury Burton
Chief Regulatory Officer,
Bruce Power
2022.03.11 16:36:27 -05'00'

Maury Burton
Chief Regulatory Officer
Bruce Power

cc: CNSC Bruce Site Office

Attach.

Enclosures:

1. B-REP-31100-00030, Revision 0, Technical Basis for Validity Limit on Equivalent Hydrogen Concentration of 120ppm for Application of Revision 2 Fracture Toughness Model within 1.5m from Front End Outlets in Bruce Unit 3.
2. NK21-06311.6-15OCT2021, Revision 000, Characterization of Pressure Tube Failure (PTF) Risk at Bruce A Nuclear Generating Station B2200/LET/0004.
3. NK29-03611.6-15OCT2021, Revision 000Characterization of Pressure Tube Failure (PTF) Risk at Bruce B Nuclear Generating Station B2200/LET/0005

References:

1. Letter, M. Burton to L. Sigouin, “Bruce A and B: CNSC Review of Industry Pressure Tube Surveillance Program – Inlet, Hydrogen Equivalent Measurements on PT from Unit Shutdown for Major Component Replacement (MCR), Action Item 2021-07-24426”, February 9, 2022, BP-CORR-00531-02495.
2. Letter, M. Burton to L. Sigouin, “Industry Pressure Tube (PT) Surveillance Program - Inlet, Hydrogen Equivalent Concentration Measurements on PT from Unit Shutdown for Major Component Replacement (MCR) – Action Item 2021-07-24426”, January 10, 2022, BP-CORR-00531-02398.

3. 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.
4. Email, J. Thompson to L. Sigouin, “FW: Bruce A and Bruce B: Semi-Annual Update on Burst Test Results to CNSC”, November 9, 2021, BP-CORR-00531-02246.

Attachment A

Supplementary Information for Defence-in-Depth Approach of Addressing Elevated Hydrogen Equivalent Concentration ($[H]_{eq}$ in the Inlet Rolled Joint

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The information provided is SENSITIVE and/or CONFIDENTIAL and may contain prescribed or controlled information. Pursuant to the Nuclear Safety and Control Act, Section 48(b), the Access to Information Act, Section 20(1), and/or the Freedom of Information and Protection of Privacy Act, Sections 17 and 21, this information shall not be disclosed except in accordance with such legislation.

Attachment A:
Supplementary Information for Defense-in-Depth Approach of Addressing Elevated Hydrogen Equivalent Concentration ($[H]_{eq}$) in the Inlet Rolled Joint

Section 1: Introduction

The purpose of this package of supplementary information is to support Bruce Power's defense-in-depth approach to evaluations of the overall risk of pressure tube rupture due to elevated $[H]_{eq}$ in the inlet rolled joint region of Pressure Tube (PT). One of the key elements of this defense-in-depth approach is the risk-informed fracture protection evaluation (Reference A1) that focuses on the implications of the presence of a localized elevated $[H]_{eq}$ point (known as the "blip") in the absence of full understanding of a) the mechanism, b) the rate of change in $[H]_{eq}$, and c) the rate of change in the extent of Region of Interest (ROI). The risk-informed fracture protection evaluation conservatively assumes that there already is a severe flaw with a depth that is deep enough to intersect with the gradient of elevated $[H]_{eq}$ at the clock position where the blip is, had already initiated and grown through-wall (due to the crack initiation model being invalid), and is not detected (due to the leak detection system postulated as being ineffective), regardless of where the flaw is located circumferentially in the ROI.

Section 2 of this document addresses the concern "what if the fracture toughness prediction is wrong – either due to the Rev. 2 fracture toughness model being invalid for elevated $[H]_{eq}$ or the Rev. 2 fracture toughness model simply being not representative for the Bruce tubes?". Section 3 addresses the concern "what if the crack initiation model is invalid for elevated $[H]_{eq}$?". Section 4 addresses the concern "what is the effect of elevated $[H]_{eq}$ and hydrogen gradient on the hydride region at the flaw tip?". Section 5 provides a summary of the frequency contribution of Pressure Tube Failure (PTF) and Pressure Tube Leak (PTL) to safety goal metrics, Conditional Core Damage Probability (CCDP) and Conditional Large Release Probability (CLRP) in Bruce Power's Probabilistic Safety Assessments (PSA). It also provides a conclusion that there is a very low likelihood of two independent PT failures occurring concurrently.

Section 2: Validity of the Fracture Toughness Model

Section 2.1: Recent Burst Test Results

The key input to the risk-informed fracture protection evaluation is the fracture toughness predicted by the Rev. 2 fracture toughness model, which is currently being reviewed by the CNSC staff. Although the technical basis document for the Rev. 2 fracture toughness model provides the $[H]_{eq}$ validity limit of the model to be 100 ppm for the pressure tube front end and 140 ppm for the rest of the tube, subsequent burst tests performed since the issuance of the technical basis document provide strong evidence that the fracture toughness values of ex-service tube sections hydrided to very high $[H]_{eq}$ are bounded by the predictions of the Rev. 2 fracture toughness model. Table A1 below provides the results of the latest burst tests and Figures 1 to 3 provide the plots of the results against the predictions. Therefore, while the effort to extend the current validity limit on the Rev. 2 model to higher $[H]_{eq}$ is ongoing, there is evidence to show that the model is valid at much higher $[H]_{eq}$. A justification to extend the limit of the Rev. 2 model to 120 ppm $[H]_{eq}$ for the front end has been documented in a report (Reference A2) and is provided as Enclosure 1 of this letter.

Section 2.2: Comparison of Predictions between Rev. 1 and Rev. 2 Fracture Toughness Models

As an added measure, comparisons between the predicted fracture toughness for [H $_{eq}$ of 160 ppm using the Rev. 1 and Rev 2 models for Bruce Unit 7 are provided as an example in Table A2. As seen in the table, the Rev. 2 model predicts comparable fracture toughness at lower temperatures but lower fracture toughness at higher temperatures than the Rev. 1 model does. This is because the Rev. 2

model was developed to ensure that for the lower-bound predictions of fracture toughness, the steep transition to the upper-shelf fracture regime that was observed in the burst tests (i.e. BT-29) was captured in the model. Furthermore, the Rev. 2 model takes into account the hydride re-orientation in the front end which in general produces lower fracture toughness values than the Rev. 1 model does. Based on the considerations above, it is more appropriate to use the Rev. 2 model for elevated $[H]_{eq}$ applications.

Section 2.3: Potential Bias in Fracture Toughness Predictions

Bruce Power acknowledges that the CNSC staff has raised comments about potential bias in fracture toughness predictions due to large scatter in the data between different operating stations/units, and the industry is working to address these comments. That said, as seen in Figures A1 and A2, the burst test results of the two tubes from Bruce Unit 6 lie above the mean predictions of the Rev. 2 model, which suggests that even at very high $[H]_{eq}$ the model predictions are very conservative for the Bruce tubes and, hence, it is conservative to use the Rev. 2 model for the risk-informed fracture protection evaluation.

Section 2.4: Results of the Risk-Informed Fracture Protection Evaluations and Conclusions

The results of the risk-informed fracture protection evaluations show sufficient safety margins to the critical pressure for all service level transients and even with elevated $[H]_{eq}$ up to 200 ppm at 20 mm inboard of the burnish mark where $[H]_{eq}$ is low (~40 ppm) based on all measurements obtained to-date, regardless where the through-wall flaw is circumferentially. Therefore, the CNSC's definition of the circumferential extent of the ROI being 360 degrees is also addressed by the risk-informed evaluations. It is realistic and physically sound to assume that the $[H]_{eq}$ at 20 mm inboard of the burnish mark would not reach 200 ppm in the short-term given the inspection and surveillance data gathered to date.

Therefore, the risk-informed fracture protection evaluation is sufficient to provide confidence that pressure tube fitness-for-service, at least for 3 to 5 years is not a concern given relatively slow hydrogen migration. This will allow the industry the time required to gain the necessary mechanistic understanding on the causes of the elevated [$[H]_{eq}$ discovered in the ROI and develop an associated $[H]_{eq}$ model.

In conclusion, considering all the burst test results and the findings of the risk-informed fracture protection evaluations, Bruce Power believes that the Rev. 2 fracture toughness model provides conservative predictions for the Bruce tubes and it is appropriate for use in the risk-informed fracture protection evaluation of elevated $[H]_{eq}$ in both the inlet and outlet rolled joint regions of Bruce tubes. Bruce Power also believes that the risk of pressure tube rupture due to elevated $[H]_{eq}$ in the inlet RJ region is low.

Table A1: Results of the Latest Burst Tests (BT)

Burst Test ID	Burst Test Specimen	Axial Location (from inlet end, m)	Kc (MPa√m)	$[H]_{eq}$ (ppm)	Chlorine (ppm)	Test Temperature (°C)
BT-50	B6N07-2 (front end)	0.56 – 1.02	42*	178	2.3	65
BT-51	B6S13-2 (front end)	0.43 – 0.88	49*	368	3.5	65
BT-40	P7O07-3	1.81 – 2.27	56*	145*	4.3	100

Note: * - preliminary results

Figure A1: BT-50 Result versus Rev. 2 Fracture Toughness Predictions

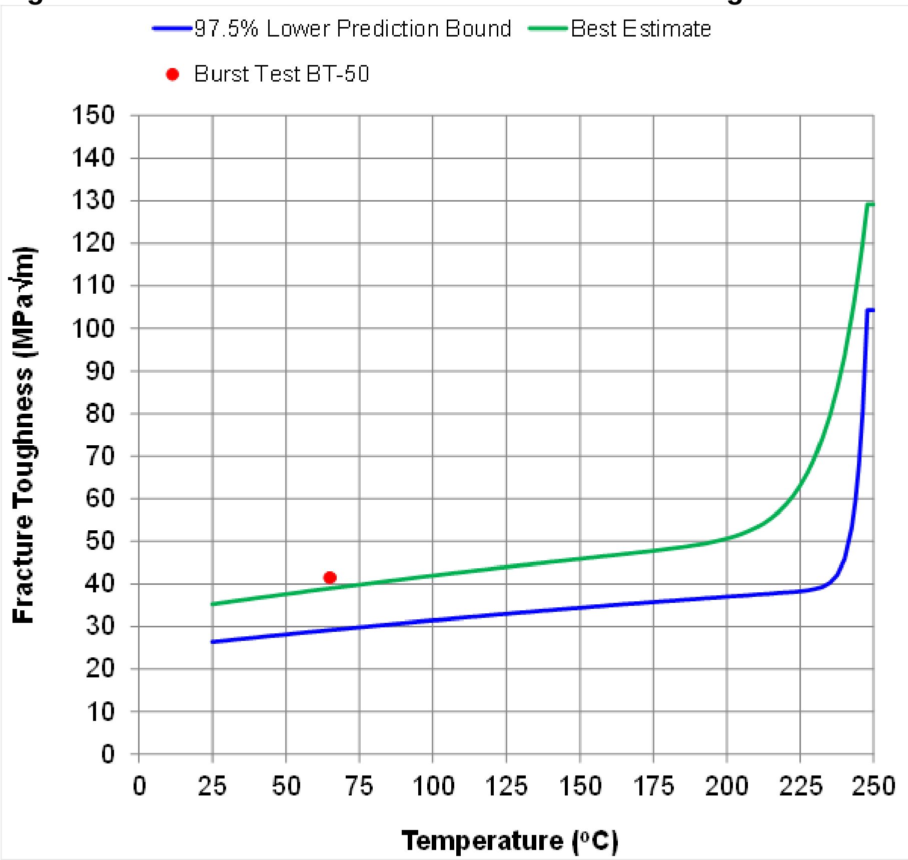

Figure A2: BT-51 Result versus Rev. 2 Fracture Toughness Predictions

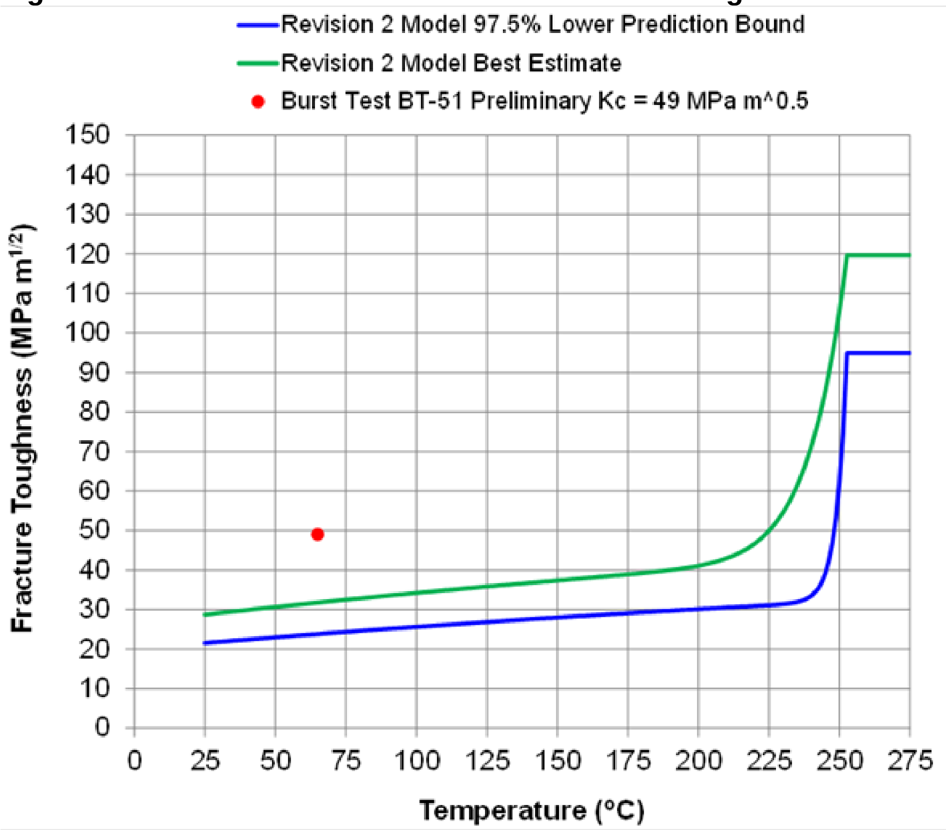

Figure A3: BT-40 Result versus Rev. 2 Fracture Toughness Predictions

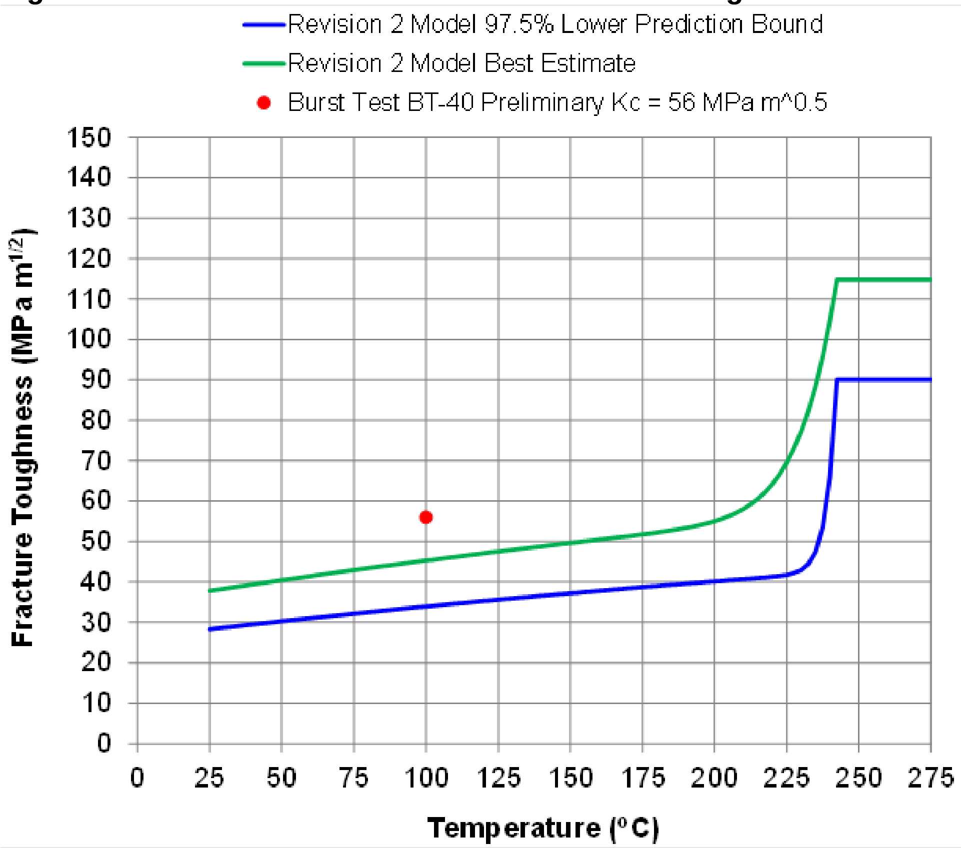

Table A2: 97.5% Lower Prediction Bounds on Fracture Toughness for Bruce Unit 7 from Rev. 1 and Rev. 2 Fracture Toughness Models

$[H]_{eq}$ (ppm)	Chlorine Concentration (ppm)	Temperature (°C)	97.5% Lower Prediction Bound on Fracture Toughness, Kc, From Revision 1 Model (MPa√m)	97.5% Lower Prediction Bound on Fracture Toughness, Kc, From Revision 2 Model (MPa√m)
160	2.5	70	29.8	30.1
160	2.5	90	31.0	31.3
160	2.5	150	35.0	34.8
160	2.5	200	45.8	37.3
160	2.5	225	63.2	38.6

Section 3: Validity of the DHC Crack Initiation Model

Section 3.1: DHC Tests with Elevated $[H]_{eq}$

Bruce Power plans to provide the results of the latest crack initiation tests with elevated $[H]_{eq}$ to the CNSC staff in the March submission. In the interest of timing, the test results are provided below, ahead of the submission, to allow the CNSC staff to take the findings of these test results into consideration.

Tables A3, A4 and A5 below provide the results of the K_{IH}, p_c, and K_{TH} tests completed to-date.

Table A3: K_{IH} Test Results

Material	[[H]$_{eq}$] (ppm)	Test Temperature	K_{IH} Measurements (MPa√m)	Average K_{IH} (MPa√m)	Lowest Measured K_{IH} (MPa√m)
Unirradiated, BB049	60	200°C	7.6 8.4 7.8 7.2	**7.8**	**7.2**
Unirradiated, BB049	240	200°C	8.5 8.6 7.2	**8.1**	**7.2**

- Description of K_{IH} Tests:
  - o K_{IH} is defined as the threshold stress intensity factor for DHC initiation from a crack under isothermal conditions, and is used in the process-zone models for evaluation of DHC initiation at flaws. Experiments have been completed recently on 60 ppm and 240 ppm [H]$_{eq}$ unirradiated C-shape specimens containing a pre-cracked to examine the effect of [H]$_{eq}$ on K_{IH} at 200°C. The lower-bound value of K_{IH} is 4.5 MPa√m as defined in CSA N285.8-15.

- Key Observation:
  - o Based on the experiments completed to date, K_{IH} is not reduced at [H]$_{eq}$ of 240 ppm.

Table A4: p_c Test Results

Material	[[H]$_{eq}$] (ppm)	Number of Specimen Groups at Different Stress Levels	Number of Specimens in Each Group	Measured p_c (MPa)
Unirradiated, G1770	50	3	5~6	**500~525**
Unirradiated, G1770	220	4	6	**>500**

- Description of p_c Tests:
  - o p_c is defined as the threshold stress for DHC initiation from a nominally smooth surface, and is used in the process-zone model for evaluation of DHC initiation at flaws. Experiments have been completed recently on 50 ppm and 220 ppm [H]$_{eq}$ unirradiated cantilever beam specimens containing a nominally smooth surface to examine the effect of [H]$_{eq}$ on p_c. The value of p_c is 450 MPa as defined in CSA N285.8-15.

- Key Observation:
  - o Based on the experiments completed to date, p_c is not reduced at [H]$_{eq}$ of 220 ppm.

Table A5: K_{TH} Test Results

Material	[[H]$_{eq}$] (ppm)	Notch Geometry	Number of Specimen Groups at Different Load Levels	Measured K_{TH} (MPa√m)
Unirradiated, BB049	60	V-notch: 0.75 mm depth, 0.015 mm root radius	2	**8~9**
Unirradiated, BB049	240	V-notch: 0.75 mm depth, 0.015 mm root radius	5	**6.5~7.0**

- Description of K_{TH} Tests:
  - K_{TH} is defined as the threshold effective stress intensity factor for DHC initiation from a blunt notch. Experiments have been completed recently on 60 ppm and 240 ppm $[H]_{eq}$ unirradiated cantilever beam specimens containing a machined V-notch with a depth of 0.75 mm and a root radius of 0.015 mm to examine the effect of $[H]_{eq}$ on K_{TH}.

- Key Observation:
  - Based on experiments completed to date on unirradiated specimens with a notch root radius of 0.015 mm, the measured K_{TH} of the 240 ppm $[H]_{eq}$ specimens is slightly lower than that of the 60 ppm $[H]_{eq}$ specimens. The cause of the measured K_{TH} of the 240 ppm $[H]_{eq}$ test specimens being lower than the 60 ppm $[H]_{eq}$ test specimens is under investigation.

Section 3.2: Conclusions

When a detected flaw is evaluated for DHC initiation, the lower-bound values of p_c and K_{IH} are used. The actual values of p_c and K_{IH} for a flaw are typically substantially higher than the lower bound values, and these result in an implicit unquantified margin that is considered to cover uncertainties in the effects of elevated $[H]_{eq}$ on the process-zone model predictions.

Based on OPEX, the root radius of most of the service-induced flaws are larger than the 0.015 mm root radius of the K_{TH} test specimens. The blunt root radius of these flaws means that p_c is the major contributor to the threshold peak stress for DHC initiation in the process-zone evaluation. As described previously, based on the experiments completed to date, p_c is not reduced at an $[H]_{eq}$ of 220 ppm. Also, the likelihood of the presence of a significant flaw at the outside surface of the pressure tube where the blip is, i.e. 1:00 clock position, is very low. In addition, in the Bruce B units, core conversion was performed with the inlet bundle removed from each fuel channel, and therefore, no new flaws can form in the inlet ROI and any flaws that are preexisted would have reduced flaw tip peak stress due to creep further reducing the likelihood of failure.

Therefore, Bruce Power believes that the current DHC initiation model remains valid for elevated $[H]_{eq}$ and that there is a low risk of crack initiation due to a flaw in the inlet rolled joint region where $[H]_{eq}$ is elevated.

Section 4: Diffusion Analysis to Understand Interaction of a Flaw with Hydrogen Gradient in Inlet Rolled Joint

The purpose of the diffusion work is to evaluate any effect of the elevated $[H]_{eq}$ adjacent to the pressure tube outside surface in the ROI ('blip') in an inlet rolled joint on the $[H]_{eq}$ concentration and build-up of the hydrided region at the tip of a postulated flaw on the inside surface of the pressure tube that is located radially outside the ROI. Finite element simulations will be performed under representative thermal and stress gradients for the diffusion of hydrogen to the tip of a postulated flaw on the inside surface of the pressure tube that is at the same circumferential and axial location as the ROI, and is radially outside of the ROI. The simulation will predict the build-up of the flaw-tip hydrided region. The radial distribution(s) of the measured concentration of $[H]_{eq}$ through the wall thickness at the same circumferential location as the ROI in the inlet rolled joint of pressure tube B6S13 will be simulated and used. The finite element results will be used to evaluate any effect of elevated concentration of $[H]_{eq}$ in the ROI, including adjacent to the pressure tube outside surface, on the concentration of $[H]_{eq}$ and the hydrided region at the flaw tip.

A high level best estimate schedule of the tasks is provided in Table A6.

Table A6: High Level Schedule of Tasks to Evaluate Effect of Elevated $[H]_{eq}$ in the Region of Interest in Inlet Rolled Joints on Hydrided Region at a Postulated Flaw Tip

Task No.	Task Description	Schedule for Task
1	Obtain Input Data and Results of Quantitative Metallography of B6S13	March 2022
2	Establish Finite Element Models and Modelling Procedures	March 2022
3	Simulate the Through-Wall [H]eq Distribution(s) with No Flaw	April 2022
4	Benchmark Simulation of Hydrogen Diffusion in an Unirradiated Notched Cantilever Beam Test Specimen	April 2022
5	Simulate the Diffusion of Hydrogen to the Postulated Flaw Tip under representative thermal and stress gradients	May 2022
6	Evaluate any Effect of Elevated [H]eq in the ROI on the Hydrided Region at the Postulated Flaw Tip under representative conditions	May 2022
7	Document the Work in a Position Paper and Calculation Note	June 2022

Section 5 – Summary of Pressure Tube Failure Risk Contributions in PSA

The second key element of the defense-in-depth approach is the PSA. Bruce Power's PSAs take into account the unlikely event of pressure tube leaks and failures. Results from the PSAs provide an indication of the robustness of the defense in depth of plant design and operation. The enclosed reports (References A3 and A4) characterize the frequency contribution of Pressure Tube Failure (PTF) and Pressure Tube Leak (PTL) to safety goal metrics, Conditional Core Damage Probability (CCDP) and Conditional Large Release Probability (CLRP) for the IE-PTL event as well as likelihood of two independent Pressure Tube (PT) failures occurring concurrently.

The results of the reports are summarized in Table A7.

Table A7: Summary of Pressure Tube Failure Risk Contributions

	Bruce A		Bruce B	
Frequency Contribution to Safety Goal Metrics	**CDF* (1E-04)**	**LRF (1E-05)**	**CDF (1E-04)**	**LRF (1E-05)**
IE-PTF	1.30E-06	2.80E-08	7.20E-07	6.50E-09
IE-PTL	1.10E-07	5.10E-09	5.60E-09	4.10E-11
Conditional Core Damage Probability (CCDP)	**CDF**	**LRF**	**CDF**	**LRF**
IE-PTL	6.50E-05	5.00E-06	6.90E-06	1.30E-07
Probability of two concurrent PTF events	**Event Frequency**		**Event Frequency**	
IE-PTF AND a second IE-PTF at same time	3.70E-09		3.40E-09	

*CDF is Core Damage Frequency.

Results show although the PTF is a significant contributor to risk at both stations, the Severe Core Damage Frequency (SCDF) and Large Release Frequency (LRF) are well below the safety goals at both Bruce A and B.

The conclusions further confirm that it is highly unlikely that a spontaneous pressure tube leak will progress to severe core damage or to a large release since the low CCDP and CLRP indicate that the credited mitigating functions after the PTL event are highly reliable. It also concludes that a PTF leading to severe core damage is not likely due to a number of means of mitigating the loss of HTS inventory. Finally, the report concludes that there is a very low likelihood of two independent Pressure Tube (PT) failures occurring concurrently.

References:

A1. Report, D. Scarth, “Risk-Informed Deterministic Evalyation of Fracture Protection for the Region of Interest in Inlet Rolled Joints in Bruce Units 3 and 4, and Inlet and Outlet Rolled Joints in Bruce Units 5, 7 and 8”, B-REP-31100-0034, January 12, 2022.

A2. Report, D. Scarth, “Technical Basis for Validity Limit on Equivalent Hydrogen Concentration of 120 ppm for Application of Revision 2 Fracture Toughness Model Within 1.5m From Front End Outlets in Bruce Unit 3”, B-REP-33110-00030, July 21, 2021 (Enclosure 1).

A3. Memorandum, J. Mok to U. Mian, Subject “Characterization of Pressure Tube Failure (PTF) Risk at Bruce A Nuclear Generating Station” B2200/LET/0004 R00, October 15, 2021 (Enclosure 2).

A4. Memorandum, J. Mok to U. Mian, Subject “Re: Characterization of Pressure Tube Failure (PTF) Risk at Bruce B Nuclear Generating Station” B2200/LET/0005 R00, October 15, 2021 (Enclosure 3).