Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

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Written submission from Bruce Power

Mémoire de Bruce Power

In the Matter of

À l'égard de

Request for authorize Bruce Power Inc. to restart Bruce Nuclear Generating Station A Unit 4 and Bruce NGS B Units 5, 7, and 8 following future outages

Demande de Bruce Power Inc. afin d'obtenir l'autorisation de redémarrer la tranche 4 de la centrale nucléaire deBruce-A et les tranches 5, 7 et 8 de Bruce-B après tout arrêt futur

Public Hearing - Hearing in writing based on written submissions

Audience Publique - Audience fondée sur des mémoires

November 2021

Novembre 2021

October 6, 2021

BP-CORR-00531-02059

Mr. M. Leblanc
Commission Secretary
Canadian Nuclear Safety Commission
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Dr. A. Viktorov
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Dear Mr. Leblanc and Dr. Viktorov:

Designated Officer Order to Bruce Power:
Unplanned Outage Restart Request – Supplemental Information

The purpose of this letter is to provide further unitized information and broader outage inspection planning context regarding Bruce Power's request for authorization to restart Units 4, 5, 7 and 8 from any unplanned outage (Reference 1), including:

1. the unitized qualitative and quantitative analysis to satisfy the conditions of the order;

2. the forced outage response protocol Bruce Power has in place should there be a need for an unplanned cooldown of Units 4, 5, 7, or 8;

3. the safety-based rationale for executing planned inspections on these units in a sequential basis over the next 18-months, starting with Unit 7 in November 2021, and

4. a status update with respect to the implementation of identified safety enhancements.

With the submission of this additional information, Bruce Power requests Commission authorization to restart Units 4, 5, 7 and 8 from any unplanned outage.

Note that this submission of additional information, demonstrating compliance with the Order for unplanned outages, has been developed using the CNSC's Region of Interest, defined as 360 degrees circumferentially and 75 mm axially.

Safety Based Rationale

While Bruce Power is committed to carrying out inspections as part of the established fuel channel life cycle program on all of Bruce units during their planned outages, Bruce Power maintains that undertaking an extensive inspection campaign in response to an unplanned, forced outage is undesirable, from both a safety and planning perspective. In outage management, Bruce Power adopts an industry excellence principle that the

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safest place to be in an outage is on the plan given the extensive rigor, challenge and preparations that go into these activities.

Bruce Power regularly plans inspections years and months in advance of outages, consistent with management system processes, to ensure high levels of safety and predictability when conducting these activities on a reactor. This practice is consistent, and in accordance with CSA N286, *Management system requirements for nuclear facilities,* which requires top management to define, plan and control activities undertaken by Bruce Power in recognition of their potential impact on health, safety, environment, security, economics and quality.

For example, in anticipation of deployment during a planned outage, the maintenance and preparation of the Bruce Reactor Inspection Maintenance System (BRIMS) and its associated inspection tooling is performed following a detailed maintenance strategy which is integrated and aligned with the planned outage schedule for the Bruce units. BRIMS maintenance is intrusive and intensive and requires significant disassembly of the system. Further note that the deployment of BRIMS and execution of the associated inspections (CWEST, ANDE) is dose intensive work.

Taken in combination, Bruce Power has recognized the critical nature of BRIMS preparation and use: any unexpected outcomes can directly result in a dose consequence to workers. As such any BRIMS activity can only be undertaken with requisite training and requires the availability of fully qualified staff to be aligned with the planned outage schedule to ensure the safety of the personnel and equipment when inspections are undertaken.

Given these factors, there are considerable logistics involved in preparing for outages. In order to ensure a plan can be executed with minimal disruption, it is developed years and months in advance of planned maintenance outages. The development of the plan includes establishing arrangements with vendor partners, identifying scope, development of resource planning and training of staff, the development of mobilization plans for onboarding of staff, and operational reviews to confirm readiness. These activities are co-ordinated closely with vendor partners as each vendor supports activities across the CANDU fleet and their availability is not dedicated to Bruce Power.

Note that the contributions of vendor partners is not limited to the physical execution of inspection activities as they also support Bruce Power through the processing and analysis of data drawn from inspections.

Since 2019 Bruce Power has carried-out pressure tube inspections on Units 4 (2020), 5 (2019), 7 (2019) and 8 (2020). Each of these inspection campaigns confirmed no elevated hydrogen concentrations in the areas inspected and supported Bruce Power's previous results that no flaws were located in the region of interest. Planned inspections are scheduled to occur in each of these units over the next 18-months as units undertake their planned maintenance outages. These inspections are expected to demonstrate compliance with the Order (Reference 3) in anticipation of requesting Commission authorization to restart each unit, in turn.

It is important to note these planned outages and their associated inspection activities have also been scheduled in a manner that is integrated with the Unit 6 Major Component Replacement (MCR) work scheduled to take place during this period, the Unit 3 MCR work scheduled to commence in 2023, and the Bruce A Vacuum Building Outage and Station Containment Outage which is scheduled to commence in the second quarter of 2022.

Bruce Power maintains that, for the reasons noted, undertaking inspections in a planned manner, consistent with the requirements of CSA N286, and the major component life cycle management programs recognized and established as part of the fundamental licensing basis within the LCH is both a safe and effective way to conduct these inspections and is expected to maintain consequential worker dose impacts as low as reasonably achievable.

Unplanned Outages

As a result of Bruce Power's focus on operational excellence, strong equipment reliability and the human performance of the Bruce Power staff, unplanned outages are an infrequent occurrence.

When unplanned forced outages do occur, they are short in duration and undertaken through the deployment of predeveloped forced outage plans and contingencies to minimize risks and to facilitate a safe and efficient return of the unit to service with minimal interruption to plant activities. This approach allows the units to operate safely and predictability between successive planned outages.

Any scope of work which is to be undertaken during an unplanned outage considers the impact on planned outage execution. The deployment of the BRIMS in multiple units within Bruce A or Bruce B is currently not possible and concurrent deployment at Bruce A and Bruce B is limited. The availability of BRIMS, associated tooling and resources to support planned outages would be negatively impacted by deployment in support of unplanned outages.

Bruce Power maintains it is essential to have certainty around the ability to safely return a unit to service from an unplanned outage for both the individual unit and collective activities underway in the plant and at site overall.

Operational Enhancements

As elevated levels of hydrogen equivalent concentrations could challenge fracture protection should conditions for a Cold Overpressure Transient occur during a unit shutdown or return to service, Bruce Power developed mitigating actions which, when implemented, improve safety margin for fracture protection should there be a desire, or need, to cool down a unit in advance of its planned maintenance outage.

The identified enhancements include:

- reducing the need for a cool-down by addressing plant items pro-actively;
- reducing the likelihood of a Cold Over Pressure Transient (COPT) through procedural guidance;

- additional training;
- further minimization of time in a cold pressurized state;
- adjustments to heat-up and cool down profiles;
- replicating an automatic heat transport feed pump trip enhancement, now implemented in Unit 3, across Units 4, 5, 7 and 8.

The generic enhancements, applicable to all units are now complete. The procedural updates have been incorporated and provide instruction to operators to assist in further minimizing the potential for already unlikely Cold Overpressure Transient. In concert, operations staff has received supplemental training to refresh their knowledge of Cold Overpressure Transients, their importance, and its relation to the current unit status.

Bruce Power is continuing to examine adjustments to heat-up and cool-down profiles; the Engineering package related to the adjustments for Bruce A Units 3 and 4 was issued on September 30th and Bruce Power expects to develop and issue the Engineering package related to the adjustments for Bruce B Units 5, 7 and 8 prior to the end of the year.

An enhancement which allows the station Digital Control Computer to automatically trip the heat transport feed pumps has been implemented within Unit 3 in support of Return to Service. This enhancement, which provides additional assurance that safety and pressure tube integrity are maintained, will be implemented in Units 4, 5, 7 and 8 at the earliest opportunity.

Inspection Findings

Details of unitized information regarding recent and upcoming outage dates and completed pressure tube inspections that demonstrate lack of dispositionable flaws in the region of interest are contained in Attachment A.

A probabilistic evaluation of the existence of dispositionable flaws using CNSC staff's defined extended region of interest is provided for information in Enclosure 1 as defense in depth. Bruce Power believes this meets the requirements of the Order and demonstrates both safety and pressure tube integrity in combination with other elements previously provided.

The analysis provided in Enclosure 2 focuses on dispositionable flaws in recognition that there has never been a dispositionable flaw identified within the region of interest. As a result, the analysis estimates that there is less than one (1) dispositionable flaw in each of Units 4, 5, 7, and 8, within the region of interest defined by the CNSC staff.

Forced Outage Response and Return to Service Evaluation

In the event of an unexpected need to cooldown and undertake a forced outage on Units 4, 5, 7, or 8, Bruce Power will undertake a series of actions to systematically diagnose the direct cause of the shutdown, ensure the proper functioning of all safety and safety-related systems, ensure the Operations personnel response was as expected, determine any detrimental effect on plant equipment, and determine whether the reactor can be restarted safely.

Regardless of whether the reactor remains in the shutdown state or whether the unit has fully recovered according to appropriate procedures and the cause of the trip is fully understood, this post-transient review is undertaken within 24 hours and is completed by a team which includes the Operations Manager, Certified Shift Manager, and Authorized Nuclear Operator, in consultation with representation from Maintenance, Training, Engineering and Reactor Safety.

This cross functional team establishes and confirms the direct cause of the event and determines appropriate corrective actions, as required.

All participants are specifically required to contribute with their extensive knowledge and experience, while wielding a questioning attitude, to ensure that the unit is operated and maintained in a rigorous and vigilant manner so as to ensure that the radiological risk to workers, the public and the environment remains low, consistent with best practices in the international nuclear community.

As all unplanned changes in reactor power are reportable to the CNSC in accordance with REGDOC-3.1.1 Item 11b), the status of individual units will be known to CNSC and Bruce Power is committed to providing any information CNSC requires to ensure the safety of all of Bruce Power's proposed activities.

Summary

Bruce Power believes this additional information with unit specific background will supplement the request for Commission approval to return Units 4, 5, 7 and 8 from an unplanned outage. With safety at the forefront, the sequential and planned inspection outage campaign will continue to demonstrate safety, pressure tube integrity and fitness for service.

In addition to inspections, Bruce Power's defense in depth approach and the additional operational measures outlined provide additional layers of safety. The systematic review and confirmation, completed by Bruce Power following unplanned shutdowns, ensures a reactor is safe to operate prior to returning a unit to service. As CNSC staff has full access to any material required to assure the on-going safe operation of the reactors, there is ample opportunity to complete any required regulatory verification activities in support, including the delay of a return to service should there be a need to do so.

As provided within this submission, Unit 7 is scheduled to be taken offline in less than one month for its planned maintenance outage followed by successive outages scheduled for Units 5, 4, and 8 respectively over the next 18 months. These activities will include confirmatory scrape sampling for hydrogen concentrations and verification of no flaws in the region of interest.

Bruce Power expects the results of these inspections, starting with the Unit 7 in the near-term and Unit 5 during the first half of 2022 will build CNSC confidence with respect to extent of the region of interest and its stability given these are the leading Bruce units. In addition, Bruce Power will continue to keep CNSC staff informed and provide technical information on the confirmatory research and modeling development as it becomes available to assist in refinement of the definition of the region of interest.

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
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2021.10.06 15:38:02 -04'00'

Maury Burton
Chief Regulatory Officer
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cc: CNSC Bruce Site Office
L. Sigouin, CNSC - Ottawa
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Attach.

Enclosures:

1. B-REP-31110-00004, Revision 001, Estimation of Encountering Reportable & Dispositionable Pressure Tube Flaws in Various Regions of Interest in Bruce Power Units 3-8".
2. B-03644.1-29SEP2021, "Updated Flaw Probability in the Region of Interest in the Uninspected Population of Pressure Tubes in Bruce Units 3-8".

References:

1. Letter, M. Burton to M. Leblanc, "Designated Officer Order to Bruce Power – Unplanned Outage Restart Request", August 4, 2021, BP-CORR-00531-01908.
2. Letter, M. Burton to M. Leblanc and A. Viktorov, "Bruce A and Bruce B: Return to Service Supplemental Information", September 9, 2021, BP-CORR-00531-02004.
3. Letter, R. Jammal to M. Burton, "Designated Officer Order Issued to Bruce Power", July 26, 2021, e-Doc 6612485. BP-CORR-00531-01904.

4. Letter, M. Burton to M. Leblanc and A. Viktorov, “Bruce A Unit 3: Return to Service Additional Information”, September 17, 2021, BP-CORR-00531-02033.

Attachment A

Unitized Inspection Findings

Attachment A – Unitized Inspection Findings

Unit 4

Unit 4 completed its last planned inspection outage in June 2020 and is scheduled to undergo its next planned inspection outage in September 2022. The upcoming inspections will include confirmatory scrapes for hydrogen concentrations and seek to confirm there are no flaws in the region of interest. All inspections completed on Unit 4 have demonstrated there were no elevated levels of hydrogen above licensing requirements in the inspected area of the tubes and no flaws within the region of interest.

Note that, of a total of 82 full channel length inspections and 119 inspections (including re-visits) completed on Unit 4 to date, no flaws have been identified in the region of interest. This result is unsurprising as the bundle and pressure tube design in Unit 4 ensures flaws do not occur in the region of interest.

A summary of detected flaws in Unit 4 is provided in Table 1, below. The tables in each section account for all unique reportable and dispositionable flaws for flaw types that have the potential for crack initiation including debris flaws, bearing pad flaws, crevice corrosion, PT/CT contact, erosion, linear indications, mechanical damage & manufacturing flaws, and exclude deposits, corrosion, roughness & proud indications, fueling scratches, OD scratches & scrapes.

Table 1: Detected Flaws in Unit 4

Unit	Number of Unique Channels Inspected Full Length	Total Full Length Channel Inspections (including revisits)	Total Number of Flaws within the first 100mm from the OBM Reportable (Dispositionable)	Total Number of Flaws within the first 100mm from the OBM in the Upper Region
4	82	119	0 (0)	0

Unit 5

Unit 5 completed its last planned inspection outage in November 2019 and is scheduled to undergo its next planned inspection outage in February 2022. The upcoming inspections will include confirmatory scrapes for hydrogen concentrations and seek to confirm there are no flaws in the region of interest. All inspections completed on Unit 5 have demonstrated there were no elevated levels of hydrogen above licensing requirements in the inspected area of the tubes and no flaws within the region of interest.

Note that of a total of 77 full channel length inspections and 129 inspections (including re-visits) completed on Unit 5 to date, no flaws have been identified in the region of interest. This result is unsurprising as the bundle and pressure tube design in this Unit ensures flaws do not occur in the region of interest.

A summary of detected flaws in Unit 5 is provided in Table 2, below.

Table 2: Detected Flaws in Unit 5

Unit	Number of Unique Channels Inspected Full Length	Total Full Length Channel Inspections (including revisits)	Total Number of Flaws within the first 100mm from the OBM Reportable (Dispositionable)	Total Number of Flaws within the first 100mm from the OBM in the Upper Region
5	77	129	4 (0)	0

Unit 7

Unit 7 completed its last planned inspection outage in June 2019 and is scheduled to undergo its next planned inspection outage in November 2021. The upcoming inspections will include confirmatory scrapes for hydrogen concentrations and seek to confirm there are no flaws in the region of interest. All inspections completed on Unit 7 have demonstrated there were no elevated levels of hydrogen above licensing requirements in the inspected area of the tubes and no flaws within the region of interest.

Note that of a total of 70 full channel length inspections and 114 inspections (including re-visits) have been conducted on Unit 7, no flaws have been identified in the region of interest. This result is unsurprising as the bundle and pressure tube design in this Unit ensures flaws do not occur in the region of interest.

A summary of detected flaws in Unit 7 is provided in Table 3,

Table 3: Detected Flaws in Unit 7

Unit	Number of Unique Channels Inspected Full Length	Total Full Length Channel Inspections (including revisits)	Total Number of Flaws within the first 100mm from the OBM Reportable (Dispositionable)	Total Number of Flaws within the first 100mm from the OBM in the Upper Region
7	70	114	1 (0)	0

Unit 8

Unit 8 completed its last planned inspection outage in December 2020 and is scheduled to undergo its next planned inspection outage in 2023. The upcoming inspections will include confirmatory scrapes for hydrogen concentrations and seek to confirm there are no flaws in the region of interest. All inspections completed on Unit 8 have demonstrated there were no elevated levels of hydrogen above licensing requirements in the inspected area of the tubes and no flaws within the region of interest.

Note that of a total of 79 full channel length inspections and 137 inspections (including re-visits) completed on Unit 8 to date, no flaws have been identified in the region of interest. This result is unsurprising as the bundle and pressure tube design in this Unit ensures flaws do not occur in the region of interest.

A summary of detected flaws in Unit 8 is provided in Table 4,

Table 4: Detected Flaws in Unit 8

Unit	Number of Unique Channels Inspected Full Length	Total Full Length Channel Inspections (including revisits)	Total Number of Flaws within the first 100mm from the OBM Reportable (Dispositionable)	Total Number of Flaws within the first 100mm from the OBM in the Upper Region
8	79	137	0 (0)	0

Enclosure 1

B-REP-31110-00004, Revision 001

Estimation of Encountering Reportable & Dispositionable Pressure Tube Flaws in Various Regions of Interest in Bruce Power Units 3-8

FORM-14287 R000*

Supplier Document Acceptance Form

Bruce Power

KINECTRICS

ESTIMATION OF ENCOUNTERING REPORTABLE & DISPOSITIONABLE PRESSURE TUBE FLAWS IN VARIOUS REGIONS OF INTEREST IN BRUCE POWER UNITS 3-8

B-REP-31110-00004

Rev. 001

- [x] Accepted
- [ ] Accepted As Noted – Revision Required
- [ ] Rejected
- [ ] Accepted As Noted – No Revision Required

FOR USE AT BRUCE POWER

ACCEPTED: **LARRY MICUDA** (Print Name) — [signature] (Signature)

TITLE: **SENIOR TECHNICAL SPECIALIST** (Print Title)

DATE: **24SEP2021** (DDMMMYYYY)

ACCEPTANCE OF THIS DOCUMENT DOES NOT RELIEVE THE CONTRACTOR OF RESPONSIBILITY FOR ANY ERRORS OR OMISSIONS.

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Estimation of Encountering Reportable & Dispositionable Pressure Tube Flaws in Various Regions of Interest in Bruce Power Units 3-8

B2266/RP/0010 R01

September 24, 2021

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Revision Summary

Rev	Date	Author	Comments
R00	Sept 2021	D. Leemans	Initial issue.
R01	Sept 2021	D. Leemans	Revised to include: 1. Additional definitions of the region of interest (180° & 360°). 2. The estimated number of flaws in the inspected population of each unit for all regions of interest.

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1.0 INTRODUCTION

As part of the evaluation of the fitness for service of Bruce Unit 3, concerns were expressed about the probability of encountering flaws of significance (flaws requiring disposition) in specific regions of interest of the pressure tubes for the population of channels which were not yet inspected full length. The region in question is centered around the top of the pressure tube over a limited axial extent inboard of the Outlet Burnish Mark (OBM), corresponding to measurements of elevated hydrogen isotope concentration. This report provides estimates of the probability of encountering flaws in the reactor in these regions and submits that these probabilities are reassuringly low. Also provided are estimates of the number of dispositionable flaws in these regions.

The following sections describe the methodology and results of the current work to estimate the flaw probability in the regions of interest.

2.0 IDENTIFYING THE REGIONS OF INTEREST

Four regions of interest are defined based on their axial extent inboard of the outlet burnish mark (OBM) and their circumferential extent referenced from the top of the pressure tube:

	Axial Extent	Circumferential Extent
Region 1	OBM + 75 mm	60° (+/- 30°)
Region 2	OBM + 75 mm	120° (+/- 60°)
Region 3	OBM + 75 mm	180° (+/- 90°)
Region 4	OBM + 75 mm	360° (+/- 180°)

While determining the most appropriate definition of the region of interest is beyond the scope of this work, measurements of deuterium concentration obtained in the A2131 outage support Region 2 (highlighted above) per [1].

3.0 OVERALL APPROACH TO ESTIMATING THE PROBABILITY OF ENCOUNTERING A DISPOSITIONABLE FLAW IN THE REGIONS OF INTEREST OF THE UNINSPECTED PRESSURE TUBES IN BRUCE REACTORS

The probability of encountering a dispositionable flaw in a region of interest in a channel is related to four constituent elements[1]:

i. The probability of encountering k reportable flaws in the outlet fuel bundle region of a channel;

ii. The conditional probability given a reportable flaw is present, its axial position (mid flaw position) is within 75 mm inboard of the OBM;

[1] For each of these probabilities the possibility of having more than one flaw in the channel being present is taken into account.

iii. The conditional probability given a reportable flaw is present close to the OBM, its circumferential location is such that it falls within the region of interest.

iv. The product of the three probabilities itemized above provides the probability of a reportable flaw being in the region of interest. Using the conditional probability that given the presence of a reportable flaw that there is actually a dispositionable flaw present allows the evaluation of the presence of a dispositionable flaw in the channel.

4.0 THE MAJOR DATABASE ON REPORTABLE FLAWS IN BRUCE REACTOR UNITS

The primary input to this analysis was a database containing the size and location of all unique flaws obtained during the inspections of the area up to the first fuel bundle with respect to the outlet burnish mark in all Bruce Units 3-8 reactors. It is this database that allows the reliable estimates of many of the conditional probabilities mentioned above. This database and its construction are detailed in [2].

The decision was made to include only flaws up to the axial extent of the first fuel bundle in the outlet end. Increasing the axial extent would increase the number of flaws per tube but would decrease the conditional probability of having the flaw in the axial region of interest. It was judged that the product of these two probabilities would be virtually unaffected by increasing the axial extent of the database. Reducing the axial extent would reduce the sample size and therefore imperil the estimation of the underlying probabilities.

5.0 DETAILED DESCRIPTION OF THE ESTIMATION OF THE PROBABILITY OF ENCOUNTERING DISPOSITIONABLE FLAWS IN THE REGIONS OF INTEREST IN THE UNINSPECTED PRESSURE TUBE POPULATION IN BRUCE POWER REACTORS

5.1 Description of the Probability of Having K Reportable Flaws up to the End of the First Bundle

This probability is assumed to follow a Poisson distribution

$$\Pr(X = k) = \frac{\lambda^k e^{-\lambda}}{k!}$$

where k is the number of flaws occurring within a channel and λ is the mean incidence rate. In the database there are 557 reportable flaws up to the end of the first bundle in the inspection of 448 unique channels and therefore the estimated λ is 1.243304. Figure 1 shows the dependence of probability on the number of flaws in the channel.

The following assumptions underpin these statements:

i. Flaws occur independently.

ii. The incidence rate is independent of reactor.

iii. The incidence rate is independent of the location of the pressure tube in the reactor (e.g., Zone[2]).

iv. The incidence rate is independent of operating time.

v. No distinction is made between different flaw types.

5.2 Description of the Probability of Having I Reportable Flaws Close to the Outlet Burnish Mark

The conditional probability of having the flaw within 75 mm of the OBM given that a flaw is present is estimated to be 0.011606. This is based on the estimation of the cumulative distribution of the axial position at 75 mm[3].

The probability of having I (≤ K) flaws close to the OBM given that there are K flaws in the pressure tube is binomially distributed.

$$\Pr(X = I|K) = \frac{k!}{I!\,(k-I)!}(1-p)^{k-I}p^{I}$$

These binomial probabilities for I are then multiplied with the Poisson probability of k flaws and then summed over all k values (up to 10 were used)[4] which gives the probability of having I flaws close to the OBM.

$$Prob(Y = I) = \sum_{k=I}^{10} \Pr\,(X = I|K)p(K)$$

Figure 2 shows how this probability drops off quickly with increasing values of I.

5.3 Description of the Probability of Having J Reportable Flaws Close to the Outlet Burnish Mark and at the Top of the Pressure Tube

The conditional probability of having a flaw circumferentially at the top of the pressure tube given that a flaw close to the OBM is present assumes that this probability is independent of axial position and therefore the whole database can be used to fit a distribution to the circumferential location. A large number of candidate continuous distribution functions were evaluated including gamma, extreme value, Weibull, Laplace, and lognormal. However, a very good fit was obtained with a simple normal distribution[5].

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[2] It is known that there is generally a zone dependency on flaw populations, with the outer zone channels generally observed to have a larger number of flaws. This was confirmed to be present in the outlet bundle flaw populations used for this exercise. Grouping flaws from channels from both zones is then in general conservative for the inner zone, to which the region of interest applies.
[3] Given the discontinuous nature of the distribution of the axial position (the majority of flaws are clustered around the residency locations of the fuel bundle bearing pads) no effort was made to fit this distribution to a known probability density distribution. The cumulative probability was estimated by linear interpolation between the two points neighboring 75 mm.
[4] The cutoff of 10 flaws is arbitrary but by this value the probabilities have become vanishingly small.
[5] A three-parameter lognormal distribution does also an adequate job in fitting the circumferential location distribution.

The parameters of this normal distribution are a mean of 176.41 degrees and a standard deviation of 39.03 degrees. Figure 3 and Figure 4 show the adequacy of the fit.

The conditional probabilities of having a flaw in the circumferential extent of the region of interest given that a flaw is present close to the OBM are as follows:

- Region 1 = 0.013%
- Region 2 = 0.22%
- Region 3 = 2.2%
- Region 4 = 100%

As above the probability of having J (≤ I) flaws at the top given that there are I reportable flaws close to the OBM is binomially distributed. Figure 5 shows the probability of having J reportable flaws in the larger area of interest (circumferentially the top 120 degrees of the pressure tube).

$$Prob(Y = J) = \sum_{I=I}^{10} \Pr(X = J|I)p(I)$$

5.4 Description of the Probability of Having H Dispositionable Flaws Close to the OBM and at the Top of the Pressure Tube

The conditional probability of having a dispositionable flaw circumferentially at the top of the pressure tube and close to the OBM given that a reportable flaw is present circumferentially at the top of the pressure tube and close to the OBM is based on the observation that from the 557 reportable flaws in the database 187 were found to be dispositionable (p= 0.335727).

The probability of having H (≤ J) dispositionable flaws at the top of the pressure tube close to the OBM given that there are J reportable flaws at the top of the pressure tube close to the OBM is binomially distributed.

$$Prob(Y = H) = \sum_{J=I}^{10} \Pr(X = H|J)p(J)$$

6.0 RESULTS

6.1 Probability Estimates for Encountering Flaws in the Regions of Interest per Channel

As noted from the outset it is assumed that there is no dependence on reactor and these estimates are applicable to the present situation. The probability of encountering at least one dispositionable flaw in the region of interest per channel is given by

$$Prob(flaw) = \sum_{H=I}^{10} \Pr(Y = H)$$

The results are tabulated in Table 1 for reportable and dispositionable flaws. As expected, these probabilities depend strongly on the circumferential extent of the region of interest. The larger the circumferential extent the larger the probability of encountering a flaw in the region of interest. Also, the probability of encountering a dispositionable flaw is about one third of the probability of encountering a reportable flaw.

6.2 Probability Estimates for Encountering Flaws in the Regions of Interest in the Uninspected Population of Pressure Tubes for Bruce Power Reactors.

The probability of encountering at least one reportable flaw in the regions of interest in the population of uninspected pressure tubes for Bruce Power reactors is tabulated in Table 2 while similar probabilities for dispositionable flaws are given in Table 3. These have been calculated as follows:

$$Prob(at\ least\ 1\ flaw\ in\ uninspected) = 1 - (1 - Prob(flaw))^n$$

where ‘n’ is the number of uninspected channels.

Estimates of the number of flaws in the regions of interest in the uninspected populations are given in Table 4 for reportable flaws, and Table 5 for dispositionable flaws. These have been calculated as follows:

$$Estimated\ \#\ of\ flaws = Prob(flaw) * n$$

where again ‘n’ is the number of uninspected channels.

7.0 DISCUSSION

The results of this estimation of the probability of encountering flaws close to the OBM indicate the following:

a. As expected, the probability of encountering flaws increases with increasing size of the region of interest (from Region 1 to Region 4).

b. As expected, the probability of encountering flaws is higher for reportable flaws than dispositionable flaws.

c. The inspections carried out in A2131 (which were not considered when deriving the probabilities) did not reveal the presence of flaws in the regions of interest for the top 180° of the pressure tube. This is consistent with the probability estimates provided in this report.

8.0 CONCLUSIONS

Available inspection data on the incidence of flaws has been used to develop probabilities of a flaw being present in the region of interest in an uninspected pressure tube. Four different definitions of the region of interest were considered with different circumferential extents. The probabilities of at least one flaw in the uninspected populations of pressure tubes in the regions of interest are given Table 2 and Table 3 for reportable and dispositionable flaws, respectively. Estimates of the number of flaws in the regions of interest in the uninspected populations of pressure tubes are given in Table 4 and Table 5 for reportable and dispositionable flaws, respectively. As expected, the predicted incidence of flaws in the region of interest increases with increasing circumferential extent, with reportable flaws being more likely than dispositionable flaws.

9.0 REFERENCES

1. H. Zhou, Letter to L. Micuda, "Hydrogen Equivalent Concentration Measurements Taken Near the Outlet Burnish Mark in the Bruce Unit 3 2021 Outage (A2131)," Kinectrics File: B2038/LET/0013 R00, September 13, 2021.
2. J. Robertson, "B3-B8 Database of Pressure Tube Flaws Just Inboard of the Outlet Burnish Mark," Kinectrics File: B2266/RP/0002 R00, September 15, 2021.

Table 1: Probability per Channel of Encountering at Least One Flaw in the Regions of Interest

	Region 1	Region 2	Region 3	Region 4
Reportable	1.87E-06	3.17E-05	3.12E-04	1.43E-02
Dispositionable	6.28E-07	1.07E-05	1.05E-04	4.83E-03

Table 2: Probability of Encountering at Least One Reportable Flaw in the Regions of Interest in the Uninspected Population of Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	7.51E-04	1.27E-02	1.18E-01	9.97E-01
4	398	7.44E-04	1.26E-02	1.17E-01	9.97E-01
5	403	7.53E-04	1.27E-02	1.18E-01	9.97E-01
6	418	7.81E-04	1.32E-02	1.22E-01	9.98E-01
7	410	7.66E-04	1.29E-02	1.20E-01	9.97E-01
8	401	7.49E-04	1.26E-02	1.18E-01	9.97E-01

Table 3: Probability of Encountering at Least One Dispositionable Flaw in the Regions of Interest in the Uninspected Population of Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	2.52E-04	4.28E-03	4.13E-02	8.57E-01
4	398	2.50E-04	4.23E-03	4.09E-02	8.55E-01
5	403	2.53E-04	4.29E-03	4.14E-02	8.58E-01
6	418	2.62E-04	4.44E-03	4.29E-02	8.68E-01
7	410	2.57E-04	4.36E-03	4.21E-02	8.63E-01
8	401	2.52E-04	4.26E-03	4.12E-02	8.57E-01

Table 4: Estimate of the Number of Reportable Flaws in the Regions of Interest in the Uninspected Population of Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	7.51E-04	1.28E-02	1.26E-01	5.76
4	398	7.44E-04	1.26E-02	1.24E-01	5.70
5	403	7.53E-04	1.28E-02	1.26E-01	5.77
6	418	7.81E-04	1.33E-02	1.31E-01	5.99
7	410	7.66E-04	1.30E-02	1.28E-01	5.87
8	401	7.50E-04	1.27E-02	1.25E-01	5.74

Table 5: Estimate of the Number of Dispositionable Flaws in the Regions of Interest in the Uninspected Population of Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	2.52E-04	4.28E-03	4.22E-02	1.94
4	398	2.50E-04	4.24E-03	4.18E-02	1.92
5	403	2.53E-04	4.29E-03	4.23E-02	1.95
6	418	2.62E-04	4.45E-03	4.39E-02	2.02
7	410	2.57E-04	4.37E-03	4.30E-02	1.98
8	401	2.52E-04	4.27E-03	4.21E-02	1.94

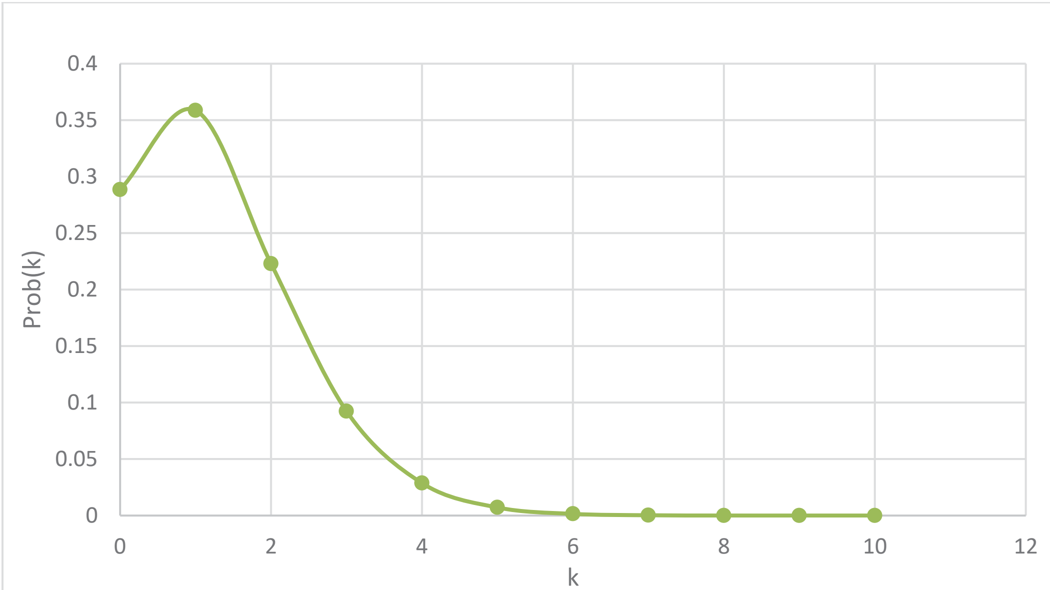

Figure 1: Probability of Encountering k Reportable Flaws in a Single Channel

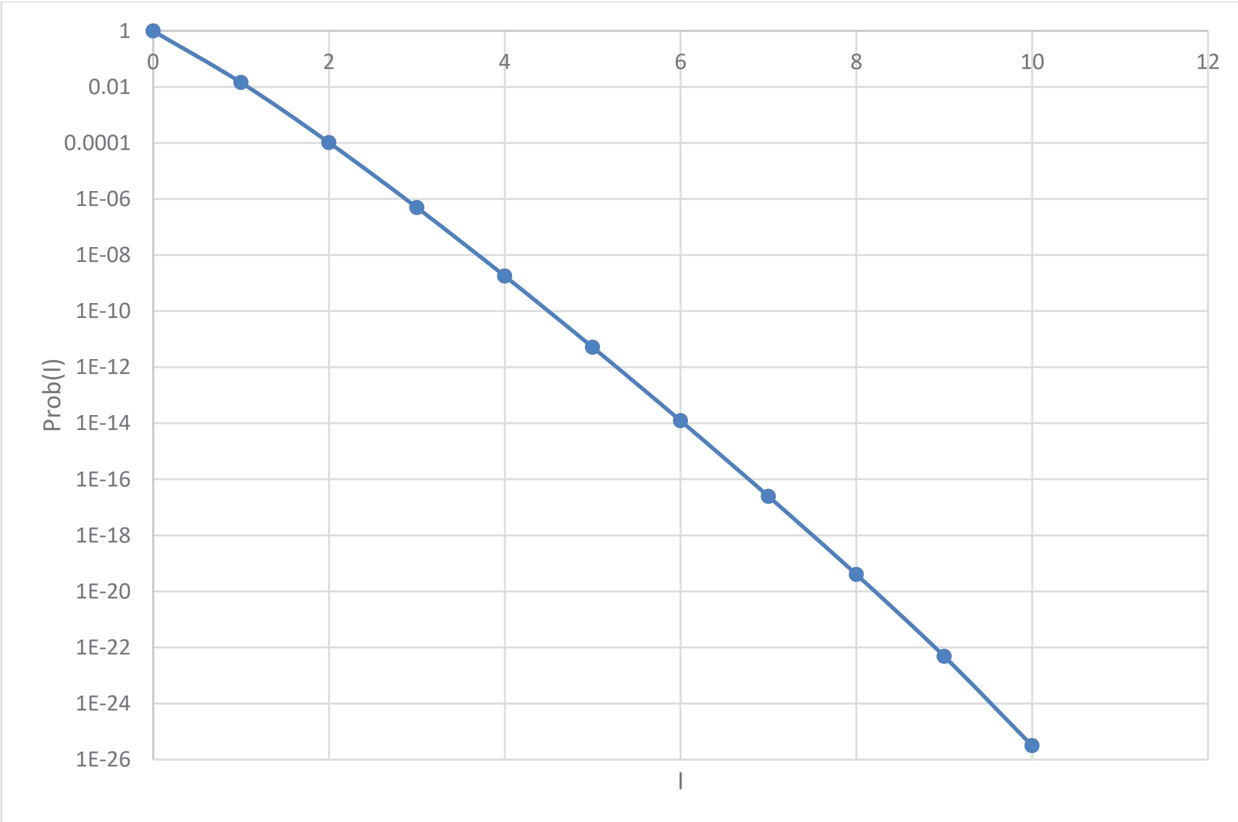

Figure 2: Probability of I Reportable Flaws Close to the OBM in a Single Channel

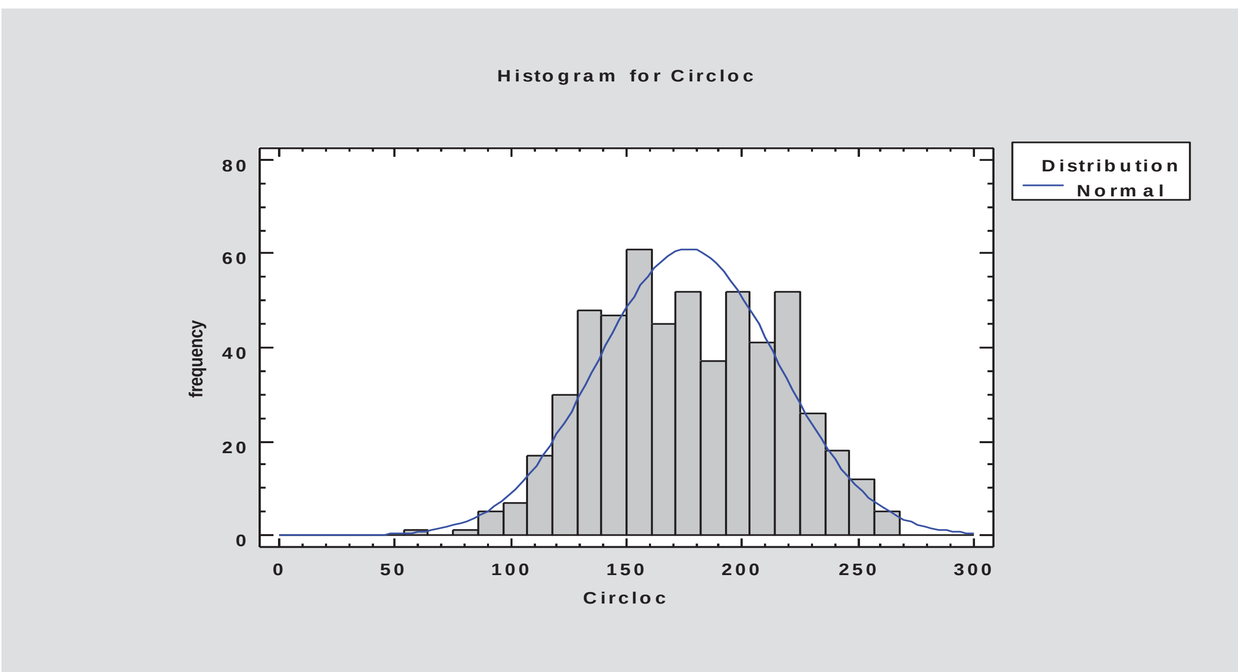

Figure 3: Histogram for the Distribution of the Circumferential Location

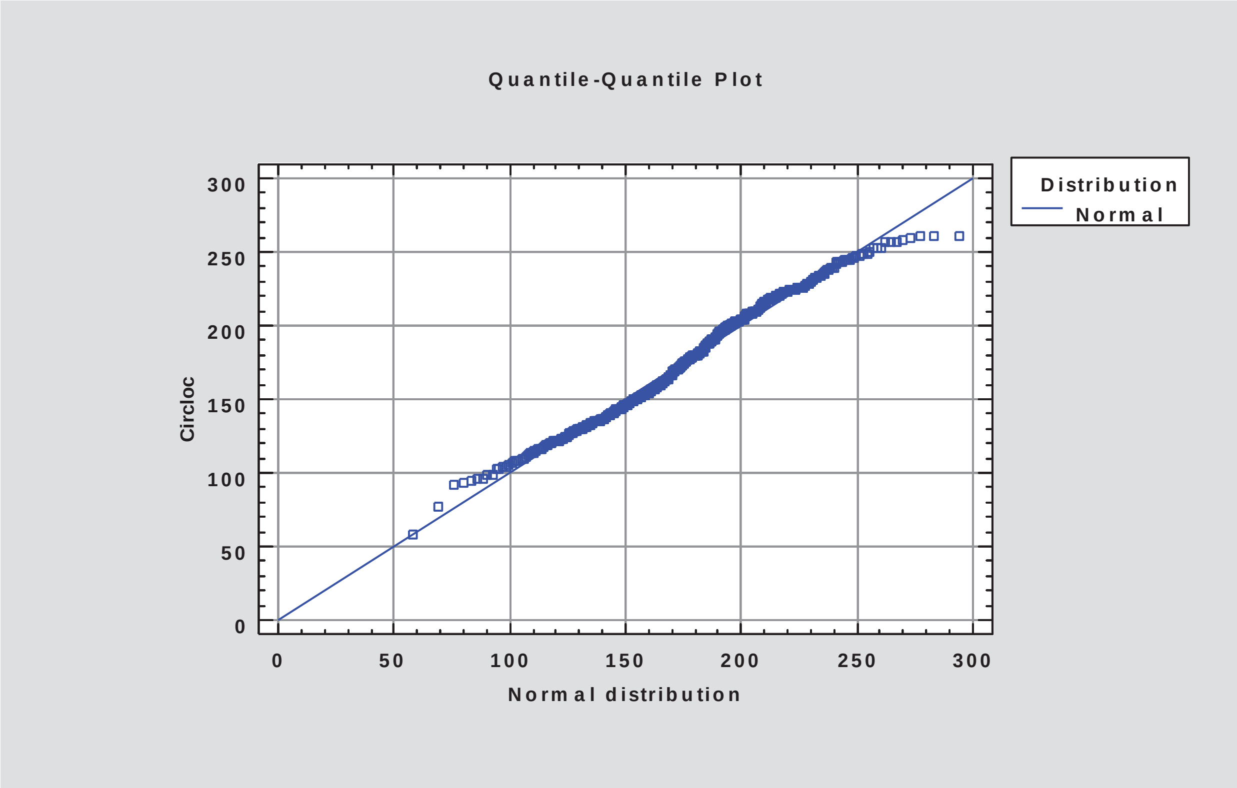

Figure 4: Quantile-Quantile Plot of Observed Distribution and Proposed Distribution

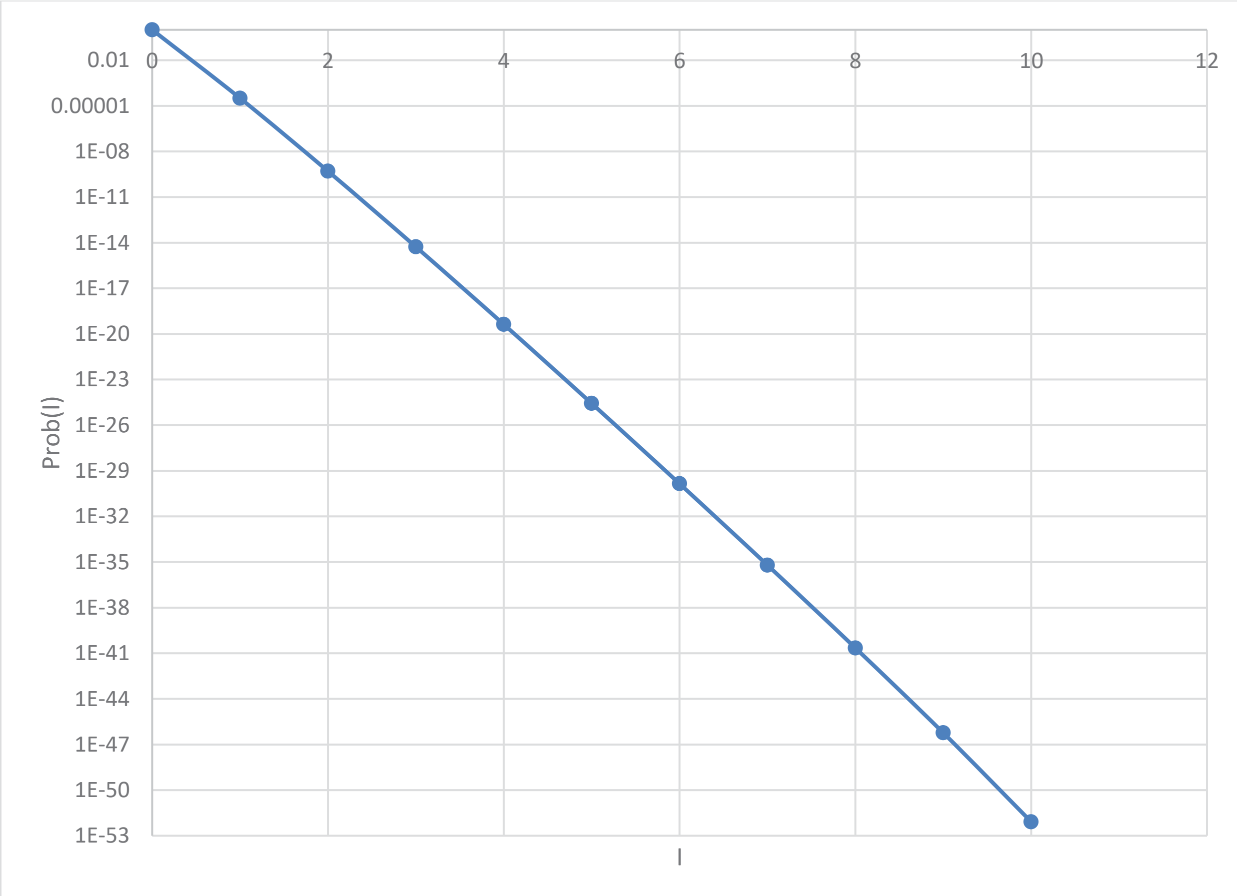

Figure 5: Probability of J Reportable Flaws in the Top 120 Degrees for the Region of Interest.

Enclosure 2

B-03644.1-29SEP2021

Updated Flaw Probability in the Region of Interest in the Uninspected Population of Pressure Tubes in Bruce Units 3-8

FORM-14287 R000*

Supplier Document Acceptance Form

Bruce Power

KINECTRICS

UPDATED FLAW PROBABILITY IN THE REGION OF INTEREST IN THE UNINSPECTED POPULATION OF PRESSURE TUBES IN BRUCE UNITS 3-8

B-03644.1-29SEP2021

☒ Accepted ☐ Accepted As Noted – Revision Required

☐ Rejected ☐ Accepted As Noted – No Revision Required

FOR USE AT BRUCE POWER

ACCEPTED: **LARRY MICUDA**

(Print Name) (Signature)

TITLE: **SENIOR TECHNICAL SPECIALIST**

(Print Title)

DATE: **29SEP2021**

(DDMMMYYYY)

ACCEPTANCE OF THIS DOCUMENT DOES NOT RELIEVE THE CONTRACTOR OF RESPONSIBILITY FOR ANY ERRORS OR OMISSIONS.

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September 29, 2021

Andrew Glover
Bruce Power
123 Front St., 4th Floor
Toronto, ON, M5J 2M2

Re: Updated Flaw Probability in the Region of Interest in the Uninspected Population of Pressure Tubes in Bruce Units 3-8

Dear Mr. Glover,

Introduction

This work is related to the task of estimating the number of dispositonable pressure tube flaws that exist in the 'region of interest' (defined 4 different ways as given in Table 1) in the uninspected populations of Bruce Units 3-8 pressure tubes. This is a follow-up to the initial work documented in Reference [1].

The purpose of this letter is twofold:

1. To refine the analysis provided in [1] to remove unnecessary conservatisms, and,

2. To address a question asked by the CNSC [2] regarding the possible dependence of the results from [1] on flaw type (e.g. debris fret marks, crevice corrosion, manufacturing flaw, erosion).

The unnecessary conservatism in Reference [1] was the result of the procedure to estimate the number of dispositionable flaws close to the outlet burnish mark (OBM) in uninspected pressure tubes in Bruce Units 3-8. In order to have as many relevant data as possible to describe the distributions of the axial and circumferential locations of flaws, the decision was made to use all reportable flaws (including dispositionable flaws) to estimate these two important distributions. This information was then used to estimate the number of reportable flaws in the uninspected population of pressure tubes and then finally scale this number back to the number of dispositionable flaws according to the ratio of dispositionable flaws to total reportable flaws. It was acknowledged that this assessment was conservative because the ratio of dispositionable flaws to total reportable flaws, while adequate for the whole database, did not hold for flaws close to the OBM. Specifically, given the observation from the flaw database that approximately 1/3 of all reportable flaws are dispositionable [1], one would have expected that 2 out of the 6 reportable flaws found within 75mm of the OBM in B3-B8 would have been dispositionable, when in fact none of them were dispositionable[1]. This discrepancy between prediction and observation strongly suggests that the observation of zero dispositionable flaws in Region 4 should be included in the analysis, which is done in this letter.

This letter compares three estimates of the number of flaws in the regions of interest of the uninspected population of pressure tubes in Bruce units 3-8. The first one, based largely on information from reportable flaws is too conservative for the reasons outlined above, is already reported in Table 5 of Reference [1] and is repeated in Table 2 of this letter for comparison purposes. The second set of estimates uses only dispositionable flaws as inputs, while the third one focuses even further by using only information from dispositionable debris flaws (i.e., the only flaw type in the database within 75 mm of the OMB) as inputs. This last set of estimates is the result of a sensitivity exercise intended to address the CNSC question related to the possible dependence of the results on flaw type.

Methodology

The methodological switch was to use exclusively the incidence and location of dispositionable flaws. This approach would eliminate the assumption that the ratio of dispositionable flaw to reportable flaws is independent of axial location.

For the first refinement analysis it was possible to undertake this approach because there was still a sizeable population of dispositionable flaws (187 flaws) from which to build a reliable distribution for the circumferential location of the flaws. The resulting distribution is still normal but has a slightly larger standard deviation compared with the one based on all flaws and reported in [1].

To estimate the cumulative density function (CDF) for the axial distribution at 75 mm, the interpolation technique described in [1] was used and gives a conditional probability estimate of 0.003535203 given that a flaw was present. The dispositionable flaw incidence has a lambda value of 0.417411 (187 dispositionable flaws / 448 unique inspected channels).

The second refinement only uses information from a further reduced population: dispositionable debris fret marks. The population is now further reduced to 143 flaws and the circumferential location distribution is similar but not identical to the one used for all dispositionable flaws. The flaws removed from the databases were almost exclusively erosion shot flaws and crevice corrosion flaws, none of which are observed in BA units. This refinement ensures a more even flaw incidence representation from each unit.

The CDF for the axial distribution at 75 mm is now 0.004622958 (slightly larger) but the lambda value describing the incidence is slightly lower 0.319196 (143/448).[2]

Results

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[1] Without bearing pads in this region to trap debris against the PT surface, it may well be that any fretting flaws that form there will tend to be less severe.

[2] The product of these two probabilities will be the same for both refinements because the anchor points for the interpolation are the same. Therefore, the results will be identical for the two refinements for Region 4.

Table 3 provides the results of the approach which uses only dispostionable flaw information, while Table 4 provides the results of the approach which uses only dispositionable debris flaw information. The fact that the estimated number of dispositionable flaws in the uninspected populations is larger for the second approach as compared to the first for Regions 1, 2 & 3 is related to the larger standard deviation of the distribution of the circumferential position for the debris flaw population. For all practical purposes these estimated values of flaws in uninspected reactors for Regions 1, 2 & 3 remain zero.

Of particular interest is the change in the estimated number of flaws in Region 4. For the former, very conservative analysis (Table 2) the estimated number of flaws in the uninspected population of each Bruce Power reactor was ~1.9-2.0. The updated, more refined analysis (Table 3 & Table 4) now provides new estimates which indicate a more realistic value of ~0.6 dispositionable flaws in the uninspected populations.

Conclusions

A refinement on the estimation of the number of dispositionable flaws in 4 regions of interest in the uninspected population of Bruce units 3-8 has been developed which does not require the assumption that the ratio of reportable to dispositionable flaws is independent of axial location. Furthermore, an additional sensitivity case has been analyzed to address the potential influence of flaw type on the results.

The following conclusions can be drawn from these improved estimates:

i. It remains highly unlikely to encounter any dispositionable flaws in Regions 1, 2 & 3.

ii. The expected number of flaws in Region 4 is around 0.6 (for all reactors) from which it can be deduced that it is possible but not very likely ($p<0.5$) that one dispositionable flaw will be present in the uninspected population of pressure tubes in Bruce reactors.

iii. The results are not very sensitive to whether all dispositionable flaws are considered, or just dispositionable debris flaws.

The implications of these estimates of the number of flaws are governed by the flaw severity and by the flaw environment with the likelihood of subpopulations of pressure tubes being present with different propensities to be exposed to high Hydrogen equivalent, meaning that associated conservatisms likely still exist in these results.

References

[1] D. Leemans, "Estimation of Encountering Reportable & Dispositionable Pressure Tube Flaws in Various Regions of Interest in Bruce Power Units 3-8", Kinectrics File: B2266/RP/0010 R01, September 24, 2021.

[2] A. Robert, e-mail to A. Glover, “RE: Request for Clarifications Regarding the Statistical Analysis of Flaws Near the Outlet Burnish Mark”, Kinectrics File: B2266/RE/0010 R00, September 22, 2021.

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Table 1 – Definition of 4 Regions of Interest in B3-B8 pressure tubes

	Axial Extent	Circumferential Extent Centred at Top of Tube
Region 1	OBM + 75 mm	60° (+/- 30°)
Region 2	OBM + 75 mm	120° (+/- 60°)
Region 3	OBM + 75 mm	180° (+/- 90°)
Region 4	OBM + 75 mm	360° (+/- 180°)

Table 2 – Reference Analysis (from Reference [1]) - Estimates of the Number of Dispositionable Flaws in the Regions of Interest in the Uninspected Population of B3-B8 Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	2.52E-04	4.28E-03	4.22E-02	1.94
4	398	2.50E-04	4.24E-03	4.18E-02	1.92
5	403	2.53E-04	4.29E-03	4.23E-02	1.95
6	418	2.62E-04	4.45E-03	4.39E-02	2.02
7	410	2.57E-04	4.37E-03	4.30E-02	1.98
8	401	2.52E-04	4.27E-03	4.21E-02	1.94

Table 3 - Refinement #1 Using Only Dispositionable Flaws - Estimates of the Number of Dispositionable Flaws in the Regions of Interest in the Uninspected Population of B3-B8 Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	5.74E-04	4.92E-03	2.83E-02	0.59
4	398	5.69E-04	4.87E-03	2.80E-02	0.59
5	403	5.76E-04	4.94E-03	2.84E-02	0.59
6	418	5.97E-04	5.12E-03	2.94E-02	0.62
7	410	5.86E-04	5.02E-03	2.89E-02	0.60
8	401	5.73E-04	4.91E-03	2.82E-02	0.59

Table 4 - Refinement #2 Using Only Dispositionable Debris Flaws - Estimates of the Number of Dispositionable Flaws in the Regions of Interest in the Uninspected Population of B3-B8 Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	9.21E-04	6.73E-03	3.42E-02	0.59
4	398	9.12E-04	6.67E-03	3.38E-02	0.59
5	403	9.24E-04	6.75E-03	3.43E-02	0.59
6	418	9.58E-04	7.00E-03	3.55E-02	0.62
7	410	9.40E-04	6.87E-03	3.48E-02	0.60
8	401	9.19E-04	6.72E-03	3.41E-02	0.59