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Written submission from Ontario Power Generation

Mémoire d' Ontario Power Generation

In the Matter of

À l'égard de

Request for authorization to return Darlington Nuclear Generating Station (NGS) Unit 4 to service following its current planned outage, also to consider whether to authorize OPG to restart Darlington NGS Units 1 and 4 following future outages

Demande pour obtenir l'autorisation de remettre en service la tranche 4 de la centrale nucléaire de Darlington après son arrêt prévu actuel, ainsi que pour redémarrer les tranches 1 et 4 de Darlington après tout arrêt futur.

Public Hearing - Hearing in writing based on written submissions

Audience Publique - Audience fondée sur des mémoires

November 2021

Novembre 2021

Canada

ONTARIO POWER GENERATION

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OPG Proprietary

September 29, 2021

CD# NK38-CORR-00531-22869

MR. M. LEBLANC
Commission Secretary

DR. A. VIKTOROV
Director General

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

Dear Mr. Leblanc and Dr. Viktorov:

Darlington NGS: Request for Authorization to Restart following the Darlington Unit 4 Fall 2021 Outage and Authorization to Restart following any Darlington Unit 1 or 4 Forced Outage with Heat Transport System Cooldown

The purpose of this letter is to request the following pursuant to the Order issued to OPG by the CNSC Designated Officer (Reference 1) and confirmed by the Commission as documented in the Summary Record of Decision (Reference 2):

- Authorization to restart Darlington Unit 4 from the planned fall 2021 outage (D2141).
- Authorization to restart Darlington Unit 1 from any forced outage that results in the cooldown of the heat transport system (HTS).
- Authorization to restart Darlington Unit 4 from any forced outage that results in the cooldown of the HTS.

OPG had previously provided information to support a request for blanket pre-authorization to restart Darlington Units 1 or 4 following a forced or planned outage that required cooldown of the HTS in the submissions to support the Opportunity to be Heard (References 3 and 4). This submission provides additional information identified as required by CNSC staff during the hearing including the qualitative and quantitative analysis to satisfy the conditions of the Order as documented by the Commission in Reference 2.

As indicated during the Opportunity to be Heard held on September 10, 2021, the only plausible mechanism for flaw formation in the Region of Interest (ROI) is debris fretting. Darlington has a robust foreign material exclusion program, which is extremely effective at keeping debris out of the HTS, thus significantly minimizing the source of flaws in pressure tubes. Additionally, Darlington utilizes a fuel carrier system that supports fuel in transition over the ROI, which eliminates the susceptibility to fuel bundle bearing pad frets during fuel in cross flow events. Notwithstanding, Enclosure 1 provides a conservative quantification of the probability of a random flaw within the ROI in Darlington Units 1 and 4 pressure tubes. The results indicate that, with a 95% confidence level, there could conservatively be about two flaws in the ROI of uninspected pressure tubes of a unit. It should be noted that this conservative quantification is statistical in nature and as such, small data size, such as Darlington's small flaw population, yields higher results. This is intrinsic to the statistical method and should be considered within the context and further assessments provided herein. As it has been previously communicated to the Commission, no flaws have been observed in the ROI for 131 unique pressure tube inspections completed in Darlington Units 1 and 4 to date. Furthermore, out of the 518 unique inspected pressure tubes in OPG units, there remains a low population of flaws near the outlet end of the pressure tube. Due to the very low population of flaws near the outlet rolled joint, the likelihood of having a flaw of significant depth which would initiate a crack is extremely low. OPG has also conservatively assessed flaws with additional [Heq] and the results indicate that flaws remain acceptable (Enclosure 1 of Reference 4). Additionally, increases in [Heq] levels are not expected to impact crack initiation models (Enclosure 2 of Reference 5). Conservative sensitivity core assessments have been completed with higher than predicted [Heq] values and continue to meet the licensing basis requirements.

Considering all material surveillance testing and in-service scrape inspections performed to date, Darlington pressure tubes are not experiencing similar levels of [Heq] concentration as observed during the recent Bruce Unit 3 and 6 findings and are expected to remain fit-for-service until the target end of operation of the units.

The quantitative analysis in Enclosure 1 documents OPG's justification, with a high degree of confidence, that there are no flaws that could pose a challenge to pressure tube fitness for service present in the ROI for Darlington Units 1 and 4.

As part of OPG's fitness for service process, OPG undertakes a regulatory management action, as documented in Table 1, to re-affirm the validity of the assessment provided in Enclosure 1 following any planned outage inspection. This affirmation will be provided to CNSC staff along with any flaw disposition as required under the Darlington Power Reactor Operating Licence (PROL).

Attachment 1 summarizes how OPG staff protect fuel channel fitness for service and monitor unit conditions for any indication of pressure tube leaks during HTS cooldown and depressurization, as these evolutions are important to fuel channel fitness for service. Operating procedures for these HTS conditions are carefully designed to ensure that, at all times, the unit remains within the safe operating envelope. The HTS pressure and temperature data for every cooldown is carefully analyzed by OPG's engineering staff. In the rare event that there is any deviation from the expected evolution, the impact on existing approved pressure tube flaw fitness for service assessment is determined prior to warm-up and pressurization of the HTS. If required under the PROL, this assessment is submitted to CNSC staff and approval is received prior to pressurization of the HTS. As well, the units are monitored continually for any early indication that pressure tube integrity has been challenged, allowing qualified, trained operators to take timely corrective actions per existing procedures. While Enclosure 1 demonstrates OPG's high degree of confidence that there are no flaws in the ROI that challenge pressure tube fitness for service, the activities described in Attachment 1 outline the existing defense-in-depth and demonstrate that OPG treats pressure tube fitness-for-service with utmost importance.

For information purposes, Attachment 1 also provides details regarding the challenges and risks associated with mobilizing OPG's inspection team to perform fuel channel inspections during a forced outage. OPG's planned fuel channel inspection campaigns are the result of years of advanced planning and coordination of resources, and injecting forced outage inspections to this presents significant risks and challenges. Based on the information presented in Attachment 1, it is OPG's position that the risks of performing fuel channel inspections during forced outages outweighs the value provided.

As a direct result of the Bruce Power OPEX, OPG has increased the scope of the planned fall 2021 Darlington Unit 4 outage as follows:

- Increased the number of hydrogen equivalent concentration [Heq] sample channels from 3 to 5 in the outlet rolled joint (the ROI) to supplement the already high level of confidence in Darlington [Heq] predictions.
- Perform an additional 8 (for a total of 18 channels) ultrasonic inspections in the ROI to augment OPG's quantitative high confidence of the low likelihood of flaws in the ROI as assessed in Enclosure 1. These results will be assessed in the new commitment discussed earlier in this letter.

Other enhancements being considered for future outages are as follows:

- Endeavour to perform future scrape sampling at standard axial locations at the pressure tube top dead center in the ROI.
- Endeavour to accelerate [Heq] analysis of scrape samples and provide to CNSC as soon as practicable.

Enclosure 1 quantitatively demonstrates that no flaws which pose any challenge to pressure tube fitness for service are present in the ROI, and that in the unlikely scenario that a significant unknown flaw is present in the ROI concurrent with unexpectedly high hydrogen equivalent concentration, OPG's robust processes and procedures effectively mitigate challenges to the fitness for service of the pressure tubes.

To further illustrate the existing defense in depth, OPG's safety analysis demonstrate that the consequences of any pressure tube failure are well within the station's licensing basis and safety goals.

Probabilistic Safety Assessment (PSA) is an important tool for assessing and managing nuclear power plant risk, and it is another key tool used to support the adequacy of the plant safety provisions. PSAs provide quantitative estimates of risk in the form of calculated risk metrics, for comparison to OPG's PSA safety goals and to support risk-informed decision making.

OPG's PSA safety goals are used as quantitative indicators of the overall safety of OPG operated reactors. To help manage risk, the safety goals are set at very low values:

- Severe core damage frequency (SCDF) should be less than 1x10-4 per reactor, per year i.e., 1 in 10,000 per reactor, per year
- Large release frequency (LRF) should be less than 1x10-5 per reactor, per year, i.e., 1 in 100,000 per reactor, per year.

These safety goals are aligned with international norms and CNSC safety goal definitions. Furthermore, as internal targets, OPG has administrative safety goals set to one order of magnitude lower than the above values.

It is important to note that the OPG 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.

Enclosure 2 summarizes the contribution of spontaneous pressure tube failure and spontaneous pressure tube leak to the SCDF and LRF for Darlington NGS and shows the contribution of pressure tube failure and leak is a small fraction of the calculated SCDF and LRF. The SCDF and LRF values are well below the safety goals, and pressure tube leaks and failures are not risk significant initiating events. Furthermore, the time spent in transition states (such as heat-up and cooldown) is very short compared to time spent operating at full-power. Therefore, the overall risk while the unit is operating in transition state is even smaller compared to at-full-power condition.

Enclosure 3 provides an estimated frequency of occurrence of two independent, concurrent pressure tube failures in OPG operated reactors. This estimate is based on existing deterministic and probabilistic analyses. The conclusion confirms that the likelihood of independent, concurrent failure of two pressure tubes is also very unlikely.

Finally, Enclosure 4 provides conditional severe core damage probability and conditional large release probability given that a pressure tube leak has occurred for Darlington NGS and Pickering 5-8 NGS. The conclusion confirms that it is highly unlikely that a spontaneous pressure tube leak will progress to severe core damage or to a large release, and that pressure tube leaks and failures are not a risk significant initiating events.

In summary, OPG has a high degree of confidence that no flaws which pose any challenge to pressure tube fitness for service are present in the ROI in Darlington Units 1 and 4. This is demonstrated in Enclosure 1. Per Attachment 1, OPG’s existing procedures and processes associated with HTS cooldown, depressurization, warm-up and repressurization assure pressure tube fitness for service during these evolutions. Continuous unit monitoring by qualified staff would give rise to early identification of indications of a pressure tube leak, and thus corrective action can be taken per existing procedures. In the very unlikely event of a pressure tube leak or failure, the safety analysis results provided in Enclosures 2, 3 and 4 demonstrate that the overall risk associated with a pressure tube failure is extremely low. As such, the information provided in Enclosures 1, 2, 3, and 4 support the assumption of a single pressure tube failure as postulated in the licensing basis Safety Report analysis.

Based on the information submitted in this correspondence and References 3 and 4, OPG reaffirms that Darlington Units 1 and 4 remain fit for service, within the licensing basis, and can safely return to service following any planned or forced outage.

Pursuant to the Order issued to OPG by the CNSC Designated Officer, OPG requests authorization to restart Darlington Unit 4 following its fall 2021 outage, as well as authorization to restart following any Darlington Unit 1 or 4 forced outage. An expedited review and decision by the Commission is appreciated. Should individual reviews of each of the three distinct requests in this submission be required to support an expedited resolution, OPG would appreciate individual record of decisions be issued for each request as they become available.

If you have any questions or require any clarification regarding this submission, please contact Dr. Jack Vecchiarelli, Vice President, Nuclear Regulatory Affairs at (905) 706-4121 or by email at jack.vecchiarelli@opg.com.

Sincerely,

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

cc: R. Jammal - CNSC (Ottawa)
J. Burta - CNSC (Ottawa)
D. Hipson - CNSC Site Office (Darlington)

References:

1. CNSC Letter, R. Jammal to S. Gregoris, “Designated Officer Order issued to Ontario Power Generation”, July 26, 2021, e-Doc 6612869, CD# NK38-CORR-00531-22721.
2. CNSC Letter, L. Levert to S. Gregoris, “Summary Record of Decision on Opportunity to be Heard on the Designated Officer Order and Request to Restart Reactors subject to the Order”, September 22, 2021, e-Doc 6646295, CD# NK38-CORR-00531-22838.
3. OPG Letter, S. Gregoris and J. Franke to M. Leblanc, “Pickering and Darlington: OPG Response to Designated Officer Orders and Opportunity to be Heard on Designated Officer Orders”, August 6, 2021, CD# N-CORR-00531-22817.
4. OPG Letter, S. Gregoris and J. Franke to M. Leblanc, “Pickering and Darlington NGS: Submission of Supplemental Information in Response to Designated Officer Orders and to Support Opportunity to be Heard Public Hearing”, September 8, 2021, CD# N-CORR-00531-22866.

5. OPG Letter, M. Knutson to M. Leblanc and A. Viktorov, “OPG Response to Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Responses to Items 1-4 Related to Measurement of Hydrogen Concentration in Pressure Tubes”, July 30, 2021, CD# N-CORR-00531-22801.

TABLE 1

Summary of Regulatory Management Actions Undertaken in this Submission

Submission Title: "Darlington NGS: Request for Authorization to Restart following the Darlington Unit 4 Fall 2021 Outage and Authorization to Restart following any Darlington Unit 1 or 4 Forced Outage with Heat Transport System Cooldown"

Regulatory Commitment Action (REGC):

No.	Commitment Description	Target Completion Date
1.	Re-affirm the validity of the assessment provided in Enclosure 1 following any planned outage inspection. This affirmation will be provided to CNSC staff along with any flaw disposition as required under the Darlington Power Reactor Operating Licence (PROL).	Effective immediately

Attachment 1

Assurance of Fitness for Service during Forced Outages:

Occasionally, OPG must incur forced outages of its running units, usually to implement repairs to equipment that supports safe operation. The organization has a forced outage plan that is proactively developed based on known issues on the unit, including any required inspections. For a forced outage, the organization reviews the outage plan and will add additional scope as needed for significant equipment degradations. The overall forced outage process is included in our governance which makes this process repeatable and rigorous.

During these evolutions, both the reactor shutdown and the cool down and depressurization follow detailed procedures executed by our trained and qualified operators. At every step of the evolution, there is oversight that includes review of the completed steps and confirmation of the expected results of the action taken. This ensures quality and performance within our safe operating envelope.

After the system is cooled and depressurized, our engineering team carefully reviews the pressures and temperatures incurred during the entire evolution. They compare this data against the assumptions in our pressure tube flaw assessments, to ensure no deviations have occurred. If there is any deviation from the typical cool down and depressurization, any impact of the deviation on pressure tube flaw fitness-for-service is evaluated. On the very rare occasion that the flaw assessment needs to be updated due to a deviation, the assessment is submitted to CNSC staff and their approval is received prior to re-pressurization of the heat transport system.

During the shutdown and cool down evolution, throughout the outage, during warm up, pressurization and return to high power, the unit undergoes rigorous surveillance. The annulus gas system, which circulates very dry carbon dioxide through the annuli between the pressure tubes and calandria tubes, is monitored by dewpoint rate-of-rise instrumentation and sensors that detect very small amounts of liquid water in the system and alert control room staff. This system is very sensitive to small amounts of water vapour and liquid water, and a leaking flaw would quickly be realized by the automatic function of the annulus gas system. Control room staff would then work within existing procedures to take any necessary precautions or actions. As well, parameters such as heat transport leakage rates, heat transport system inventory accounting, off normal indications, changes in dewpoint, dryer collection rates are monitored. Collectively, these elements all ensure staff are quickly made aware of any challenge to pressure tube fitness for service so appropriate actions can be taken.

OPG recognizes the importance of pressure tube fitness for service and is confident that the robust measures described are sufficient to monitor pressure tube conditions during forced outages.

Mobilization for Forced Outage Fuel Channel Inspection Campaigns:

For OPG to plan and execute a fuel channel inspection campaign during a forced outage, approximately 3 months of planning and preparation is required. Activities such as tooling readiness (tool maintenance and rebuilds, cutter qualification of scrape tools, documentation etc.) as well as readying of personnel (i.e. training, qualification refreshers etc.) and mobilization of equipment are required for safe and reliable execution of inspection activities.

For a forced outage fuel channel inspection campaign, there is a variety of tooling combinations available. The likely selection for deployment would be the Channel Inspection Gauging Apparatus for Reactors (CIGAR) drive for volumetric inspections and the manual rolled joint (RJ) scrape tooling for sampling pressure tube material in situ for hydrogen equivalent concentration. For simplicity, the added complication of considering already in-progress inspection campaigns on other reactors has not been considered in the readiness timelines provided below.

Manual scrape sampling would require the deployment the damp circumferential scrape tooling to scrape in the rolled joint area. Each channel to be sampled requires defueling, feeder freezing, and draining the channels prior to deploying the scrape sampling. Maintenance platforms are installed on the fueling machine bridge for the workers to access the closure plug and install tooling into the target channel. Preparations for scrape sampling typically require three (3) months for planning, maintenance, training and mobilization prior to execution. The largest portion of the preparation work is the tooling and the resource preparations. The tooling preparation is rebuilding execution tools, cutter qualifications, preventative maintenance and documentation to support deployment on the reactor. Since this work program involves high hazard work and high radiation dose, staffing is augmented with temporary mechanical maintenance staff. Therefore, a detailed training program is required to ensure basic nuclear training, hands-on and on-the-job performance demonstrations are completed.

For flaw inspections, CIGAR allows for remote inspection of defueled fuel channels with a drive system that is installed on the fueling machine bridge, and an inspection package which is installed in the fuel channel by the fuelling machine. The drive is used to rotate the inspection heads along the pressure tube, collecting inspection data in areas of interest. Using a 10-channel inspection as an example, expedited preparations require six (6) to eight (8) weeks to perform extensive rebuild maintenance and testing on both the inspection packages and drive mechanisms. Once maintenance is performed, the equipment is mobilized, and calibrations are performed on a mock-up to ensure the system is ready for service. The main maintenance facility for CIGAR is at Darlington NGS, so an additional week is required when shipping to Pickering NGS. OPG internal staff support CIGAR inspections, so training time may be reduced with refresher and just-in-time training.

In a forced outage scenario, expedited timelines are estimated to reduce this window to ~ 2.5 months by dispositioning some activities based on OPEX and maximizing regular staff to reduce training timelines. Even with these preparations, there are still significant risks associated with performing fuel channel inspections during forced outages. Rushed training and the expediting of tooling maintenance and rebuild could lead to human performance issues, which can result in risk of tool malfunction. For example, broken scrape tool cutters could lead to severe flaws in pressure tubes in the region of interest, which would challenge fitness for service. For flaw inspections, the same risks are incurred when expediting, resulting in risks when deploying the inspection tooling on channel. This in turn could lead to tool malfunction, poor data quality and even the need to manually recover a failed inspection package from a channel.

Furthermore, diverting resources to forced outage inspections interrupts intricate preparation work for OPG’s other very important planned outage inspection campaigns, which are planned years in advance of execution.

ENCLOSURE 1

Re: Flaw Probability in the Region of Interest for Pickering B Units 5-8 and Darlington Units 1 & 4 Pressure Tubes

N-CORR-31100-0953933

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KINECTRICS

N-CORR-31100-0953933

ONTARIO POWER GENERATION

ACCEPTED ☒
ACCEPTED AS NOTED ☐
REVISE AND RESUBMIT ☐

Signature — Sept 27, 2021 Date

Name: Pierre Le Dreff-Kerwin

Department: MCED

THIS ACCEPTANCE DOES NOT RELIEVE THE CONTRACTOR FROM RESPONSIBILITIES FOR ERRORS OR OMISSIONS OR FROM ANY OBLIGATIONS OR LIABILITY UNDER THE CONTRACT

September 27, 2021

Trevor Carneiro
Ontario Power Generation
777 Brock Rd.
Pickering, Ontario
L1W 4A7

Re: Flaw Probability in the Region of Interest for Pickering B Units 5-8 and Darlington Units 1 & 4 Pressure Tubes

Dear Mr. Carneiro,

Introduction

The purpose of this letter is to document the statistical assessment of the expected number of dispositionable flaws, which cannot be attributed to known fuelling events, in the uninspected population of pressure tubes in Pickering B Units 5 to 8 and Darlington Units 1 and 4.

The region of interest is defined as the surface area of the pressure tube with an axial extent of 75 mm inboard of the outlet burnish mark and a circumferential extent of 120 degrees centred at the top of the tube [1]. Results are also provided as a sensitivity case for the CNSC defined region of interest, having the same axial extent but with a 360 degree circumferential extent.

Inputs

Of the 225 unique pressure tubes inspected in Pickering B Units 5 to 8, there are two dispositionable flaws in the 120 degree region of interest [2] (see Figure 1). However, both flaws were caused by known operational events (fuel bundle being stuck in cross-flow leading to a bearing pad fret) and were targeted for inspection based on these events, with procedures subsequently having been put in place to prevent recurrence [1]. Similarly, of the 61 unique pressure tubes inspected in Pickering A Units 1 and 4, there are three dispositionable flaws in the 120 degree region of interest [2] (see Figure 2); these three flaws were caused by known fuelling events and were targeted for inspection based on these events, with procedures subsequently having been put in place to prevent recurrence [1]. Of the 232 unique pressure tubes inspected in Darlington Units 1 to 4, there are no dispositionable flaws in the 120 degree region of interest [2] (see Figure 3). As noted in Reference [1], a fuel carrier is used at Darlington to support the fuel as it moves through cross-flow conditions, which eliminates the potential for pressure tube fretting due to fuel bundle cross-flow.

The statistical assessment is an evaluation of the probability of a dispositionable flaw in the region of interest in the uninspected population of Pickering B and Darlington 1 & 4 reactors, given the observation of no dispositionable flaws in the region of interest from the inspected population [1]. This approach was taken as other approaches that include other flaw incidence information from the balance of the tube were deemed less appropriate due to the limited population of flaws in the surrounding region of OPG pressure tubes from which to build representative distributions. Though the general paucity of flaws found in OPG units does limit the analytical options for quantifying the potential number of flaws in the region of interest, it is in itself a very reassuring condition to begin with and speaks to the positive performance of the foreign material exclusion (FME) practices that are in place.

The analysis is dependent on the fuel channel inspection data pooling strategy that is adopted. The following 3 pooling scenarios were evaluated:

1. Base Case – All inspection information for all OPG units pooled
    - Since there are no observations of dispositionable flaws (that cannot be attributed to known fuelling events) in any unit, there is no evidence that the units and stations are behaving differently from one another in this regard and this is considered the most appropriate basis for the analysis and chosen as the Base Case.
2. Sensitivity Case A – Pickering A / Pickering B units pooled separately from Darlington units
    - This scenario was evaluated in acknowledgement of the differences in fuel channel design, fuel handling and operating conditions between Pickering units and Darlington units that theoretically could affect flaw incidence.
3. Sensitivity Case B – All OPG reactors and Bruce Power Units 3 to 8
    - An extension of the base case, recognizing that the observations from the Bruce Power reactors, where there were also no detected dispositionable flaws in the 120 degree region of interest, could also be pooled together with the OPG observations to maximise the available database.

Methodology

The geometric distribution is applied to calculate the maximum probability of an event (with a certain confidence) consistent with the observation of zero observations in k trials (in this case zero observations of dispositionable flaws in the region of interest in k inspected pressure tubes). The geometric distribution models the number of trials before the first occurrence of an event given a certain probability of an event. The cumulative distribution function (CDF) is expressed as:

$$CDF = 1 - (1 - p)^k$$

Where p is the probability of encountering a dispositionable flaw in the region of interest in a single tube.

By equating CDF to 95% and solving the above equation for p, the limiting probability (with 95% confidence) is calculated as:

$$p = 1 - e^{\ln(1-\alpha)/k}$$

Example Calculation for Pickering Unit 5 – Geometric Distribution

$\alpha = 0.95$	(95% confident that the actual probability will not exceed this limiting probability)
$k = 518$	(the pooled inspected population for all OPG reactors (232 for Darlington Units 1-4 + 61 for Pickering A Units 1&4 + 225 for Pickering B Units 5-8))
0	(the number of detected dispositionable flaws from the inspected population in the region of interest after removing flaws caused by known operational events [1])
p = 5.767E-03	(given the observation of 0 flaws in the inspected population, the limiting probability (with 95% confidence) of encountering a dispositionable flaw in the region of interest in a single tube)
318	(number of uninspected tubes in P5 (380 – 62))
84.1%	$(1 - (1 - 5.767E-03)^{318}$, the probability of at least one dispositionable flaw in the region of Interest in the uninspected population of Pickering Unit 5 with a 95% confidence)
1.83	(5.767E-03 * 318, expected number of dispositionable flaws in the region of interest in the uninspected population of Pickering Unit 5 using the limiting probability)

Region of Interest Sensitivity & Example Calculation

A sensitivity evaluation of the CNSC defined region of interest, 75 mm axially by 360 degrees circumferentially, has also been performed. As shown in Figure 1, there are two Pickering B dispositionable flaws at the bottom of the pressure tube within 75 mm of the outlet burnish mark that cannot be attributed to known operational events [1]. The above approach using the geometric distribution cannot be used when there are some (non-zero) observations (dispositionable flaws) in *k* trials (inspected channels). Therefore, the CDF of the binomial distribution is used to establish limits to the probability of an event (i.e. presence of a dispositionable flaw).

For 2 observations in 518 trials (the number of full length unique inspected pressure tubes from Pickering A, Pickering B and Darlington), the best estimate of the probability of an event is 2/518 or 0.003861. The 95% upper limit of this probability is obtained by setting the CDF of the binomial (2, 518, *p*) equal to 0.05 and solving for *p* yielding *p(UL)* = 0.0121. Likewise, the 95% lower limit is obtained by setting the CDF of the binomial (2, 518, p) equal to 0.95 and solving for *p*, yielding *p(LL)*= 0.0016. Using the upper limit, *p(UL)*, the expected number of dispositionable flaws in the region of interest in the uninspected population of Pickering Unit 5 can reach as high as 0.0121 * 318 = 3.9.

Results

The results for the 75 mm by 120 degree region of interest using the geometric distribution (given zero observations in the inspected population) are provided in Table 1. It is observed that:

- Base Case (OPG units pooled) – The highest estimated number of dispositionable flaws in the region of interest of the uninspected population of any single unit is 2.4 flaws, for D4.
- Sensitivity Case A (Pickering A / Pickering B units pooled separately from Darlington units) – The highest estimated number of dispositionable flaws in the region of interest of the uninspected population of any single unit is 5.4 flaws, for D4.
- Sensitivity Case B (OPG units pooled with Bruce Power units) – The highest estimated number of dispositionable flaws in the region of interest of the uninspected population of any single unit is 1.3 flaws, for D1/D4.

The results for the 75 mm by 360 degree region of interest sensitivity case using the binomial distribution (given 2 observations in the inspected population) are provided in Table 2. It is observed that:

- Base Case (OPG units pooled) - The highest estimated number of dispositionable flaws in the region of interest of the uninspected population of any single unit is 5.1 flaws, for D4.
- Sensitivity Case A (Pickering A / Pickering B units pooled separately from Darlington units) - The highest estimated number of dispositionable flaws in the region of interest of the uninspected population of any single unit is 7.3 flaws, for P6.
- Sensitivity Case B (OPG units pooled with Bruce Power units) - The highest estimated number of dispositionable flaws in the region of interest of the uninspected population of any single unit is 2.7 flaws, for D1/D4.

Discussion & Conclusion

Other approaches to estimating the number of dispositionable flaws in the region of interest of the uninspected population that might have led to more optimistic results were not appropriate for OPG, simply due to the lack of sufficiently large flaw populations from which to build representative distributions of flaw incidence in the vicinity of the outlet rolled joint. Even using the present approaches, the number of expected flaws in the specified regions in the uninspected population in any single reactor shown in Table 1 and Table 2, is clearly low. Though the general paucity of flaws found in OPG units does limit the analytical options for quantifying the potential number of flaws in the region of interest, it is in itself a very reassuring condition to begin with and speaks to the positive performance of the FME practices that are in place.

Furthermore, the following should be considered in conjunction with the estimates provided in Table 1 and Table 2:

- The uninspected population of channels for which the number of flaws in the region of interest is estimated includes sub-populations that are empirically less likely to be susceptible to the mechanism that led to high [H]eq measurements in the Bruce Power channels. The estimated number of channels in the uninspected population perceived to be ‘at risk’, and therefore subject to this evaluation, would be less if this preliminary observation were established.
- The estimated number of dispositionable flaws provided in this letter is for any and all dispositionable flaws. Dispositionable flaws have distributions of depth, length and root

radius that in turn affect their severity from a PT integrity perspective. The estimated number of severe flaws within a region of interest would be less if these distributions were also accounted for.

  - A quantitative illustration of this is provided in Figure 4 for flaw depth. This figure shows the cumulative distribution of Pickering B debris flaw depths (orange curve) along with the P6 estimate of the number of dispositionable flaws in the region of interest corresponding to varying flaw depths (blue curve). It is apparent that the number of dispositionable flaws exceeding certain depth thresholds in P6 in the region of interest diminishes rapidly with increasing depth. A similar trend is expected for both increasing length and decreasing root radius.

- Recent work showed that flaw tip hydride accumulation and resistance to cracking under hydride ratcheting conditions is actually governed by peak temperature during hydride formation and not the bulk [H]eq. Other parameters such as K_{IH} and p_c are not affected by bulk [H]eq [3]. Therefore, even in the unlikely event that there were a severe flaw in a region with elevated [H]eq, it is believed that the concentration in excess of TSSD would not affect flaw-tip hydride accumulation, meaning there would be little incremental impact of elevated [H]eq on flaw assessment outcomes.

References

[1] OPG Letter, S. Gregoris and J. Franke to M. Leblanc, "Pickering and Darlington NGS: Submission of Supplemental Information in Response to Designated Officer Orders and to Support Opportunity to be Heard Public Hearing", OPG CD# N-CORR-00531-22866, September 8, 2021.

[2] Record, "OPG Inspections and Flaws Near the Outlet Burnish Mark Based on PCA Input Files", Kinectrics File PV073/RE/0011 R00, September 23, 2021.

[3] Letter, Various Authors to T. Carneiro, "Re: Evaluation of Postulated High $[H]_{eq}$ Levels on OPG Pressure Tube Fitness for Service Based on Recent Bruce Power Measurements", Kinectrics File PV073/LET/0002 R00, July 27, 2021.

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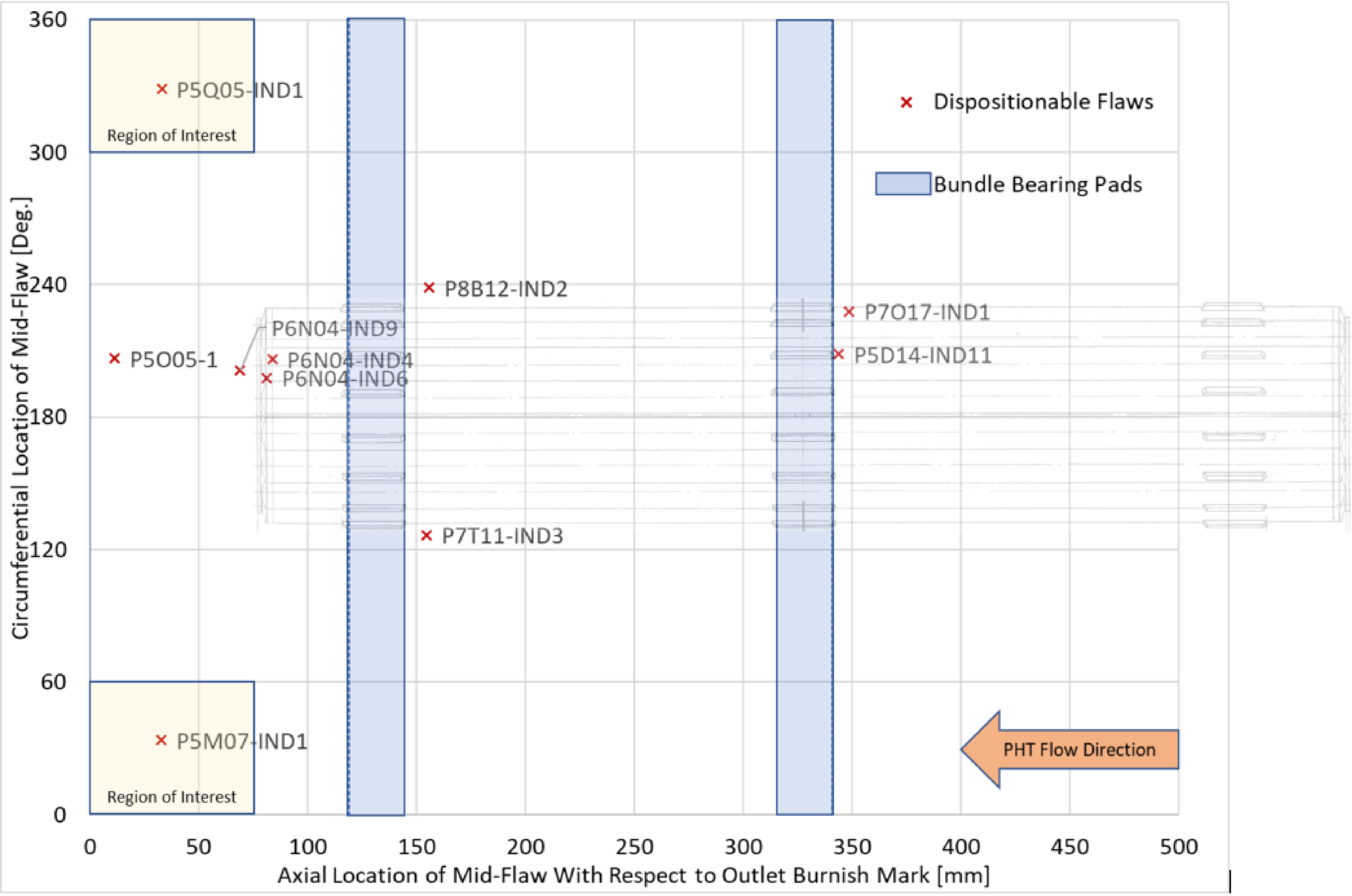

Figure 1: Overlay of Outlet End Fuel Bundle with Unique Dispositionable Flaws from the Inspected Population of Pickering B Units 5 to 8

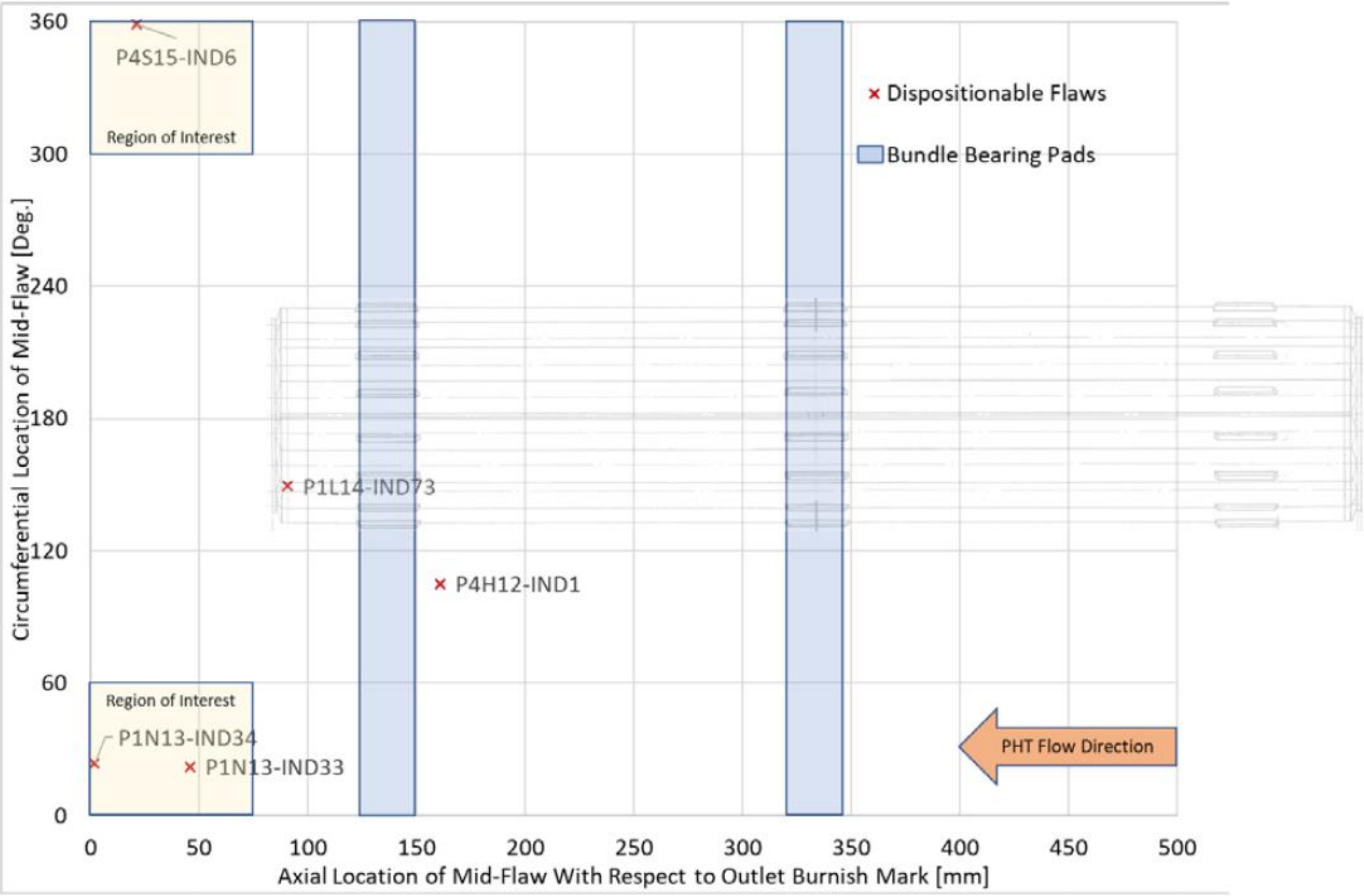

Figure 2: Overlay of Outlet End Fuel Bundle with Unique Dispositionable Flaws from the Inspected Population of Pickering A Units 1 and 4

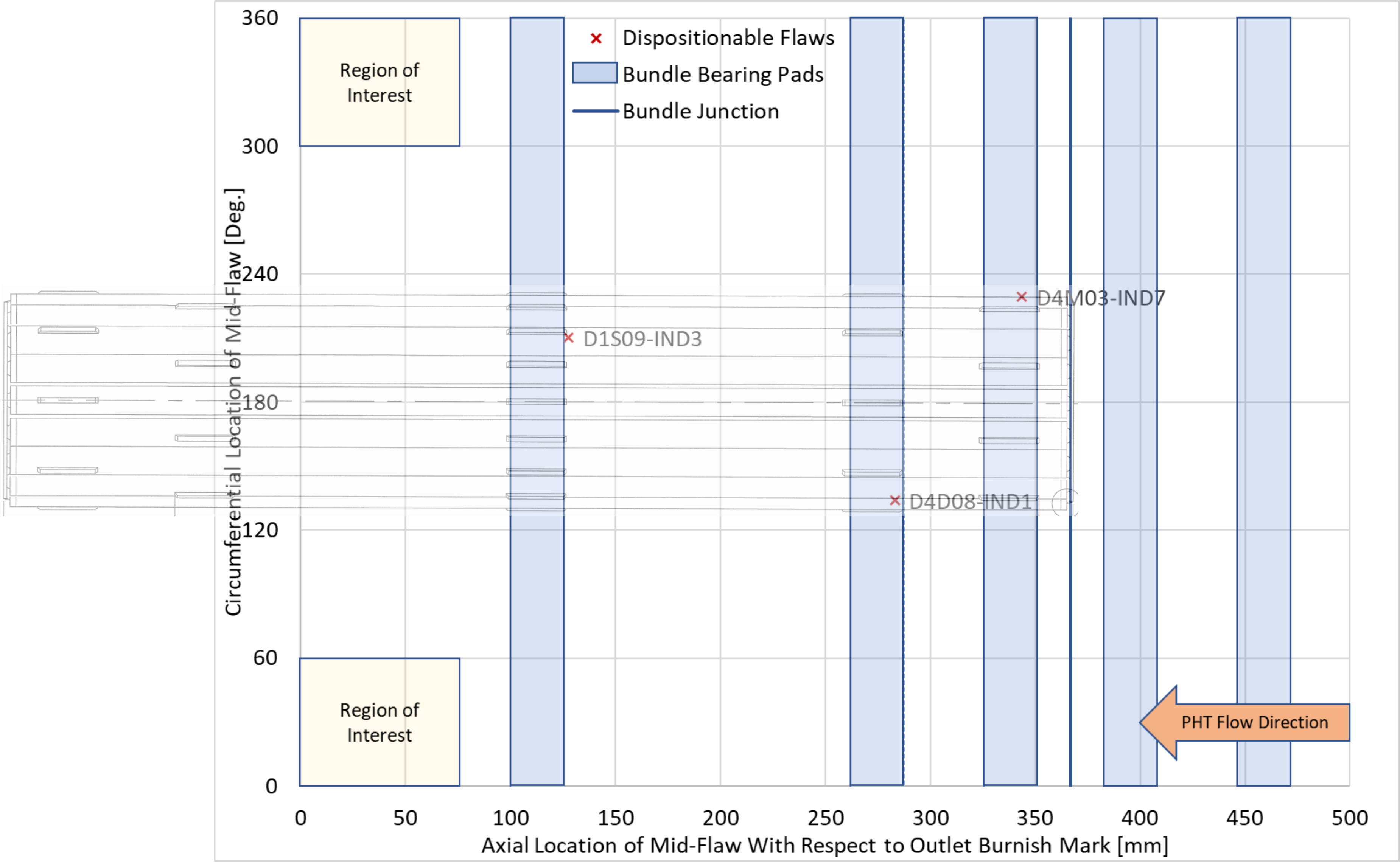

Figure 3: Overlay of Outlet End Fuel Bundle with Unique Dispositionable Flaws from the Inspected Population of Darlington Units 1 and 4

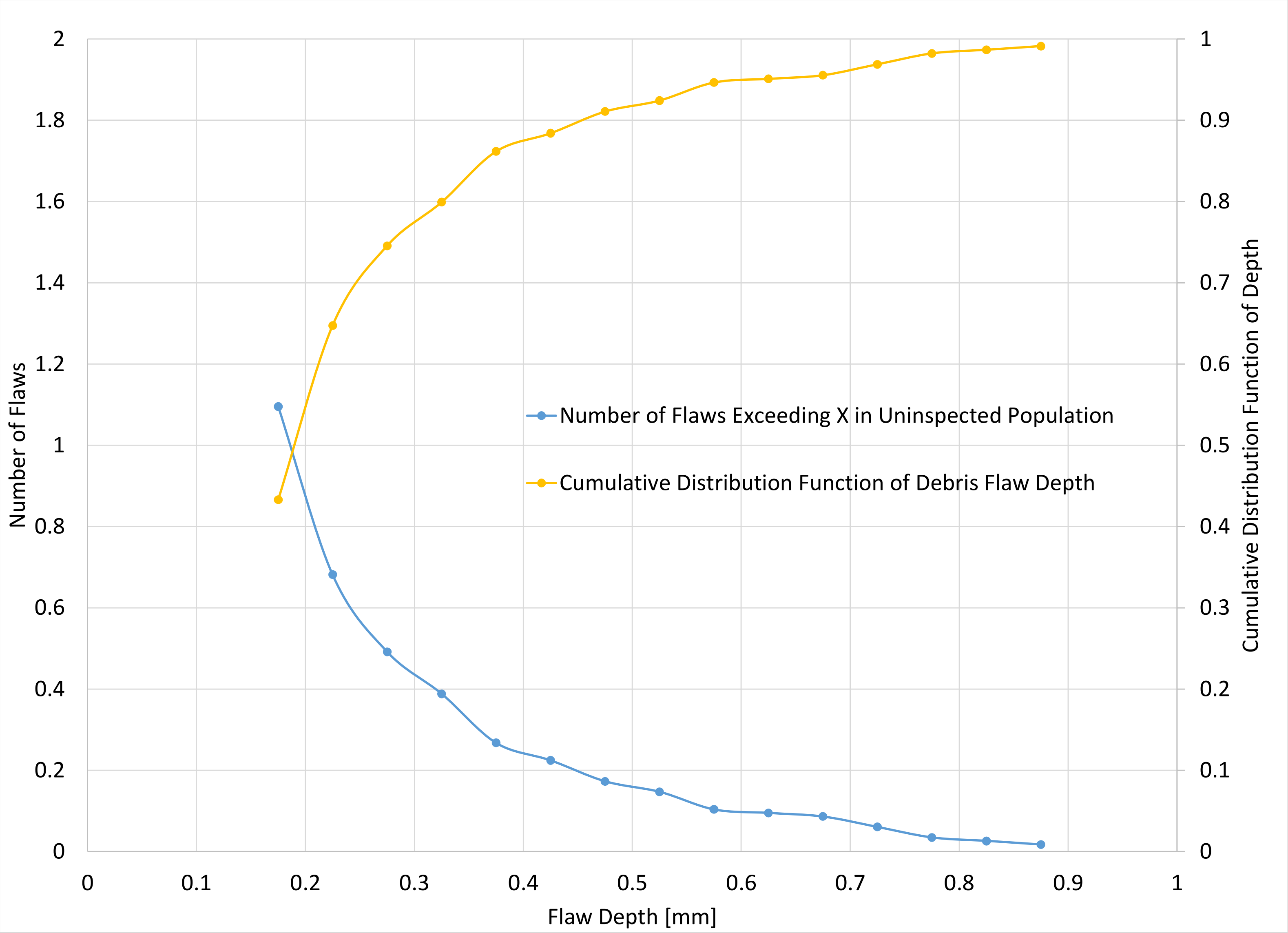

Figure 4: Cumulative Distribution of Pickering B debris Flaw Depths (Orange Curve) and P6 Estimate of the Number of Dispositionable Flaws in the Region of Interest Corresponding to Varying Flaw Depths (Blue Curve)

Table 1: Results for the 75 mm by 120 Degree Region of Interest Using the Geometric Distribution

					Base Case		**Sensitivity Case A**		**Sensitivity Case B**	
					All OPG unit data pooled		**Pickering A and Pickering B unit data pooled separately from Darlington unit data**		**All OPG and Bruce Power unit data pooled**	
Unit	**Station**	**Number of Full Length Inspections**	**Number of Pressure Tubes**	**Uninspected Population of Pressure Tubes**	**Probability of at least 1 Dispositionable Flaw**	**Expected Number of Dispositionable Flaws**	**Probability of at least 1 Dispositionable Flaw**	**Expected Number of Dispositionable Flaws**	**Probability of at least 1 Dispositionable Flaw**	**Expected Number of Dispositionable Flaws**
D1	DN	70	480	410	91%	2.4	99%	5.3	72%	1.3
D4	DN	61	480	419	91%	2.4	100%	5.4	73%	1.3
P5	PB	62	380	318	84%	1.8	96%	3.3	63%	1.0
P6	PB	45	380	335	86%	1.9	97%	3.5	65%	1.0
P7	PB	64	380	316	84%	1.8	96%	3.3	62%	1.0
P8	PB	54	380	326	85%	1.9	97%	3.4	64%	1.0

Table 2: Results for the CNSC Defined 75 mm by 360 Degree Region of Interest Sensitivity Case Using the Binomial Distribution

					Base Case	**Sensitivity Case A**	**Sensitivity Case B**
					All OPG unit data pooled	**Pickering A and Pickering B unit data pooled separately from Darlington unit data**	**All OPG and Bruce Power unit data pooled**
Unit	**Station**	**Number of Full Length Inspections**	**Number of Pressure Tubes**	**Uninspected Population of Pressure Tubes**	**Largest Expected Number of Flaws**	**Largest Expected Number of Flaws**	**Largest Expected Number of Flaws**
D1	DN	70	480	410	5.0	5.3	2.7
D4	DN	61	480	419	5.1	5.4	2.7
P5	PB	62	380	318	3.9	6.9	2.1
P6	PB	45	380	335	4.1	7.3	2.2
P7	PB	64	380	316	3.8	6.9	2.1
P8	PB	54	380	326	4.0	7.1	2.1

ENCLOSURE 2

Contribution of Pressure Tube Failures in the Darlington Internal Events At-Power Probabilistic Safety Assessment

N-CORR-03611-0951188

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ONTARIO POWER GENERATION

NUCLEAR SAFETY & TECHNOLOGY DEPT.	
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Date:	20-Sep-2021
Signature:	
OPG Confidential	

OPG Purchase Order Number:

Kinectrics:	300215	☑
Worley Parsons:	300216	☐
Candu Energy:	300217	☐
Calian Ltd:	300219	☐
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This acceptance does not relieve the contractor from responsibility for errors or omissions or from any obligations or liability under this contract.

N-CORR-03611-0951188

September 20, 2021

Noémie Duvivier
Ontario Power Generation
889 Brock Road
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Re: Contribution of Pressure Tube Failures in the Darlington Internal Events At-Power Probabilistic Safety Assessment

Dear Noémie,

This letter summarizes the contribution of spontaneous pressure tube failure (PTF) and spontaneous pressure tube leak (PTL) initiating events to the severe core damage frequency (SCDF) and large release frequency (LRF) calculated in the Darlington Level 1 and Level 2 At-Power Internal Events Probabilistic Safety Assessment studies (DARA-L1P and DARA-L2P). The present assessment is limited to the DARA-L1P and DARA-L2P studies and does not consider the outage PSAs or the PSAs for other hazards (e.g., internal fires, internal floods, seismic events, or high winds). The spontaneous PTF and PTL initiating events only appear in the internal events PSA studies.

The contribution of the PTF and PTL initiating events to SCDF is based on the DARA-L1P study results documented in Reference [R-1]. The contribution to LRF is based on the DARA-L2P study results documented in Reference [R-2]. The information is summarized in Table 1 below.

Table 1: Contribution of PTF and PTL IEs to SCDF and LRF in DARA-L1P and DARA-L2P

Initiating Event	IE Description	Baseline IE Frequency (occ/yr)	IE Contribution to SCDF (occ/yr) Note 1	IE Contribution to LRF (occ/yr) Note 2
IE-38-PTF	Pressure tube break resulting in a discharge rate in excess of 1 kg/s	4.78E-04	6.50E-08	1.27E-09
IE-38-PTL	Pressure tube break resulting in a discharge rate of less than 1 kg/s	1.91E-03	7.18E-09	1.04E-10

Note 1: The baseline total SCDF in DARA-L1P is 1.7E-06 occ/yr, per [R-1].

Note 2: The baseline total LRF in DARA-L2P is 7.9E-07 occ/yr, per [R-2].

[R-1] OPG, “Darlington NGS Level-1 At-Power Internal Events Probabilistic Safety Assessment”, NK38-REP-03611-10003 R003, Kinectrics file number K-410209-REPT-0001 R00

[R-2] OPG, "Darlington NGS Level-2 At-Power Internal Events Probabilistic Safety Assessment," NK38-REP-03611-10044 R003, Kinectrics file number PS363/RP/0020 R00

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ENCLOSURE 3

Frequency of Two Independent, Concurrent Failures of Pressure Tubes in an OPG Operated CANDU Reactor

File No. N-CORR-03611-0952082

ONTARIO POWER GENERATION

MEMORANDUM

September 22, 2021

File No.: N-CORR-03611-0952082 LOF

Ghulam Khawaja
Manager
Regulatory Programs, Strategy and Support
Nuclear Regulatory Affairs

Mr. Khawaja,

Re: Frequency of Two Independent, Concurrent Failures of Pressure Tubes in an OPG Operated CANDU Reactor

1.0 PURPOSE

The purpose of this memo is to provide an estimated frequency of occurrence of two independent, concurrent pressure tube (PT) failures in an OPG operated CANDU reactor, based on existing deterministic and probabilistic analyses of record.

2.0 SCOPE

The scope of this memo is limited to pressure tube failures, and does not discuss the probabilities of pressure tube leaks. Due to the body of knowledge surrounding the leak before break phenomena, it is fully expected that upon the identification of a pressure tube leak, the affected unit will be shut down in a timely manner before the pressure tube crack will grow to the critical crack length, leading to rupture. Leaks will not lead to PT failures, thus are not germane to the discussion in this document.

The information presented in this memo to estimate the frequency of occurrence of two independent, concurrent pressure tube failures is based primarily on Darlington Nuclear Generating Station (DNGS) information. Nevertheless, the conclusions of the memo are equally applicable to units at the Pickering Nuclear Generating Station (PNGS), but the actual frequency numbers may differ slightly.

3.0 DISCUSSION

Values for the occurrence of DNGS PT failures from both the deterministic and probabilistic analyses of record are presented below.

3.1 Deterministic Analysis

Appendix 12 of the Darlington Safety Report (Reference 1) lists the initiating event frequency of a PT failure as 1 x 10^{-2} occurrences/year. To calculate the frequency of occurrence of two independent, concurrent PT failures, the second occurrence would need to occur at the same time as the first occurrence, thus a time component would need to be considered in the calculation. Assuming that the concurrent PT failure window is 8 hours in duration (the time assumed for the two independent failures to occur within), the likelihood of two independent pressure tubes failing within the 8 hour period would be the occurrence of one PT failure, and the occurrence of the other PT failure within the 8 hours of the first failure. Mathematically, this would be 1 x 10^{-2} (first failure occurrence) multiplied by 1 x 10^{-2} (subsequent failure occurrence) multiplied by 8/24/365 (8 hour window, 24 hours in a day, 365 days in a year). This would equal approximately 9.1 x 10^{-8} occurrences/year. This initiating event would be deemed incredible as per the original DNGS licensing characterization (initiating event frequency less than 10^{-7} occurrences/year). This is a very conservative estimation of the event frequency of two independent, concurrent PT failures, as after the first PT failure, the primary heat transport (PHT) system would be depressurized. The reduction in PHT pressure would reduce the driving force to fail the second PT, so a subsequent independent failure would be highly unlikely.

3.2 Probabilistic Analysis

The PT failure initiating event frequency in the DNGS PSA is 4.78 x 10^{-4} occurrences/year (Reference 2). This frequency is taken from the Level 1 at power analysis, where the units are assumed to be operating the majority of the time. Time spent in start-up or shutdown sequences would be expected to be significantly less than operation at full power, thus making the initiating event frequency for those sequences much lower. Taking into consideration the time component of the concurrent failure, the result of multiplying 4.78 x 10^{-4} by 4.78 x 10^{-4} by 8/24/365 is approximately 2.1 x 10^{-10}. This would indicate that an independent concurrent failure of two pressure tubes is a very unlikely event, orders of magnitude below the Level 1 at power Severe Core Damage Frequency (SCDF) estimates.

It should be noted that the deterministic event frequency for a PT failure is much larger than that for the probabilistic PT failure. The deterministic failure rate is meant to be a conservative, bounding estimation, whereas the probabilistic PT failure frequency is meant to be more of a best estimate frequency.

4.0 CONCLUSIONS

The frequency of occurrence of two independent, concurrent pressure tube failures at Darlington has been shown to be very low both probabilistically and deterministically. The deterministic initiating event frequency of two independent, concurrent PT failures was conservatively estimated to be 9.1 x 10^{-8} occurrences/year. The probabilistic frequency of occurrence of two independent, concurrent PT failures has been demonstrated to be orders of magnitude below limiting SCDF values.

These conclusions are equally applicable to the Pickering units, as the PT designs are similar, and the analysis results are similar in nature. The numbers quoted above for Darlington units will differ from those which could be calculated for Pickering Units, but the conclusions would still remain valid. The temperatures and pressures at the Pickering Units are lower than those of DNGS, and the number of pressure tubes per reactor is also lower. This further supports the use of DNGS numbers to be representative or bounding for Pickering.

5.0 REFERENCES

[R-1] NK38-SR-03500-10002 R05 – Darlington Nuclear 1-4 Safety Report, Part 3 – Accident Analysis, dated 2017-10-30.

[R-2] NK38-REP-03611-10003 R03 – Darlington NGS Level-1 At-Power Internal Events Probabilistic Safety Assessment, dated 2019-12-04.

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ENCLOSURE 4

Darlington Internal Events At-Power Probabilistic Safety Assessment: Conditional Probabilities of Severe Core Damage and Large Release Following a Pressure Tube Leak

File No. N-CORR-03611-0951190

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ONTARIO POWER GENERATION

NUCLEAR SAFETY & TECHNOLOGY DEPT.

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Date:	27-Sep-2021
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Kinectrics:	**300215**	☑
Worley Parsons:	**300216**	☐
Candu Energy:	**300217**	☐
Calian Ltd:	**300219**	☐
Other:	**PO** ______	

This acceptance does not relieve the contractor from responsibility for errors or omissions or from any obligations or liability under this contract.

N-CORR-03611-0951190

September 27, 2021

Noémie Duvivier
Ontario Power Generation
889 Brock Road
Pickering ON, L1W 3J2

Re: Darlington Internal Events At-Power Probabilistic Safety Assessment: Conditional Probabilities of Severe Core Damage and Large Release Following a Pressure Tube Leak

Dear Noémie,

This letter documents the calculation of the conditional severe core damage probability (CCDP) and conditional large release probability (CLRP) following a spontaneous pressure tube leak (PTL) initiating event, as determined using the Darlington Level 1 and Level 2 At-Power Internal Events Probabilistic Safety Assessment studies (DARA-L1P and DARA-L2P). The present assessment is limited to the DARA-L1P and DARA-L2P studies and does not consider the outage probabilistic safety assessment (PSA) or the PSAs for other hazards (e.g., internal fires, internal floods, seismic events, or high winds). The spontaneous PTL initiating event only appears in the internal events PSA studies.

The CCDP is based on the DARA-L1P model documented in Reference [R-1]. The CLRP is based on the DARA-L2P model documented in Reference [R-2]. The truncation values were selected based on top cutset probability, in accordance with the OPG PSA Guide [R-3]. The information is summarized in Table 1 below. The following can be observed from the analysis results:

- Overall, it is highly unlikely that a spontaneous pressure tube leak will progress to severe core damage or to a large release; that is, the CCDP and CLRP values are less than the probability of 1.0E-04 that is used for ‘highly unlikely’ events per Table 2.4-3 of the PSA Guide [R-3].
- The annulus gas system is credited in the PSA and is a reliable means of detecting a pressure tube leak.
- If the pressure tube leak is not detected or if operators fail to promptly shut down the reactor and cool down the heat transport system, the PTL initiating event progresses to a pressure tube failure with consequential calandria tube failure and end-fitting ejection, leading to a loss of coolant and a loss of moderator inventory (LOCA-LOMA). In this scenario, make-up to the primary heat transport system from either the emergency coolant injection system or from the new connection from the emergency service water system can prevent severe core damage.
- The results reflect some conservative model simplifications that are significant to the CCDP and CLRP solutions given the occurrence of the PTL initiating event, but that are

not significant to the overall time-average severe core damage frequency (SCDF) or large release frequency (LRF) results. For example, some post-initiating event human interaction events that are significant to CCDP are assigned a preliminary screening probability and have not been re-quantified because they are not significant to the overall SCDF in DARA-L1P.

- The CCDP and CLRP values (dimensionless probabilities) from this analysis cannot be directly compared to the overall SCDF and LRF values (frequencies in occurrences per year) from the DARA-L1P and DARA-L2P studies.

Table 1: CCDP and CLRP Following a PTL IE in DARA-L1P and DARA-L2P

Source	Metric	Conditional Probability (dimensionless) Given IE-PTL	Solution Truncation
DARA-L1P [R-1]	CCDP: Conditional Severe Core Damage Probability	5.6E-06	4.0E-11
DARA-L2P [R-2]	CLRP: Conditional Large Release Probability	5.1E-07	1.0E-12

[R-1] OPG, “Darlington NGS Level-1 At-Power Internal Events Probabilistic Safety Assessment”, NK38-REP-03611-10003 R003, Kinectrics file number K-410209-REPT-0001 R00

[R-2] OPG, "Darlington NGS Level-2 At-Power Internal Events Probabilistic Safety Assessment", NK38-REP-03611-10044 R003, Kinectrics file number PS363/RP/0020 R00

[R-3] OPG, “OPG Probabilistic Safety Assessment (PSA) Guide - Level 1 Internal Events At-Power”, N-GUID-03611-10001 Volume 1 R005

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