



CNSC Staff Update on Elevated Hydrogen Equivalent Concentration Discovery Events in the Pressure Tubes of Reactors in Extended Operation



CNSC Staff Presentation

Commission Meeting
November 3, 2022

CMD 22-M37.A





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Purpose

This CMD provides an update on:

- CNSC staff evaluation of the industry's activities to address safety impacts related to elevated hydrogen equivalent concentration (Heq)
- CNSC staff assessment of the potential risk implications

This CMD is provided for information only



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BACKGROUND



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Chronology of Regulatory Activities

**Discovery outlet rolled joint
Heq issue reported by Bruce
Power**
via REGDOC-3.1.1 Event Reports
July 5, 2021 (Unit 6) [\[1\]](#)
July 8, 2021 (Unit 3) [\[2\]](#)

**GNSCR Subsection
12(2) requests sent to
all NPP licensees**
July 13, 2021 [\[5-7\]](#)

**GNSCR Subsection 12(2)
responses received from all
NPP licensees**
July 30, 2021 [\[11-13\]](#)

**Commission
Meeting**
September 3, 2021
[\[14\]](#)

**Discovery inlet rolled
joint Heq issue reported
by Bruce Power**
via REGDOC-3.1.1 Event
Report
December 5, 2021 [\[21\]](#)

**CNSC letters sent to
Bruce Power**
requesting additional
information
July 8, 2021 (Unit 6) [\[3\]](#)
July 9, 2021 (Unit 3) [\[4\]](#)

**Orders issued to
Bruce Power July 26, 2021 [\[8\]](#)
OPG July 27, 2021 [\[9, 10\]](#)**

**Commission Authorization
to restart**
OPG and Bruce Power
October 2021 to March 2022 [\[15, 16, 17-20\]](#)

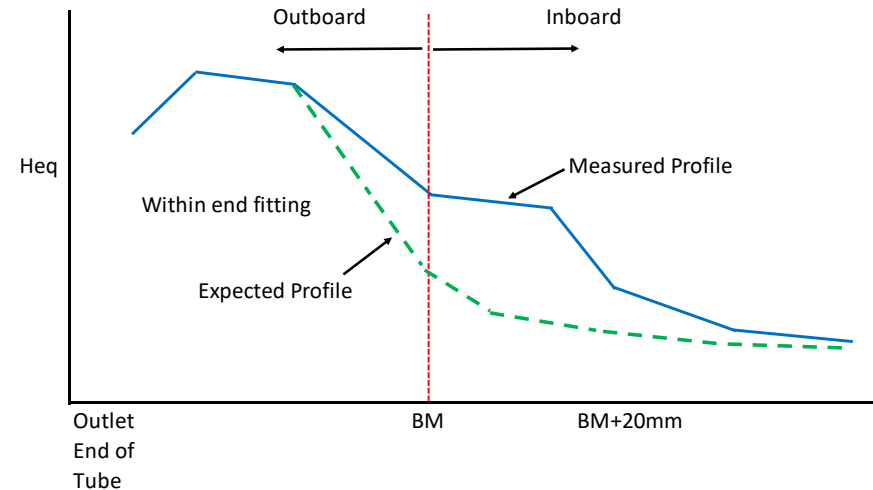
**Commission
Meeting**
March 24, 2022 [\[22\]](#)



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Discovery Event: ORJ-BM High Heq

- Event Initial Report (EIR) to the Commission on findings in the Bruce A & B pressure tubes near the outlet rolled joint burnish mark (ORJ-BM) in September 2021
- Commission Meeting held to discuss the potential effect on units in extended operation



Extended Operation = Operation Beyond 210,000 Equivalent Full Power Hours (EFPH)



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CNSC Staff Regulatory Actions for the ORJ-BM Event

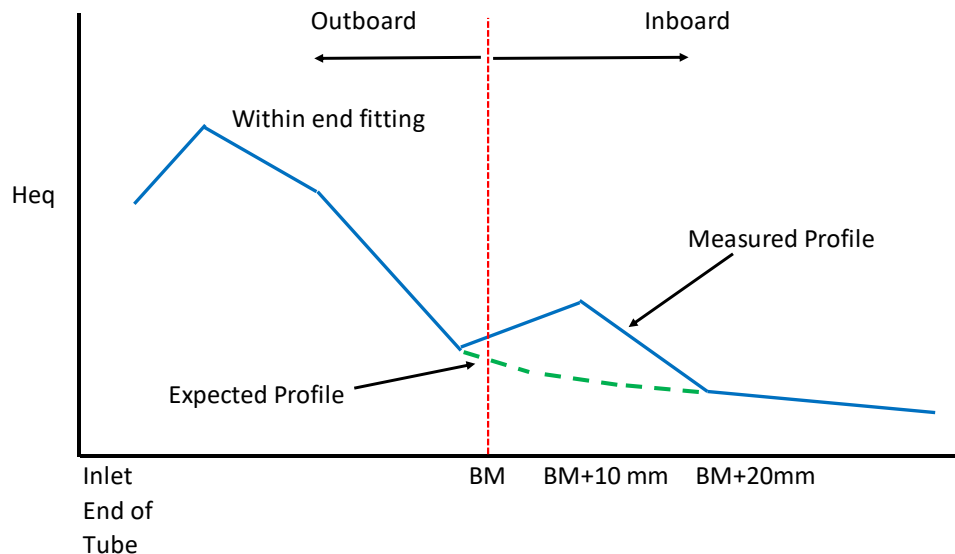
- CNSC Designated Officer (DO) orders were issued to OPG and Bruce Power in July 2021, requiring the licensees to obtain authorization from the Commission prior to the restart of reactors
- In consideration of CNSC staff's recommendations and input from the external advisory committee (EAC), the Commission authorized OPG and Bruce Power to restart their units following any outage



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Discovery Event: IRJ-BM High Heq

- In December 2021, further testing on pressure tube B6S13 identified Heq above 120 ppm near the inlet rolled joint burnish mark (IRJ-BM)
- Commission Meeting held in March 2022 to discuss the safety impact





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History and New Observations for IRJ-BM Blips

- IRJ-BM Heq “blips” was observed in punch samples from Darlington pressure tubes
 - Maximum Heq values were below 120 ppm and only marginally higher than Heq model predictions
- Significant through-thickness Heq gradient
 - Only identified after Bruce Power finding
 - Presents a challenge for identifying potentially affected tubes through in-service scrapes



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CNSC Staff Preliminary Conclusions

- CNSC staff's preliminary conclusions were presented to the Commission during the March 2022 meeting
 - Continued operation of reactors does not pose unreasonable risk to nuclear safety
 - Existing safety analyses remains valid and indicate minimal radiological consequences in case of pressure tube rupture
 - More work will be required to confirm the fitness for service can be demonstrated for pressure tubes with flaws near the IRJ-BM



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Follow-up Actions

- To address the findings at the rolled joints, industry has:
 - Undertaken material surveillance and modelling activities such as investigating the root cause of the locally elevated Heq near the IRJ-BM and ORJ-BM
 - Introduced operational changes and training for operators to minimize the possibility of cold overpressure transients
 - Produced plans for research and development (R&D) to update predictive model capabilities and analytical tools for the rolled joint region of pressure tubes



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DEVELOPMENTS SINCE MARCH 2022



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CNSC Staff Activities Since Last Commission Meeting

- Assessment of Heq modeling activities, including industry's R&D plan
- Assessment of licensees' most recent submissions regarding the discovery of elevated Heq and its impact on fitness for service assessments
- Evaluation of the impacts of the IRJ-BM finding using the CNSC's risk informed decision making (RIDM) process



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MODELLING ACTIVITIES and R&D PLAN



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Background of Modelling Activities and R&D Plan

- OPG and Bruce Power responded to CNSC staff's formal request for information relating to the analysis of the hydrogen uptake model validity
- The submissions provided a high-level overview of the industry's planned work to improve ORJ-BM Heq predictive capability
- Industry provided an update on the R&D plan being carried out under a joint project by CANDU Owners Group (COG)



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Expanded Modelling Activities and R&D Plan

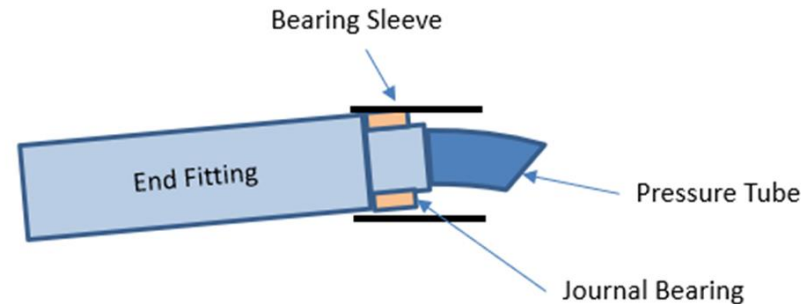
- To address the IRJ-BM finding, the industry expanded the scope of the Heq modeling activities
 - The focus was shifted from the ORJ-BM discovery to the Heq discovery near the IRJ-BM in the near term
- For the ORJ-BM region alternate compliance verification was in place, but not for the IRJ-BM region



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Preliminary Modelling of Hydrogen Diffusion Near the IRJ-BM

- Bruce Power asserted that the 'blip' was due to localized contact between the pressure tube and the end fitting
- Preliminary modelling of hydrogen diffusion demonstrated that it was possible to simulate the formation and evolution of the IRJ-BM 'blip' in the B6S13 pressure tube
- Industry is expected to support the preliminary results through ongoing model development activities



Note: Schematic illustration, not to scale



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Assessment of Industry-Wide ORJ and IRJ Heq R&D Plans

- Outlet and inlet rolled joint evaluation plans were provided by Bruce Power, Ontario Power Generation and New Brunswick Power
- CNSC staff conclude that:
 - Industry is adequately targeting the key issues regarding pressure tube fitness for service evaluations
 - Industry is carrying out experimental and modelling activities with adequate scope and deliverables throughout the plan
- Industry will provide semi-annual updates to CNSC staff on the overall status until the Heq modelling activities have been completed (by summer of 2026)



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Crack Initiation Testing



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Background of Crack Initiation Testing

- Three models are used to evaluate the potential for crack initiation from flaws in pressure tubes related to:
 - Delayed hydride cracking (DHC)
 - Fatigue
 - Hydrided Region Overload (HROL)
- Heq has a direct impact on DHC and HROL
- Changes in material properties due to Heq may indirectly impact crack initiation due to fatigue



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Basis for the Crack Initiation Testing Program

- Prior to the outlet rolled joint event, the crack initiation models were confirmed for Heq levels up to 120 ppm
- Necessary to confirm that the flaws created from scrape samples will not initiate cracking
- DHC testing carried out on unirradiated material with nominal Heq values of 240 ppm to compare with unirradiated material with nominal Heq values of 60 ppm



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Early Observations from Crack Initiation Testing

- A 19% reduction in the crack initiation threshold was observed for the 240 ppm tests compared to the 60 ppm test
- This finding is not expected to impact pressure tubes with hydrogen measurement scrape marks near the outlet rolled joint burnish mark like Bruce unit 3
- Testing program continuing with planned completion date in 2024, which aligns with the evaluated operating period in the CNSC RIDM assessment



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Revision 2 of the Fracture Toughness Model



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Background of the Revision 2 Fracture Toughness Model

- CNSC staff recommended licence condition 15.3 during 2018 licence renewal hearings for Bruce Power and OPG-Pickering
- 120 ppm Heq limit in LC 15.3 was based on available test data for Revision 1 fracture toughness model
- Experimental program to increase the limit was established by industry
 - Intent to revise the fracture toughness model (Revision 2) for higher Heq values and satisfy LC 15.3 before pressure tubes exceed 120 ppm

LC 15.3 – Before hydrogen equivalent concentrations exceed 120 ppm, the licensee shall demonstrate that pressure tube fracture toughness will be sufficient for safe operation beyond 120 ppm



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Adoption of the Revision 2 Fracture Toughness Model

- Industry requested acceptance for the use of the Revision 2 model for Heq values up to a maximum of 140 ppm, with a 100 ppm restriction for material within 1.5 m of the end of the pressure tube
- CNSC staff conditionally accepted the use of the model
 - Accepted for the Heq levels specified above
 - No conditions on the use of the model for deterministic evaluations
 - Condition placed on the fracture toughness distributions used for probabilistic evaluations



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Future Work

- The Revision 2 fracture toughness model is an improvement, however additional work is required
 - to validate the model for higher Heq levels with consideration given to the elevated Heq values observed near rolled joints
 - to remove the restrictions for probabilistic evaluations
 - to confirm if the model can be used for material with significant through-thickness Heq gradients like those observed near the IRJ-BM in some pressure tubes



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CNSC Staff's Risk Informed Assessment



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CNSC Staff's Risk Informed Assessment of the IRJ-BM Discovery

- A group of CNSC subject matter experts applied the CNSC Risk Informed Decision Making (RIDM) Process
- The purpose was to assess whether the discovery of elevated Heq near the IRJ-BM significantly impacts the risk posed by continued reactor operation
- The team followed the principles established in the following:
 - The CNSC Policy document on the *Use of a Risk-Informed Approach for Regulatory Oversight of Nuclear Activities and Facilities*
 - The RIDM process as outlined in CSA N290.19, *Risk-informed decision making for nuclear power plants*



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Fitness for Service at the IRJ-BM

- For Pickering units, the mechanisms to generate flaws that would lead to crack initiation are not active within 20 mm axial distance from the IRJ-BM
- For Bruce and Darlington reactors in extended operation, the same approach could not be applied to pressure tubes with elevated Heq since flaws are known to exist near the IRJ-BM



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Conclusions - Defence in Depth Effectiveness

- Based on the information currently available, CNSC staff cannot conclusively confirm provisions for Levels 1 and 2 defence-in-depth (DiD) are fully effective
 - Level 1 DiD – Achieved through process and activities to prevent failures including evaluations of aged pressure tubes to confirm they meet the intent of the design standard
 - Level 2 DiD – Achieved through equipment and process that allow early detection of, and response to, pressure tube leaks



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Conclusions - Defence in Depth Effectiveness

- CNSC staff's risk assessment determined the following:
 - Level 3 DiD is not adversely affected by the type of pressure tube failure that could potentially result from reduced fracture toughness
 - The increase in risk metrics such as severe core damage frequency (CDF) and large release frequency (LRF) due to postulated increases in pressure tube failure frequency is negligible for 2-3 years of continued operation



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Risk Assessment Report Recommendations

- CNSC staff's Risk Assessment Report (RAR) included the following Recommendations to licensees:
 1. Licensees should establish and provide to CNSC an Heq R&D plan with timelines that are acceptable to CNSC staff
 2. Licensees should undertake material surveillance activities by removing and testing pressure tubes during upcoming refurbishment/major component replacements, and to provide a statistically significant sample size in order to validate updated Heq models in the outlet rolled joint and inlet rolled joint regions



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Risk Control Measure

Given the longer-term timeframe that will be required to implement Recommendations #1 and #2, CNSC staff recommends that the following Risk Control Measure be implemented:

Licensees to ensure there are adequate procedures, surveillance programs, as well as training in place to monitor the dominant contributors to pressure tube failure and pressure tube leak event sequences leading to core damage

Risk Control Measure – Those measures implemented to address adverse conditions that are not part of the established plant design or operating envelope (CSA N290.19)





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Conclusions



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Overall Conclusions

Based on available information assessed to date, CNSC staff conclude that:

- Alternate fitness for service compliance verification criteria are in place to address the potential impact of both IRJ-BM and ORJ-BM for Pickering Reactors
- The increase in risk to nuclear releases for the Bruce Power and Darlington units is negligible for continued operation in the short term
- CNSC staff intend to actively engage with industry on the key issues regarding pressure tube fitness for service and on the execution of the R&D plans through to completion, which is targeted for the summer of 2026
- CNSC staff are committed to providing updates to the Commission, for example during the annual regulatory oversight reports or as requested



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References (1/3)

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- [2] Bruce Power Detailed Event Report, “REGDOC-3.1.1 Report B-2021-93819 DR – A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements”, June 15, 2021, e-Doc 6597908 (CMD 21-M37.1)
- [3] CNSC Letter, L. Sigouin to M. Burton, “Bruce A and B: CNSC Review of REGDOC-3.1.1 Event Report B-2021-98077 DR on Pressure Tube Surveillance Hydrogen Equivalent Concentration Measurements on Unit Shutdown for Major Component Replacement – New Action Item 2021-07-23406”, July 8, 2021, e-Doc 6600766 (CMD 21-M37.A)
- [4] CNSC Letter, L. Sigouin to M. Burton, “Bruce A: CNSC Review of REGDOC-3.1.1 Event Report B-2021-93819 on A2131 Outage Scrape Campaign Hydrogen Equivalent Concentration Measurements – New Action Item 2021-07-23424”, July 9, 2021, e-Doc 6603183 (CMD 21-M37.A)
- [5] CNSC Letter, A. Viktorov to M. Burton, “Bruce A and B: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes”, July 13, 2021, e-Doc 6603948 ([EN](#), [FR](#))
- [6] CNSC Letter, A. Viktorov to S. Gregoris and J. Franke, “Darlington and Pickering NGS: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Concentration in Pressure Tubes”, July 13, 2021, e-Doc 6603931 ([EN](#), [FR](#))
- [7] CNSC Letter, A. Viktorov to M. Power, “PLNGS: Request pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Issues Relating to Measurement of Hydrogen Equivalent Concentration in Pressure Tubes”, July 13, 2021, e-Doc 6604246 ([EN](#), [FR](#))
- [8] Designated Officer Order, R. Jammal to Bruce Power, “Order by a Designated Officer Under Paragraph 37(2)(f) and Subsection 35(1) of the *Nuclear Safety and Control Act*”, July 26, 2021, e-Doc 6612405 ([EN](#), [FR](#))



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- [9] Designated Officer Order, R. Jammal to Bruce Power, “Order by a Designated Officer Under Paragraph 37(2)(f) and Subsection 35(1) of the *Nuclear Safety and Control Act*”, July 26, 2021, e-Doc 6612405 ([EN](#), [FR](#))
- [10] Designated Officer Order, R. Jammal to Bruce Power, “Order by a Designated Officer Under Paragraph 37(2)(f) and Subsection 35(1) of the *Nuclear Safety and Control Act*”, July 26, 2021, e-Doc 6612405 ([EN](#), [FR](#))
- [11] Bruce Power Letter, M. Burton to M. Leblanc and A. Viktorov, “Bruce A and B: Response to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Measurement of Hydrogen Equivalent Concentration in Pressure Tubes”, July 30, 2021, BP-CORR-00531-01884, e-Doc 6616619 (CMD 21-M37.1)
- [12] 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, N-CORR-00531-22801, e-Doc 6616028 (CMD 21-M37.2)
- [13] NB Power Letter, M. Power to M. Leblanc and A. Viktorov, “Request pursuant to Subsection 12(2) of the *General Nuclear Safety and Control Regulations*: Issues Relating to Measurements of Hydrogen Equivalent Concentration in Pressure Tubes”, July 30, 2021, e-Doc 6616141 (CMD 21-M37.3)
- [14] CMD 21-M37, “Presentation – Impact on NPPs of Bruce Unit 3 and 6 Licence Limit Exceedance of Hydrogen Equivalent Concentration in Pressure Tubes”, September 3, 2021, e-Doc 6626961
- [15] Record of Decision, DEC 21-H110, “In the Matter of Bruce Power Inc. – Request for Authorization to Restart Bruce Nuclear Generating Station A Unit 3 following its current planned outage”, November 10, 2021, e-Doc 6672394
- [16] Record of Decision, DEC 21-H111, “In the Matter of Ontario Power Generation Inc. – Request for Authorization to Restart Pickering Nuclear Generating Station B Unit 5 following a forced outage”, December 6, 2021, e-Doc 6695848



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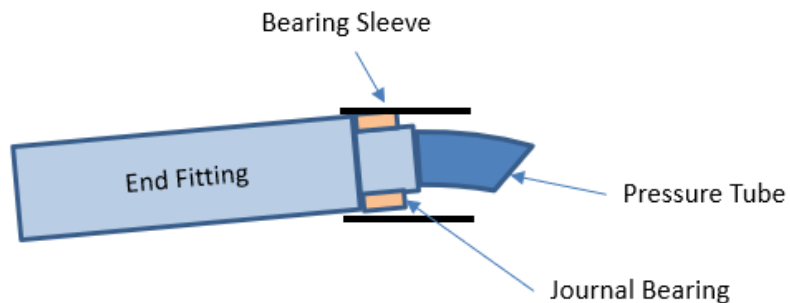
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- [17] Record of Decision, DEC 21-H112, “In the Matter of Ontario Power Generation Inc. – Request for Authorization to Restart Pickering Nuclear Generating Station B Units 6-8 following future outages”, December 22, 2021, e-Doc 6706447
- [18] Record of Decision, DEC 21-H112, “In the Matter of Ontario Power Generation Inc. – Request for Authorization to Restart Darlington Nuclear Generating Station Units 1 and 4 following future outages”, February 4, 2022, e-Doc 6731461
- [19] Record of Decision, DEC 21-H113, “In the Matter of Bruce Power Inc. – Request for Authorization to Restart Bruce Nuclear Generating Station A Unit 4 and Bruce NGS B Units 5, 7 and 8 following future outages”, February 28, 2022, e-Doc 6746710
- [20] Record of Decision, DEC 22-H100, “In the Matter of Bruce Power Inc. – Request for Authorization to Restart Bruce Nuclear Generating Station A Unit 3 following future outages”, March 9, 2022, e-Doc 6752596
- [21] Bruce Power Detailed Event Report, “REGDOC-3.1.1 Report B-2021-135624 DR – Industry Pressure Tube (PT) Surveillance Program – Inlet Hydrogen Equivalent Concentration Measurements on PT from Unit Shutdown for Major Component Replacement”, November 19, 2021, e-Doc 6699742 (CMD 22-M16).
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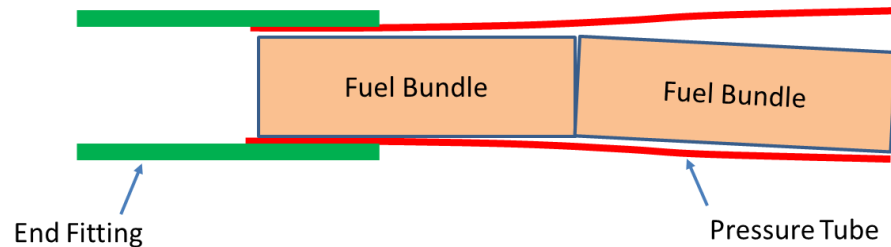


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Proposed IRJ and ORJ Scenarios



Inlet Rolled Joint



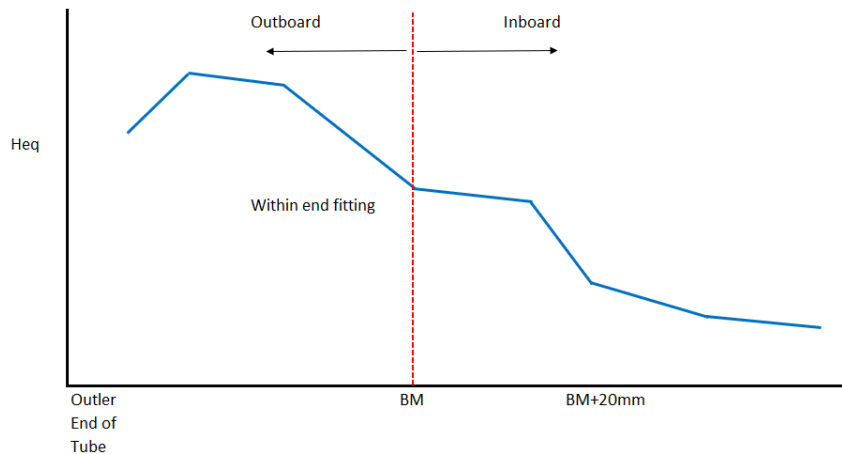
Outlet Rolled Joint

Note: Schematic illustrations, not to scale

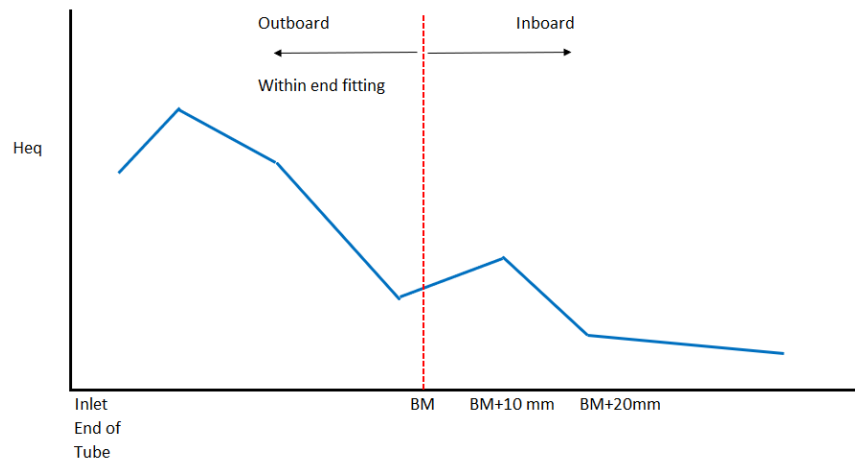


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Example Axial Profiles at Circumferential Orientation for Peak Values



ORJ-BM



IRJ-BM

Note: Schematic illustrations, not to scale



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Observed Locations of Elevated Heq

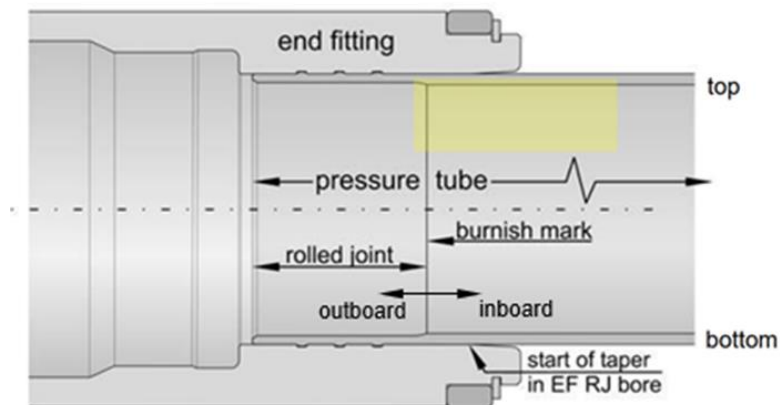


Diagram of Pressure Tube and End Fitting