Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

CMD 22-M37.1

Date: 2022-08-25
File / dossier : 6.02.04
Edocs pdf : 6858724

Written submission from Ontario Power Generation

Mémoire d' Ontario Power Generation

CNSC staff update on elevated hydrogen equivalent concentration discovery events in the pressure tubes of reactors in extended operation

Mise à jour du personnel de la CCSN sur les événements liés aux découvertes de concentrations élevées d'hydrogène équivalent dans les tubes de forces de réacteurs en exploitation prolongée

Responses from OPG to the request from the Commission for an update

Réponses d'OPG à la demande de la Commission pour une mise à jour

Commission Meeting

Réunion de la Commission

November 3, 2022

Le 3 novembre 2022

Canada

ONTARIO POWER GENERATION

Mark R. Knutson, P. Eng.
Senior Vice President
Chief Enterprise Engineer and Chief Nuclear Engineer

889 Brock Road, Pickering, Ontario L1W 3J2 (905) 839-6746 x5418 mark.knutson@opg.com

OPG PROPRIETARY

Date: July 19, 2022

CD# N-CORR-00531-08536

MR. D. SAUMURE
Commission Registrar
Legal and Commission Affairs Branch
Canadian Nuclear Safety Commission
P.O Box 1046
280 Slater Street
Ottawa, Ontario
K1P 5S9

DR. A. VIKTOROV
Director General
Director of Power Rector Regulation
Canadian Nuclear Safety Commission
P.O Box 1046
280 Slater Street
Ottawa, Ontario
K1P 5S9

Dear Mr. Saumure and Mr. Viktorov:

OPG Response - Darlington and Pickering NGS – Request for an Update to the Commission on Activities Related to the Discovery of Elevated Hydrogen Equivalent Concentration (Heq) – New Action Item 2022-OPG-23135

The purpose of this letter is to provide to the Canadian Nuclear Safety Commission (the Commission) the update regarding the activities related to the discovery of elevated Hydrogen Equivalent Concentration ([Heq]), per requests in Reference 1, under Action Item (AI) 2022-OPG-23135.

Attachment 1 of this correspondence submits to the Commission the following:

- A summary of relevant activities undertaken since the fall of 2021 in response to elevated Hydrogen Equivalent Concentration ([Heq]) observations within the industry, including the results of in-service and ex-service tests of Pressure Tube (PT) material (Monitoring), progress in Fuel Channel (FC) deformation and [Heq] model developments (Modelling), and assessments of PT Fitness for Service (FFS) in extended operation considering potential elevated [Heq] (Assessment); and
- A detailed plan to improve [Heq] predictions near the rolled joints and a path forward plan to implement and a path forward to further evaluate the effect of increased hydrogen equivalent concentrations on pressure tube fitness-for-service evaluations.

Since initial discovery of elevated [Heq] OPEX, OPG has provided regular updates to CNSC staff on [Heq] observations through various correspondence and meetings. In March 2022 an industry workshop on elevated [Heq] was held to present the status of

work completed to improve the mechanistic understanding of [Heq] evolution and enhance predictive modelling capabilities. This workshop provided a forum to solicit CNSC staff's feedback on future work. As requested in Reference 1, Attachment 1 provides industry's detailed plan to improve [Heq] predictions near the rolled joints. This plan provides a target schedule and summary of key deliverables, established through industry's [Heq] roadmap.

OPG has demonstrated through the completion of activities since fall 2021, as documented in Attachment 1, that the PTs installed in OPG units remain fit-for-service and safe for operation. OPG will continue working with industry to update FFS assessments to incorporate the results of the activities identified in Attachment 1 as they become available and as per established processes.

OPG commits to provide a semi-annual update to CNSC staff on the status of actions identified in Attachment 1, with the first submission provided by end of Q1 2023.

Conclusions from Completed Work Since Fall 2021

Since fall 2021, OPG has undertaken various activities to address industry OPEX of elevated [Heq] observed in the inlet / outlet RJ regions PTs in extended operation (i.e., DNGS pre-refurbishment and PNGS 5-8 PTs). OPG has provided regular updates to the CNSC staff on this subject through various correspondences and meetings, including status communications provided via References 2 and 3. Further summaries of relevant activities and findings are provided below:

1. Monitoring actions have been funded or co-funded by OPG that support characterization of potential elevated [Heq] observations and/or confirmation of material performance in the presence of elevated [Heq]:
    - Ex-service material surveillance results and in-service scrape measurements have been obtained, providing continued confidence in OPG's existing inlet and outlet Region of Interest (ROI) assertions (based on allowable concentrations per the Revision 2 cohesive zone fracture toughness model limits), as follows:
        i. OPG's definition of the outlet region of interest (ROI) for circumferential redistribution is from outlet BM to outlet BM +75 mm axially inboard and over the top third (10:00 to 2:00 o'clock orientations) of the PT circumferentially (based on all available industry information from material surveillance and scrape sampling performed to-date).
        ii. OPG's definition of the inlet and outlet ROI for 'blip' formation is from inlet BM to inlet BM +20 mm axially inboard and outlet BM to outlet BM +20 mm axially inboard respectively, and over 3 of 12 clock positions circumferentially (based on all available industry information from material surveillance performed to-date).
    - OPG in-service scrape sampling has been transitioned to PT Top Dead Center (TDC) to provide assurance of bounding data acquisition (TDC

scrape performed in outages D2141, P2171, and P2251 with no observed step change in [Heq]).
- OPG in-service Volumetric and Dimensional (V&D) inspections have been performed in ROIs (no new service-induced flaws detected in outages D2141, P2171, and P2251)

2. Modelling actions have been funded or co-funded by OPG that support improved understanding of late-life FC conditions and identification of key monitoring activities for the purpose of iterative technical basis validation:
    - Outlet RJ top of PT elevated [Heq] observations and associated circumferential redistribution have been simulated accounting for temperature variation due to coolant flow bypass. Predictions from this modelling are consistent with measured data in the outlet ROI.
    - Inlet RJ 'blip' formation observations and associated [Heq] localization have been simulated accounting for late life FC deformations. Preliminary results suggest that the blip formation occurs once local Terminal Solid Solubility of Dissolution (TSSD) has been exceeded at the PT to End Fitting (EF) taper interface in late life PTs. Preliminary predictions from this modelling are consistent with measured data in the inlet ROI.
    - Inlet RJ modelling has been performed postulating the presence of PT Inner Diameter (ID) flaw directly coincident with the 'blip' location. Current predictions from this modelling indicate that the local zone of high [Heq] at the 'blip' is considered to have no significant effect on the hydride region at a postulated PT ID flaw tip in the context of the potential for crack initiation at the flaw.
    - Results from short term crack initiation tests at high [Heq] indicate that the threshold stress intensity factor for delayed hydride cracking (DHC) initiation from a crack, K_{IH}, and the threshold stress for DHC initiation from a planar surface, p_c, are not affected by high [Heq]. It is therefore considered that there is a low likelihood that the model for DHC initiation under constant loading would not be applicable to detected service-induced flaws since lower-bound values of K_{IH} and p_c are utilized in these assessments. Results from burst tests performed at high [Heq] continue to support Fracture Toughness (FT) model predictions based on nominal through-wall [Heq].
    - A roadmap is in place to integrate industry efforts related to inlet and outlet RJ [Heq] modelling under a unified path forward.

3. Assessment actions have been funded by OPG that support evaluation of potential elevated [Heq] impacts on PT FFS and confirmation of [Heq] model validity.
    - Results from PT Volumetric and Dimensional (V&D) inspections support the assertion of a very low risk of a PT flaw leading to integrity concerns being located coincident with regions of interest in OPG PTs
    - Results from ex-service PT monitoring and in-service PT scrape sampling continue to support the validity of existing OPG Body of Tube (BOT) and

RJ [Heq] predictive models for use in FFS assessments (excluding the localized ROIs at the inlet and outlet of the PT)

- Engineering fracture protection evaluations performed while postulating elevated [Heq] in the outlet ROI due to circumferential redistribution demonstrate the deterministic acceptability of outlet PT material in the presence of elevated [Heq].
- Core assessments demonstrate compliance to acceptance criteria based on the current methodology. Assessments performed while postulating elevated [Heq] in the inlet and outlet ROIs demonstrate low risk with respect to inlet and outlet PT material in the presence of 'blip' formation while methodology and [Heq] model enhancements progress.

All of the activities summarized in this document support OPG's position that the PTs installed in all OPG reactors remain safe for operation with postulated elevated [Heq] in the both the inlet and outlet ROIs. Accordingly, based on multiple overlapping approaches applied to demonstrate acceptability of postulated elevated [Heq] in ROIs, OPG PTs continue to be fit for service.

With the submission of the requested information, OPG requests closure of the Action Item 2022-OPG-23135.

Should you require further information, please contact Paul Fabian, Senior Manager, Major Components Engineering Department at [redacted]

M.R. Knutson
Senior Vice President
Nuclear Engineering and Chief Nuclear Engineer
Ontario Power Generation Inc.

Attach.

cc: CNSC Pickering Regulatory Program Division
CNSC Darlington Regulatory Program Division
CNSC Records Office

References:

1. CNSC Letter, A. Viktorov and D. Saumure to M.R. Knutson, "*Darlington and Pickering NGS – Request for an Update to the Commission on Activities Related to the Discovery of Elevated Hydrogen Equivalent Concentration (Heq) – New Action Item 2022-OPG-23135*", OPG CD# N-CORR-00531-23194, CNSC e-Doc 6783023, April 28, 2022.
2. OPG Letter, M.R. Knutson to D. Saumure and A. Viktorov, "*OPG Response to Request Pursuant to Subsection 12(2) of the General Nuclear Safety and Control Regulations: Follow Up Response to Item 5 Related to Hydrogen Concentration in Pressure Tubes*", OPG CD# N-CORR-00531-23083, February 8, 2022.
3. OPG Letter, M.R. Knutson to R. Richardson and J. Burta, "*Fitness for Service Justifications Prepared in Response to Localized High [Heq] ('Blip') Formation Observed in OPG Pressure Tube Inlet Rolled Joints*", OPG CD# N-CORR-00531-23160, April 14, 2022.

ATTACHMENT 1

OPG letter M. Knutson to D. Saumure and Dr. A. Viktorov, "Darlington and Pickering NGS – Request for an Update to the Commission on Activities Related to the Discovery of Elevated Hydrogen Equivalent Concentration (Heq) – New Action Item 2022-OPG-23135"

CD# N-CORR-00531-08536

Summary of OPG Activities Related to the Discovery of Heq Since Fall 2021 and Industry Path Forward, and Responses to CNSC Staff's Statements/Questions Regarding Fitness for Service Justifications Prepared in Response to Localized High Heq ('Blip') Formation Observed in OPG Pressure Tube Inlet Rolled Joints

Prepared By: [redacted]

Checked By:

ATTACHMENT 1

Summary of OPG Activities Related to the Discovery of Heq Since Fall 2021 and Industry Path Forward, and Responses to CNSC Staff's Statements/Questions Regarding Fitness for Service Justifications Prepared in Response to Localized High Heq ('Blip') Formation Observed in OPG Pressure Tube Inlet Rolled Joints

I) Update on Activities Undertaken to the Discovery of Heq Since Fall 2021 and Industry Path Forward:

Actions Undertaken Since Fall 2021:

As documented in Reference A-1 and supplemented below, OPG, with industry collaboration, has performed various monitoring, assessment, and modelling actions to both provide assurance of PT FFS, and foster the fulsome mechanistic understanding of late life [Heq] evolution.

Since fall 2021, the following monitoring actions have been funded or co-funded by OPG that support characterization of potential elevated [Heq] observations and/or confirmation of material performance in the presence of elevated [Heq]. For each monitoring action, scope and key findings/conclusions are summarized in Table 1, below:

Table 1: COMPLETED MONITORING

Item	Activity	Scope	Findings/Conclusions	Submission(s) / Documentation	Remarks
Ex-Service Monitoring (Joint Project Funded)					
1A	Perform Surveillance Activities in Removed PTs	Perform material surveillance (including Body of Tube (BOT), inlet, and outlet RJ sampling at various axial and circumferential locations), focusing on characterization of spatial variation of [Heq] as follows: • B6S13 Material Surveillance (Q4 2021) • P8P10 Material Surveillance (Q3 2022)	Ex-service sampling results were consistent with expectation with the following notable findings providing continued confidence in existing inlet and outlet ROI assertions: • BP B6S13: Inlet RJ punch samples showed evidence of 'blip' formation at the PT to EF taper interface location. Outlet RJ punch samples showed evidence of elevated [Heq]. • OPG P8P10: Inlet RJ punch samples showed evidence of possible incipient 'blip' formation (very low [Heq]). Outlet RJ punch samples showed evidence of elevated [Heq] in the compressive region (no [Heq]	B6S13: • COG-JP-4680-V001 P8P10: • COG-JP-4682-V001 • NK30-CORR-00531-08516	Additional PT Research and Development (R&D) activities related to ex-service material surveillance are planned via the industry roadmap. See item 3B for model validity confirmations associated with this measured data. Additional details of B6S13 and P8P10 sampling will be included in a future CANDU

Item	Activity	Scope	Findings/Conclusions	Submission(s) / Documentation	Remarks
			found to exceed CSA limits in tensile regions).		Owner's Group (COG) Work Package (WP) 10369 report
In-Service Monitoring (OPG Funded)					
1B	Perform In-Service PT [Heq] Measurements	Update scrape locations to sample coincident with PT TDC. This includes all BOT and new RJ measurements where overlap with previous scrape locations can be avoided (Q4 2021).	Sampling at PT TDC locations was accommodated with minimal impact to existing scrape tool performance and no observed step change in [Heq].	N/A	Future PT scrape samples will be obtained from PT TDC (where possible while meeting existing repeat RJ sampling requirements)
		Perform in-service scrape sampling as follows: • D2141 (Q4 2021): Perform scrape sampling in fifteen (15) channels in the BOT region and eight (8) channels in the RJ region. • P2171 (Q4 2021): Perform scrape sampling in twenty (20) channels in the BOT region and twenty-one (21) channels in the RJ region. • P2251 (Q1 2022): Perform scrape sampling in ten (10) channels in the BOT region and eleven (11) channels in the RJ region including twelve (12) RJs.	D2141, P2171, and P2251 scrape results were consistent with expectations. For all OPG [Heq] data obtained via in-service scrape sampling and evaluated using the current assessment methodology, CSA N285.4 RJ [Heq] acceptance criteria were met (P2251 final assessment pending).	NK38-CORR-00531-23351 NK30-CORR-00531-08491 Preliminary P2251 [Heq] data provided to CNSC staff via NK30-CORR-00531-08543, formal results pending	Additional PT scrape sampling in the BOT and RJ regions is planned during remaining outages of late life OPG reactors. See item 3B for model validity confirmations associated with this measured data.
1C	Perform In-Service PT Flaw Monitoring	Perform PT volumetric inspections during the D2141, P2171, and P2251 outages to inspect for the presence of flaws within ROIs.	Based on volumetric inspections performed during D2141, P2171, and P2251, no new service-induced dispositionable flaws were identified within the ROIs.	NK38-CORR-00531-22967 NK30-CORR-00531-08375 NK30-CORR-00531-08468	Additional V&D inspection in ROIs are planned during remaining outages of late life OPG reactors

Since fall 2021, the following modelling actions have been taken that support improved understanding of late-life FC conditions and identification of key monitoring activities for the purpose of iterative technical basis validation. For each listed modelling action, scope and key findings/conclusions are summarized in Table 2 2, below:

Table 2: COMPLETED MODELLING

Item	Activity	Scope	Findings/Conclusions	Submission(s) / Documentation	Remarks
Enhancements to PT Modeling Capabilities (OPG Only / Industry / Joint Project Co-Funded)					
2A	Enhance ANSYS FC Deformation / Heat Transfer Model to Provide More Detailed Information about PT Boundary Conditions Applicable to [Heq] Modelling	Simulate FC deformation / heat transfer including PT to EF rolling, inboard bearing contact orientation evolution, PT to EF contact interface pressure, and steady state heat transfer (Q4 2021).	FC deformation simulations predict the following: • Non-uniform spatial distributions of residual stress in the RJ compressive region (relaxed with operating time). • Evolution of bearing contact orientation from nominally PT Bottom Dead Center (BDC) at Beginning of Life (BOL) to PT TDC at End of Life (EOL). • PT to EF contact interface variation with localization at the axial location of EF taper blended radius. • Non-uniform heat transfer from the PT to the end shield through the inboard bearing assembly.	Preliminary findings shared at March 2022 Workshop N-CORR-00531-23160 Further documentation pending	ANSYS FC deformation modelling remains ongoing with additional work planned to support the industry roadmap. Further documentation pending
2B	Determine Coolant Temperature Inputs (ASSERT-PV) to Support Outlet RJ [Heq] Modelling	Simulate axial-circumferential coolant temperature distributions as inputs to multi-dimensional [Heq] predictive models (Q4 2021).	Coolant temperature simulations predict: • Non-uniform coolant temperature distributions in the PT outlet end due to coolant flow bypass. • Coldest temperatures at PT TDC and hottest temperatures at PT BDC. Note: Consistent with these predictions, Stern Labs test data shows that there exists a top-to-bottom temperature asymmetry, with lower coolant temperatures at the top of the PT than at the bottom of the PT	COG-19-1027 COG-20-1009	ASSERT-PV modelling remains ongoing with additional work planned via the industry roadmap.
2C	Develop/Revise Finite Element Software (H3DMAP) to Simulate Outlet RJ [Heq] Evolution	Simulate outlet RJ [Heq] evolution accounting for ASSERT temperature distributions associated with coolant flow bypass (via H3DMAP) (Q1 2022).	Preliminary H3DMAP [Heq] simulations accounting for ASSERT axial-circumferential PT temperature variation support redistribution of [Heq] from the bottom to the top of PT at the outlet end. • These simulations demonstrate the preliminary capability to model outlet circumferential redistribution consistent with observations	Preliminary findings shared at March 2022 Workshop Further documentation pending	H3DMAP [Heq] modelling remains ongoing with additional work planned via the industry roadmap. Further documentation pending. To date, the primary focus of H3DMAP modelling has been the simulation of outlet RJ [Heq] evolution including consideration for TSS input variation.
2D	Develop Finite Element Software (Hydrogen Finite Element (HFE)) to Simulate Inlet RJ [Heq] Evolution	Simulate [Heq] evolution accounting for potential PT OD ingress at the axial location of the PT to EF taper, predicted PT stress distributions, and predicted PT temperature distributions (Q1 2022).	Preliminary inlet RJ HFE [Heq] simulations have been performed accounting for OD ingress in addition to predicted temperature and stress distributions: • These simulations demonstrate the preliminary capability to model inlet 'blip' formation consistent with observations in all PT planes at the 'blip' location.	Preliminary findings shared at March 2022 Workshop Further documentation pending	HFE [Heq] modelling remains ongoing with additional work planned via the industry roadmap. Further documentation pending. Outlet RJ [Heq] evolution was also simulated via HFE; however, to date, the primary focus of HFE modelling has been the simulation of inlet end [Heq] evolution (including 'blip' formation).

Item	Activity	Scope	Findings/Conclusions	Submission(s) / Documentation	Remarks
2E	Perform Evaluation of the Potential Impact of the ROI with High Levels of [Heq] on the Hydride Region at a Flaw Tip in the Inlet RJ	Perform preliminary diffusion analysis using HFE and ANSYS to simulate a through-wall [Heq] distribution ('blip' formation) at the inlet ROI and to investigate potential effects of elevated [Heq] on the hydrided region at a postulated PT ID flaw tip.	The results of the diffusion analysis show that the predicted through-wall [Heq] gradient at the inlet 'blip' location is representative, or slightly conservative, relative to the punch measurements and image analysis [Heq] estimates. Accordingly, the local zone of high [Heq] at the 'blip' is considered to have no significant effect on the hydrided region at a postulated PT ID flaw tip in the context of the potential for crack initiation at the flaw	Prepared for BP Submission with OPG / Industry Involvement	Additional sensitivities are planned. HFE [Heq] modelling remains ongoing with further work planned via the industry roadmap.
2F	Confirm validity of FT Model	Confirm continued validity of the PT FT model based on recently performed elevated [Heq] (≥120 ppm) burst test results.	For burst tests performed since fall 2021, all results exceeded the lower prediction bound of the Rev 2 FT model, such that the Rev 2 FT model continues to be supported based on nominal through-wall [Heq] including: • BT-44 (Q4 2021), BT-51 (Q4 2021), BT-40 (Q1 2022), and BT-48 (Q1 2022)	N-CORR-00531-23044 BT-40 and BT-48: • Formal results pending	Additional elevated [Heq] PT burst tests are planned to further validate the integrity of late life PT material and support model extension. A position paper documenting possible effects of a through wall hydride gradient is planned (target schedule, end of 2022)
2G	Confirm validity of Crack Initiation Model	Confirm continued validity of the PT crack initiation model based on recently performed Delayed Hydride Crack (DHC) material property testing at high [Heq] levels focusing on Threshold Stress Intensity Factor for DHC Initiation at a Blunt Notch (K_{TH}), Threshold Stress Intensity Factor for DHC Initiation at a Crack (K_{IH}), and Threshold Stress for DHC Initiation at a Planar Surface (p_c) (Q1 2022).	Noting a small decrease in the measured K_{TH} value at high [Heq] levels, the results confirm that there is a low likelihood that the DHC initiation model would not be applicable to detected in-service flaws with high [Heq] since lower bound K_{IH} and p_c values are utilized in assessments.	N-CORR-00531-23020 N-CORR-00531-23116	Additional elevated [Heq] crack initiation testing is planned to further validate the integrity of late life PT material (DHC and overload – WP 10258, fatigue – WP 10259, DHCR and KIH – WP 10224 / 10260). This work will be included in the FFS assessment roadmap as appropriate. Recurring model validity confirmation and extension is planned following future crack initiation testing.

Since fall 2021, the following assessment actions have been taken that support evaluation of potential elevated [Heq] impacts on PT FFS. For each listed assessment action, scope and key findings/conclusions are summarized in Table 3 3, below:

Table 3: COMPLETED ASSESSMENTS

Item	Activity	Scope	Findings/Conclusions	Submission(s) / Documentation	Remarks
Evaluations to Confirm FFS (OPG Funded)					
3A	Evaluation of In-Service Flaws	Confirm the integrity of known flaws in Darlington 1,4 and Pickering 5-8 PT ROIs (original review performed prior	Per CSA N285.4/N285.8 requirements, all known flaws in D1,4 and P5-8 inlet and outlet ROIs have been shown to be fit for service when assuming elevated [Heq]. This	NK38-CORR-00531-22967 NK30-CORR-00531-08375 NK30-CORR-00531-08468	Continued flaw monitoring in inlet and outlet ROIs is planned during future V&D inspections

Item	Activity	Scope	Findings/Conclusions	Submission(s) / Documentation	Remarks
		to fall 2021 with results reaffirmed after each V&D inspection campaign): • D2141 (reaffirmed Q1 2022) • P2171 (reaffirmed Q1 2022) • P2251 (reaffirmed Q2 2022)	status was originally confirmed in mid-2020 via NK38-REP-31100-10262 and P-REP-31100-00006, and has since been reaffirmed after each volumetric and dimensional inspection campaign (i.e., no new service-induced flaws discovered in ROIs).		
		Assess the likelihood of a flaw existing in an uninspected D1,4 or P5-8 PT outlet circumferential redistribution ROI (original review performed during fall 2021 with results reaffirmed after each V&D inspection campaign): • D2141 (reaffirmed Q1 2022) • P2171 (reaffirmed Q1 2022) • P2251 (reaffirmed Q2 2022)	The likelihood of a flaw being present in an uninspected D1,4 or P5-8 outlet ROI has been shown to be low based on all past V&D inspections. This status was originally confirmed in fall 2021, and has since been reaffirmed after each volumetric and dimensional inspection campaign (i.e., no new service-induced flaws discovered in ROIs).	NK38-CORR-00531-22869 NK30-CORR-00531-08328 N-CORR-00531-22916 NK38-CORR-00531-22967 NK30-CORR-00531-08375 NK30-CORR-00531-08468	Continued flaw monitoring in inlet and outlet ROIs is planned during future V&D inspections
3B	Assessment of BOT and RJ [Heq] Model Validity	Confirm continued validity of BOT and RJ [Heq] models based on recently performed [Heq] material surveillance and scrape sampling campaigns as follows: • P2181 (Q4 2021) • D2141 (Q1 2022) • P2171 (Q2 2022) • P2251 (Q3 2022) • P8P10 (Q3 2022)	Based on results from ex-service material surveillance testing and BOT and RJ scrape performed during P2181, D2141, P2171 and P2251, BOT and RJ [Heq] model predictions continue to be appropriate for use in OPG FFS assessments (excluding the highly localized ROIs at the PT inlet and outlet RJs).	NK30-CORR-00531-08323 NK38-CORR-00531-23351 NK30-CORR-00531-08491 Preliminary [Heq] data provided to CNSC staff via NK30-CORR-00531-08543, formal results pending COG-JP-4682-V001 NK30-CORR-00531-08516	Recurring model validity confirmation is planned following future OPG scrape sampling campaigns per the standard 120 day process.
3C	Perform Probabilistic Core Assessment (PCA)	Probabilistically evaluate PT FFS via revisions to the issued PCAs accounting for elevated [Heq] at both the inlet and outlet: • D1 (Q4 2021) • P6 (Q4 2021) • P8 (Q1 2022)	Updated PCAs for demonstrate compliance to CSA N285.8 acceptance criteria with respect to allowable events per calendar year based on the current methodology. Assessments performed while postulating elevated [Heq] in the inlet and outlet ROIs demonstrate low risk with respect to inlet and outlet PT material in the presence of 'blip' formation while methodology and [Heq] model enhancements progress.	NK38-CORR-00531-23064 NK30-CORR-00531-08370 NK30-CORR-00531-08437	The schedule for PCA revisions has been established to first focus on units expected to be bounding, with remaining assessments planned or in progress.
3D	Perform Leak-Before-Break (LBB) Assessment	Probabilistically evaluate PT FFS via revisions to the issued PLBB Assessments accounting for elevated [Heq] at both the inlet and outlet (Q4 2021): • D1 (Q4 2021)	Updated PLBB assessment for D1 demonstrates compliance to CSA N285.8 acceptance criteria with respect to maximum allowable conditional probability of Break Before Leak (BBL) based on the current methodology. Assessments performed while postulating elevated [Heq] in the inlet and outlet ROIs demonstrate low risk with respect to inlet and outlet PT material in the presence of 'blip' formation while methodology and [Heq] model enhancements progress.	NK38-CORR-00531-23012	The schedule for LBB assessment revisions has been established to first focus on units expected to be bounding with remaining assessments (including those for PNGS 5-8) planned or in progress.

Item	Activity	Scope	Findings/Conclusions	Submission(s) / Documentation	Remarks
3E	Perform Fracture Protection (FP) Assessment	Probabilistically evaluate PT FFS via revisions to the issued Probabilistic FP Assessments accounting for elevated [Heq] at both the inlet and outlet: • D1 (Q1 2022)	Updated FP assessment for D1 demonstrates compliance to annual failure frequency and cumulative reliability requirements accepted by CNSC staff in N-CORR-00531-23039. Assessments performed while postulating elevated [Heq] in the inlet and outlet ROIs demonstrate low risk with respect to inlet and outlet PT material in the presence of 'blip' formation while methodology and [Heq] model enhancements progress. Note: Deterministic engineering evaluations for D1,4 and P5-8 PTs (performed as a defense in depth measure in mid 2021) also demonstrate acceptable factors of safety on PT integrity in the presence of elevated outlet RJ [Heq].	NK38-CORR-00531-23177	The schedule for probabilistic FP assessment revisions has been established to first focus on units expected to be bounding, with remaining assessments (including those for PNGS 5-8) planned or in progress.
3F	Review Contribution of PT Failure to Probabilistic Safety Assessment (PSA) Goals	As a defense in depth measure, confirm contribution of PT leaks and failure remain within the PSA safety goals (Q4 2021).	Based on a review of the existing Darlington and Pickering PSAs, it was confirmed that: • Contribution of PT leak and failure is a small fraction of severe core damage frequency (SCDF) and large release frequency (LRF) • Likelihood of two (2) independent, concurrent PT failures is very unlikely • Likelihood that PT leak progresses to severe core damage or large release is highly unlikely • PT leaks and failures are not risk significant initiating events	NK38-CORR-00531-22869 NK30-CORR-00531-08328	In the unlikely event of PT leak or failure, safety analysis results demonstrate the overall risk associated with a PT failure is extremely low.

Path Forward Actions (Planned via Industry [Heq] Roadmap):

As recommended through the industry roadmap, OPG, with industry collaboration, has identified various experimental and modelling path forward actions. For COG WP items, schedule targets reflect the overall report due date. Preliminary results will be shared for information as they become available.

The following experimental actions are planned to support [Heq] technical basis validation and identification of key input parameters for modelling and assessment. For each planned experimental action listed in Table 4 below, scope and schedule requirements are summarized. Note that all schedule targets are subject to revision/refinement as the roadmap progresses.

Table 4: PLANNED MONITORING

Item	Activity	Sub-Activity	Scope	Schedule Target
Testing to Establish [Heq] Technical Basis				

Item	Activity	Sub-Activity	Scope	Schedule Target
4A	Improve Characterization of 'Blip' Existing Condition and Expected Evolution	COG WP 10369: Circumferential Gradients in Hydrogen Isotope Concentration in Rolled Joints	• Perform further 'blip' characterization using a combination of HVEMS, metallography, and surface analysis during 2022/2023 and expand WP 10369 into 2023/2024	• Document results of additional H/D sampling, metallography, and/or surface analysis in RJ regions (Q1 2024)
4B		COG WP 10384: Determination of Deuterium Concentration in Regions of Through-Wall Gradients from Rolled Joint Blips and Denuded Zones	• Determine through-wall deuterium concentration in regions of Blips to provide additional empirical data of through-wall concentration gradients.	• Document results of additional H/D sampling and with a focus on through wall gradients and 'blip' characterization (Q2 2024)
4C	Confirm the Cause of 'Blip' Formation Differentiating the Potential Roles of Ingress and Redistribution	COG WP 10379: Measurements of Hydrogen and Deuterium Concentrations in Ex-Service Pressure Tube material to Assess Circumferential Gradients and Axial Distributions	• If visible, perform HIC sampling/analysis in GS residence marks to understand the potential impact of localized thermal gradients on [Heq] evolution.	• Document Results of targeted H/D sampling (Q3 2023)
4D		Evaluate the Viability of RJ Mock-up Temperature Measurements	• Perform a feasibility study to determine if RJ temperature measurements could be obtained via mock-up assembly to help inform thermal inputs to RJ [Heq] models.	• Document conclusions of feasibility study (Q2 2023, testing to be performed after this date if viability confirmed)
4E	Improve Characterization of TSS Hysteresis	COG WP 10383: Assess the Effect of Hold Time on Hydrogen Solubility Limit Hysteresis and Hydride Redistribution in a Temperature Gradient	• Investigate potential TSSD/TSSP hysteresis reduction associated with sustained holds at temperature in ex-service PT material. • Investigate the effect of applied thermal gradients on [Heq] evolution.	• Document results of hysteresis and thermal testing (Q1 2024)

The following modelling actions are planned to support improved projection of PT condition evolution. For each planned modelling enhancement listed in Table 5 5, below, scope and schedule requirements are summarized. Note that all schedule targets are subject to revision/refinement as the roadmap progresses.

Table 5: PLANNED MODELLING

Item	Activity	Sub-Activity	Scope	Schedule Target
			Actions to Enhance [Heq] Predictability	
5A	Develop PT Temperature Model Enhancements – (ASSERT-PV) Updates	COG WP 10630: Development of a Pressure Tube Heat Transfer Model for ASSERT-PV.	• Model the PT thermal interaction in ASSERT as part of the ASSERT-PV Heat Transfer Model to help inform thermal inputs to [Heq] models by providing direct coolant to PT heat transfer predictions (supports modelling of [Heq] evolution in the presence of coolant thermal gradients).	• Document model development and simulation results (Q3 2023)
5B	Define Interim Temperature, Stress, Ingress, and TSS Inputs for [Heq] Models (Validate and/or Revise Existing Inputs as Required)		• Document interim inputs to [Heq] models to account for temperature, stress, ingress (including H-ingress as applicable), and hydrogen isotope solubility impacts on [Heq] evolution. This item identifies temporary inputs based on current technical basis understanding, to be validated as experimental roadmap work progresses.	• Document interim [Heq] model inputs (Q3 2023)

Item	Activity	Sub-Activity	Scope	Schedule Target
5C	Develop Interim [Heq] Model		• Develop means to approximate elevated [Heq] effects and issue an interim [Heq] predictive model. This model will incorporate current technical basis understanding for the purpose of short to medium term [Heq] projection.	• Document and issue Interim [Heq] Model (Q4 2023)
5D	Confirm Interim [Heq] Model Continued Validity as Roadmap Actions Progresses		• Based on information/understanding gained via this roadmap and interfacing programs, review the interim model for ongoing acceptability and either reaffirm or revise the model accordingly	• Document review(s) of interim model validity (Q4 2024, Q4 2025)
5E	Define Final Temperature, Stress, Ingress, and TSS Inputs for [Heq] Models (Validate and/or Revise Interim Inputs as Required)		• Document final inputs to [Heq] models to account for temperature, stress, ingress (including H-ingress as applicable), and hydrogen isotope solubility impacts on [Heq] evolution. This item identifies final inputs after all experimental roadmap work has been completed.	• Document final [Heq] model inputs (Q3 2025)
5F	Define the Relative Importance of Variables Influential to [Heq] Evolution		• Perform a parametric study using both interim and enhanced RJ models to establish which variables are most influential to [Heq] evolution and which can be simplified/excluded. • Note that completion of this item will require parametric study performed. This work is targeted to begin in Q2 2024 as part of the modelling process, noting for clarity that a final comprehensive model will not be available as of Q2 2024.	• Document influential variables that most significantly impact [Heq] evolution (Q4 2025)
5G	Develop Comprehensive [Heq] Model		• Develop and issue a comprehensive [Heq] predictive model. This model will incorporate enhanced technical basis understanding from the roadmap for the purpose of long term [Heq] projection.	• Document and issue comprehensive [Heq] Model (Q2 2026)

The planned actions specified in Table 4 and Table 5, above, establish a path forward schedule and logic relationship as shown in Figure 1 and Figure 2, below.

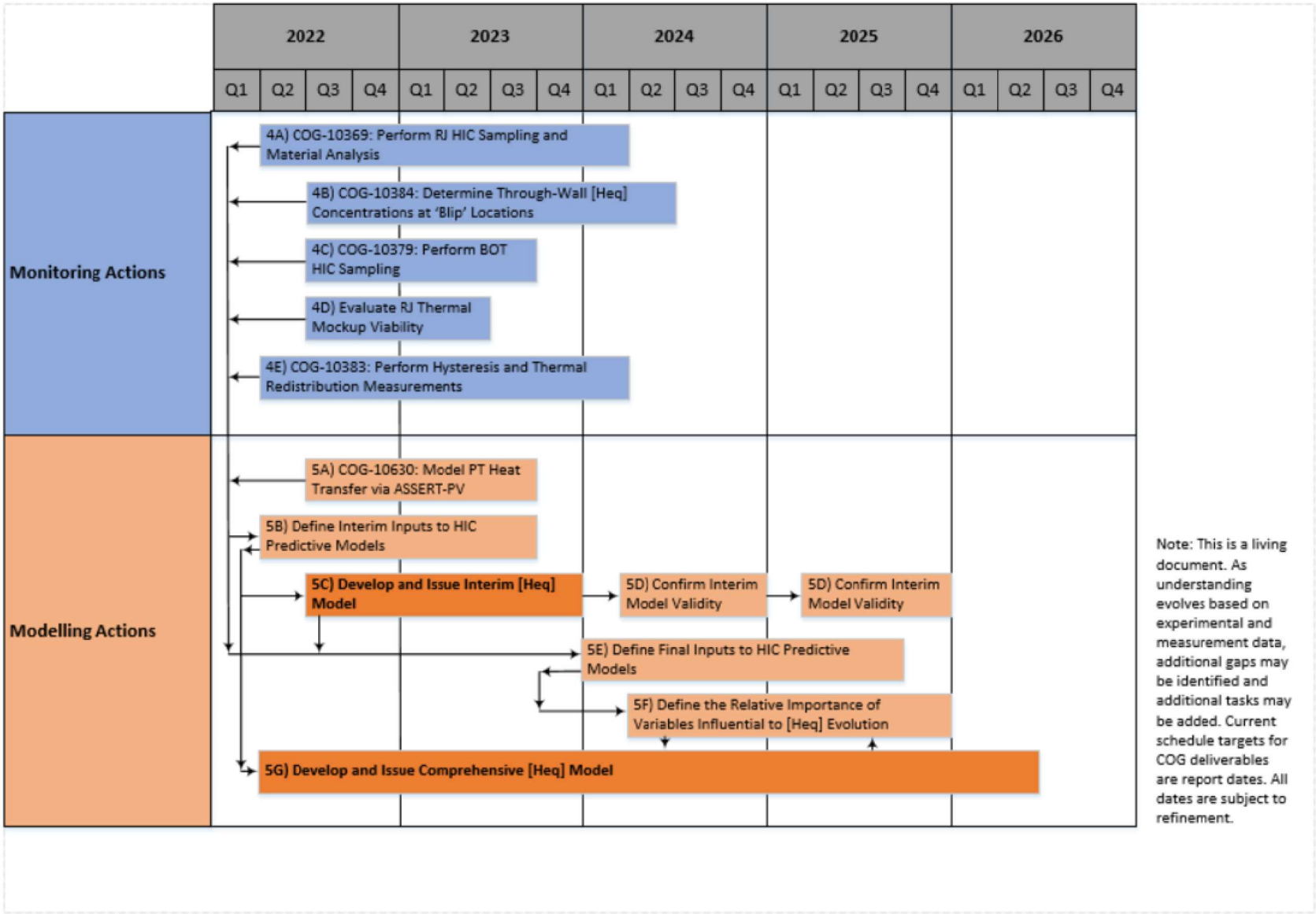

Figure 1: Industry Roadmap to Improve [Heq] Predictive Capabilities – Schedule Relationship

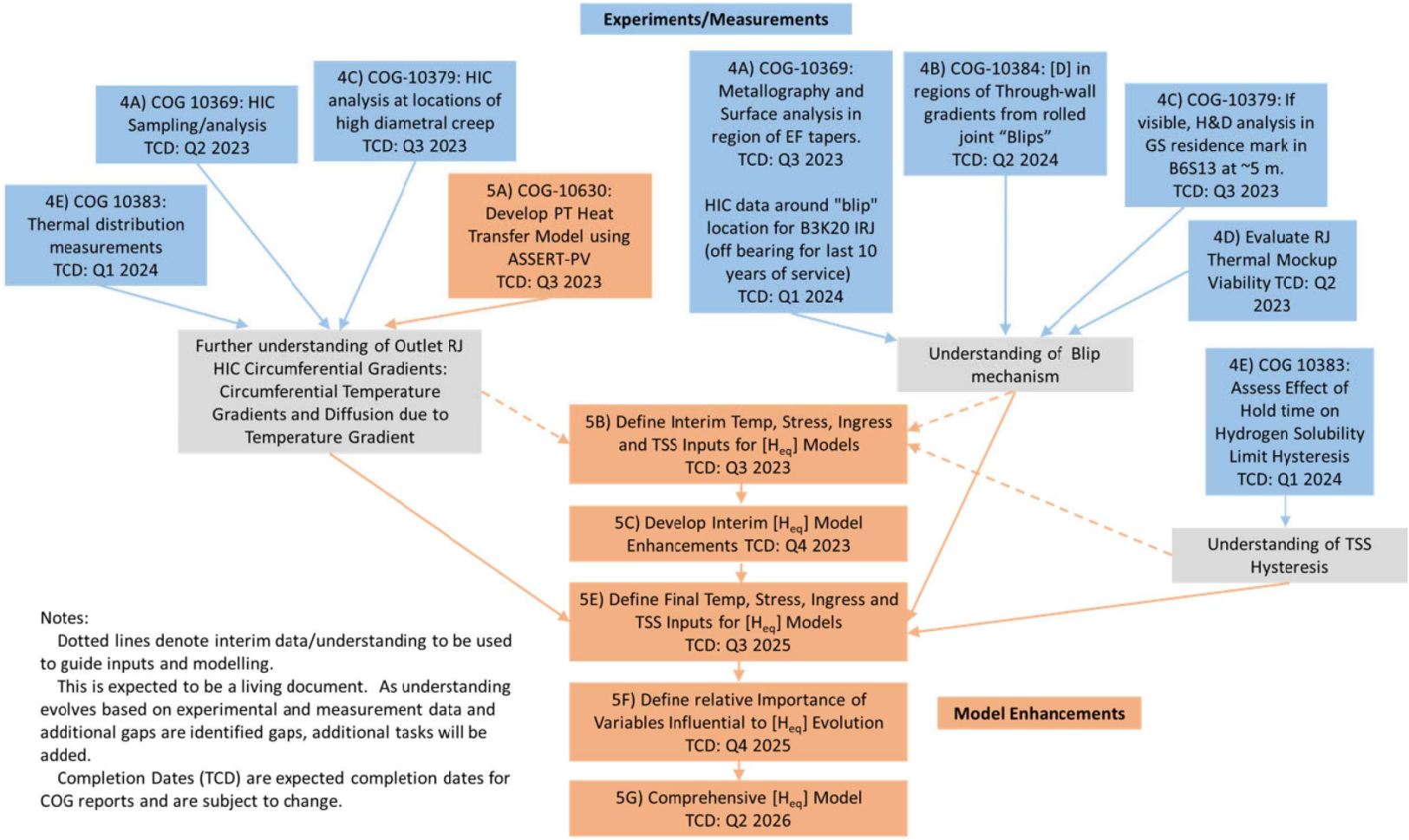

Figure 2: Industry Roadmap to Improve [Heq] Predictive Capabilities

Attachment 1 References:

A-1. OPG Letter, M.R. Knutson to R. Richardson and J. Burta, "*Fitness for Service Justification Prepared in Response to Localized High [Heq] ('Blip') Formation Observed in OPG Pressure Tube Inlet Rolled Joints*", OPG CD# N-CORR-00531-23160, April 14, 2022.

Summary of Regulatory Commitments, Regulatory Obligations and Regulatory Management Actions Made/Concurrence Requested

N-CORR-00531-08536

Submission Title: **OPG Response - Darlington and Pickering NGS – Request for an Update to the Commission on Activities Related to the Discovery of Elevated Hydrogen Equivalent Concentration (Heq) – New Action Item 2022-OPG-23135**

Regulatory Commitments (REGC):

No.	Description	Date to be Completed
	None	

Regulatory Management Action (REGM):

No.	Description	Date to be Completed
1.	Provide a semi-annual update to CNSC staff on the status of actions identified in Attachment 1.	End of Q1 2023

Regulatory Obligation Action (REGO):

No.	Description	Date to be Completed
	None	

Concurrence Requested: OPG requests closure of the Action Item 2022-OPG-23135.