Type 3 Business Case Summary

Final Security Classification of the BCS: **OPG Confidential**

To be used for investments/projects meeting Type 3 criteria in OPG-STD-0076.

Executive Summary and Recommendations

Project #:	10-80014	**Title:**	Fuel Channel Life Extension Project
Phase:	Definition and Execution	**Release:**	Partial
Facility:	Nuclear	**Records File:**	N-BCS-31100-10009 R0
Class:	OMA	**Investment Type:**	Value Enhancing

Project Overview

We recommend the release of $41.2 M [redacted] base costs plus [redacted] contingency).

This partial release is to fund Phase 1 of the Fuel Channel Life Extension (FCLE) project during 2014 and 2015. The project covers the period 2014 – 2017 with closeout activities taking place in the first half of 2018. The total project estimate is $105.8M (including [redacted] contingency). Another CANDU operator is expected to share the costs on a portion of the research and development (R&D) requirements of the project scope. Net of this cost sharing, costs to OPG are estimated to be $67.4 M (including [redacted] contingency). The project estimate is considered an AACE Class 4 estimate and includes [redacted] contingency, including a [redacted] annual escalation contingency for the work expected to be conducted by R&D vendor, plus [redacted] specific contingency should non-OPG irradiated pressure tube (PT) material need to be acquired.

There are also consequential costs associated with operating the units longer, should this project be successful (mainly additional Spacer Location and Repositioning (SLAR) campaigns at Pickering and several single fuel channel replacements in which annulus spacers are retrieved). These consequential costs total approximately $147M, including $71M for contingent work which may not be required.

This project is required in order to extend confidence statements on fuel channel (FC) component life past the current 247k Equivalent Full Power Hours [EFPH] to at least 261k EFPH for Pickering and past 210k EFPH to at least 235k EFPH for Darlington. This project supports the OPG and Canadian Nuclear Safety Commission (CNSC) Protocol Agreement "Additional Protocol for Probabilistic Leak Before Break Assessments and X-750 Annulus Spacer Hold Points" [1]. This would enable OPG to achieve the following business objectives:

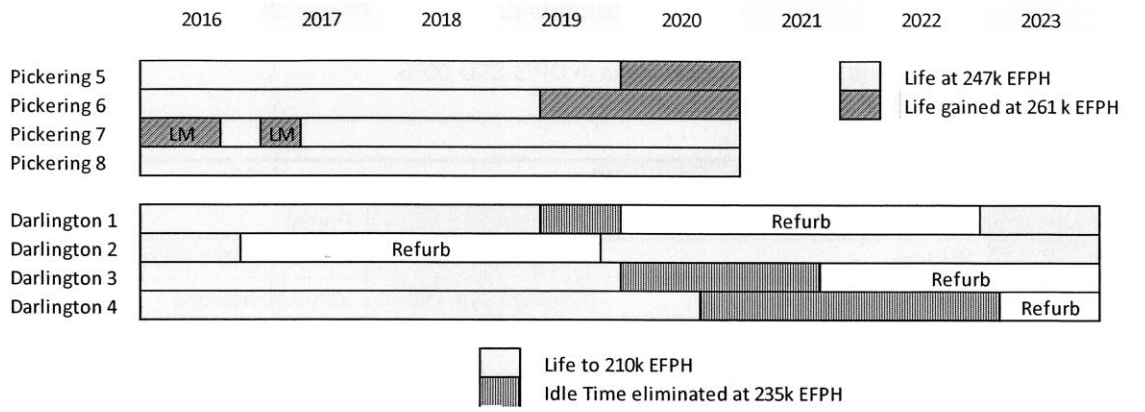
- Operate all Pickering units to the end 2020, without life management outages on any units, which requires high confidence in fitness-for-service of the Pickering fuel channels to 261k EFPH
- Operate the Darlington units to the planned start of refurbishment dates for all units without any idle time or life management outages, given a management decision to remove the overlap of the first two units' refurbishment outages. This would require high confidence in fitness-for-service of the Darlington fuel channels to 235k EFPH, with a confidence level statement available by Q2 2018

To meet these business objectives, and to be able to continue to provide assurance of fitness-for-service for OPG fuel channels, the FCLE project must start in early 2014. Additional business commitments above the base program and beyond this project to achieve/maintain high confidence in operating Darlington to 235k EFPH and Pickering to 261k EFPH are outlined in Part A.

The schematic in Figure 1 shows the additional life which would be enabled by extending high confidence in the Pickering fuel channels fitness-for service from 247k EFPH to 261k EFPH and in the Darlington fuel channels fitness-for-service from 210k EFPH to 235k EFPH. The idle time avoided on the last 3 Darlington units to be refurbished is estimated at 57 months.

*Associated with OPG-STD-0076, Developing and Documenting Business Cases

Figure 1: Impact of Fuel Channel Life Extension on Operating Times for Darlington and Pickering



The value to the electricity system if the FCLE Project is pursued and successfully achieves high confidence in fitness-for-service of the fuel channels to 261k EFPH at Pickering and to 235k EFPH at Darlington is estimated at $1.1 B (PV 2013$). The majority of the value ($0.9 B (PV 2013$)) arises from enabling the elimination of approximately 57 months of idle time on the Darlington units, which would occur if the planned refurbishment schedules is implemented, but fitness-for-service of the fuel channels beyond 210k EFPH were not achieved. The remainder of the value ($0.2 B (PV 2013$)), arises from enabling operation of all Pickering units to the end of 2020. This value is net of the estimated $105.8 M cost ($64 M (PV 2013$)) of implementing the FCLE project, as well as net of the estimated $147 M ($77 M (PV 2013$)) of consequential costs associated with longer operation and increased life cycle management work on both Darlington and Pickering.

This FCLE project continues work done under Project 62444 – Fuel Channel Life Management (FCLM). R&D work and technical assessments conducted under that project enabled the establishment of a high confidence statement in fitness-for-service of the Pickering fuel channels to 247k EFPH. The FCLM project also had, as a target, the establishment of high confidence in fitness-for-service of the Darlington fuel channels to 210k EFPH; however, this objective was not achieved by the end of 2012, primarily because of emergent issues with the integrity of Inconel X-750 annulus spacers in the Darlington fuel channels. On-going work in the FCLM project as well as some funding ($4.5 M) from this FCLE project, primarily for irradiation of Darlington spacers in a high flux R&D reactor, is required to enable assessment of high confidence in 210k EFPH for the Darlington fuel channels by 2015.

Major degradation mechanisms on Fuel Channels to be investigated can be categorized as follows:

- Effect of Hydrogen/Deuterium ingress on pressure tube fracture toughness.
- Pressure tube crack initiation by delayed hydrogen cracking (DHC), fatigue, or overload.
- Mobility and integrity of Inconel X-750 annulus spacers and prevention of pressure tube/calandria tube contact.

The FCLE project is planned to be executed in two stages:

Phase 1 Partial Release (this release):

- Research and Development (R&D) scope definition, inspection and maintenance scope definition
- CNSC concurrence on the Burst Test Matrix and scope of subsequent HFIR Irradiation work.
- Initial R&D execution including Phase 1 of Burst Test matrix and Phase 2 of High Flux Isotope Reactor (HFIR) irradiation work
- Surveillance testing of the PT removed from D1321 SFCR
- Third party reviews of technical submissions to CNSC and supporting project management activities

Phase 2 Full Release (future release planned for 2015):

- Complete remaining R&D including remaining Burst Tests and HFIR determined from the Phase 1 results
- Complete remaining inspection and maintenance scope assessments
- Refinement of models and methodologies based on the R&D results
- Surveillance testing of the PT and spacers from P1561 SFCR
- Third party reviews of technical submissions to CNSC and supporting project management activities

At the completion of the project, it is expected that tools and methodologies will have been established to enable assessment of high confidence in the fitness-for-service of pressure tubes to 235k EFPH for Darlington and to 261k EFPH for Pickering.

Project Cash Flows

M$	LTD	2014	2015	2016	2017	2018	2019	Future	Total
Currently Released									
Requested Now	-	8.5	32.7						41.2
Future Required	-			37.6	26.5	0.6			64.6
Total Project Cost		8.5	32.7	37.6	26.5	0.6			105.8
Ongoing Costs	-		22.0		4.5	63.6	53.5	3.1	146.7
Grand Total		8.5	54.7	37.6	31.0	64.1	53.5	3.1	252.5

Estimate Class:	Class 4	**Estimate at Completion:**	[redacted]
NPV:	$1,100 M	**OAR Approval Amount:**	252.5

Additional Information on Project Cash Flows (optional):

Project Cash Flows, Estimate at Completion, and OAR approval amount show in the table above assumes no co-funding by any other party. The Estimate at Completion does not include contingency of [redacted]

Ongoing Costs are composed of Consequential costs and contingency Single Fuel Channel Replacements (SFCR):

$M	To Enable 261k EFPH for Pickering	To Enable 235k EFPH for Darlington	Total
Consequential Costs*	52.0	23.6	75.6
Contingency repeat CT-LISS nozzle inspection	5.1		5.1
Contingency SFCR (including material surveillance)		66.0	66.0
Total	57.1	89.6	146.7

*Consequential costs are composed of: material surveillance of pressure tubes and annulus spacers post the FCLE project, incremental station OM&A for fuel channel inspection and maintenance, incremental major components (Feeders, Steam Generators) life cycle management costs.

With another CANDU operator co-funding the R&D effort at 50%, OPG's forecast expenditure would be the following:

($M)	2014	2015	2016	2017	2018	Total
Base	[redacted]					
Contingency						
Total	5.7	21.0	24.9	15.3	0.6	67.4

Approvals

	Signature	Comments	Date
This BCS represents the best option to meet the validated business need in a cost effective manner.			
Recommended by: Mark Elliott, SVP & Chief Nuclear Engineer Project Sponsor			Oct 30, 2013
I concur with the business decision as documented in this BCS.			
Finance Approval: Donn Hanbidge, SVP & Chief Financial Officer Position per OPG-STD-0076			Nov 7/13
I confirm this project will address the business need, is of sufficient priority to proceed, and provides value for money.			
Approved by: Tom Mitchell, President & Chief Executive Officer Position per OAR, per OAR 1.1			Nov 11, 13

Business Case Summary

Part A: Business Need

Business Need:

As Darlington and Pickering reactors age, OPG needs to continually update its assessments of degradation mechanisms on fuel channel components. These degradation mechanisms may impact OPG's ability to demonstrate fitness-for-service of the units and, consequently, the success of continuing to operate these units to planned end of life (EOL).

Major degradation mechanisms can be categorized as follows:

1. Effect of Hydrogen/Deuterium ingress on pressure tube fracture toughness
2. Pressure tube crack initiation by delayed hydride cracking (DHC), fatigue, or overload
3. Mobility and integrity of annulus spacers and prevention of pressure tube/calandria tube contact

Significant research and development (R&D) as well as improved methodologies such as Probabilistic Core Assessment (PCA), Probabilistic Leak Before Break (PLBB) assessments, and Probabilistic fracture protection are required, to provide OPG with assurance that its units remain fit-for-service to the end of their targeted service lives.

R&D work and technical assessments co-ordinated under the current Fuel Channel Life Management Project (FCLMP 10-62444), have enabled an improved understanding of degradation mechanisms behind the aging of fuel channel components. Under this project, high confidence has been established in the fitness-for-service of Pickering fuel channels to operate to 247k EFPH. Together with the required R&D, inspection and maintenance activities, this enables continued operation of Pickering Units (EOL 2019-2020).

At FCLMP (Project #62444) completion (mid 2015) it is expected that plans, tools, and methodologies will have been established to acquire and analyze inspection and surveillance data to assess technical confidence in the fitness-for-service of Darlington pressure tubes to 210k EFPH. A Darlington 10 year Spacer Management Plan [2] has also been submitted to the CNSC. It is expected that the confidence of Darlington operation to 210 kEFPH will be determined in 2015.

A Protocol agreement has been established with CNSC with hold points going beyond FCLMP. Some of the hold points are tied to the current Pickering Operating License [2], while others may be required for the future Darlington Operating License. In order to be released from these hold points, OPG must complete inspection, assessments and R&D activities as per the Protocol, including those specified in "Long Term Darlington Life Management Plan for Inconel X-750 Annulus Spacers" [2].

Economic value exists in OPG's ability to increase operational flexibility with respect to the sequencing and timing for the refurbishment of Darlington units. For example, refurbishment of the first unit (U2) with no overlap of the second unit refurbishment outage would require the remaining three units (with overlaps of their refurbishment outages) to operate up to and beyond 210k EFPH. This would require demonstrating capability (for the last unit to be refurbished) to operate to approximately 235k EFPH. There is also economic value in the extended operation of Pickering units to beyond 247k EFPH. For example, extended operation of all Pickering units to year end 2020 would require operation to 261k EFPH. This increased operational flexibility or opportunity for additional economic value is offset by the cost /risk of extending the understanding of the degradation mechanisms.

Surveillance testing of the PT from D1321 SFCR (spacer testing is part of FCLMP) and that of the PT and spacers from P1561 SFCR is included in the scope of this project.

BUSINESS COMMITMENTS NOT INCLUDED IN THE PROJECT:

OPG has the following commitments related to fuel channel component life cycle management beyond the FCLE project scope. These costs have been included in the economic assessment for this business case.

1. Material Surveillance Testing of Pressure Tubes and Spacers from SFCR and D2 Refurbishment:

One (1) pressure tube removed from Darlington Unit 2 in 2017 will be subject to surveillance testing required by CSA N285.4, and surveillance testing of all 24 spacers and fractography of the tested material, which are expected to be included in the new revision of the CSA 285.4. There will also be Pressure Tubes and Spacers during later lives (1 SFCR planned for P1951, 1 SFCR to be evaluated for DNGS) requiring same testing. Conceptual estimate for these activities is $23M.

2. Incremental Station OM&A Costs for Fuel Channel Inspection and Maintenance

Includes 1 SFCR campaign at Pickering in 2019 (P1951 outage), 3 SLAR campaigns, Scrape sampling etc., for total estimated cost of $48M.

3. Additional Life Cycle Management Cost of Other Major Components due to extended operations

Estimates are: Feeders: $0.4 M; Steam Generators: $4.5 M and Reactor Components: $5.1 M, for a total of $10 M

4. Contingency SFCRs

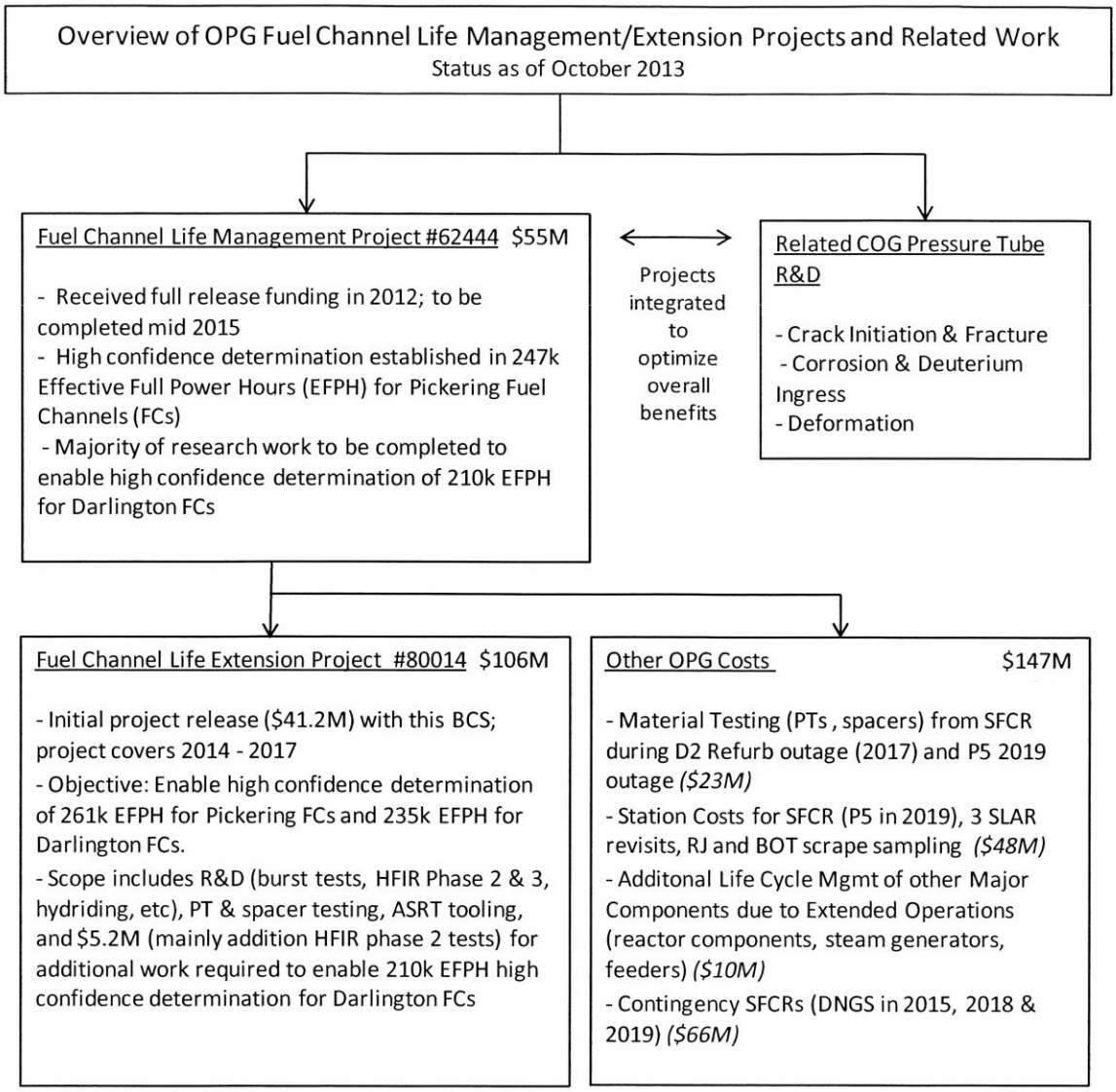
There could be three contingent SFCRs at Darlington; in 2015 (D1531 outage), 2018 (D1831 outage) and in 2019 (D1941 outage) depending on the results of earlier SFCRs related to spacer integrity assessments. Spacer testing is estimated at $2M/SFCR with a Station cost of $20M/SFCR.

5. Burst Test post 2017

Funding for additional BTs post 2017, if required.

6. HFIR Irradiation post 2017

Funding for additional HFIR post 2017, if required.



Part B: Preferred Alternative

Description of Preferred Alternative: Execution of Fuel Channel Life Extension Project

Upon completion of the project, OPG will have the plans, tools, and methodologies to acquire and analyze inspection and surveillance data to assess fitness for service of fuel channels to the targeted lives of 261k EFPH plus margin at Pickering and 235k EFPH plus margin at Darlington. This would enable OPG to achieve its business objectives for Pickering Continued Operations and the Darlington Refurbishment.

The work scoped in the BCS is also required for planning flexibility with respect to the sequencing and timing for the refurbishment of Darlington units. For example, refurbishment of the first unit (U2) with no overlap of the second unit refurbishment outage would require the remaining three units (with overlap) to operate longer. This would require demonstrating capability (for the last unit to be refurbished) to operate to approximately 235 k EFPH.

PROJECT SCOPE AND RELEASE STRATEGY

The FCLE project will be released and executed in two phases:

- Phase 1 partial release (2014-2015) to define R&D scope, to execute phase 1 of the Burst Test Matrix and Phase II of HFIR Irradiation work, and to complete surveillance testing of the PT from D1321 SFCR.
- Phase 2 final release (2016-2017) will include the BTs from the Matrix logic and HFIR as determined from the Phase I results (from BTs conducted and HFIR completed), and refinement of models and methodologies based on the R&D results, and to complete surveillance testing of the PT and spacers from P1561 SFCR. Since R&D work is planned for the full year of 2017, minor funding ($600k) is included for the project management and close-out activities in 2018.

Table 1 - Breakdown of the project work scope and estimates

Item	This Release (2014-2015)	Est. Cost	Future Release (2016-2017)	Est. Cost
Inspection & Maintenance Scoping	Complete majority of R&D, inspection and maintenance scoping including assessment of target end of life hoop stress, PT/CT contact. Pilot assessment of LBB and FP using new FT models	$2.4M	Complete remaining assessment work for the extended operations, including PCA, LBB and FP assessment using new FT models	$1.8M
Materials Testing	Complete surveillance testing of PT from D1321 SCFR and issue test reports. Complete removal and shipping to AECL of PT and Spacers from P1561 SCFR.	$3.4M	Complete surveillance testing of PT and Spacers from P1561 SCFR and issue test reports.	$4M
Core R&D	Complete 4 Burst Tests (BTs) for Fracture Toughness (FT) model validation for the extended end of life conditions (higher [H]eq and higher hoop stress)	$8M	Complete 10 BTs for FT model expansion to extended life conditions	$20M
	Hydriding to achieve 130 ppm. High Pressure Hydriding (HPH), Electrolytic and/or alternative hydriding techniques development to simulate higher [Heq] in later life reactor conditions	$3M	Hydriding to achieve 150 ppm	$2M
	High Flux Isotope Reactor (HFIR) phase II scope.	$6M	HFIR Phase III and Irradiation of spacer material and ex-service spacers	$6M
	Interim Spacer models established. Further development/refinement of the Empirical and structural models for the Darlington tight fitting spacers	$1M	Formal Spacer models established for extended life	$1M
	Other related R&D activities (Hydride Reorientation Stress, Chlorine Content etc.)	$4M	Other related R&D activities (Deuterium Ingress, Tight Fitting Spacer Movement etc.)	$3.5M
Third Party Reviews	Key submission to the CNSC on FT and Spacer models	$0.3M	Key submission to the CNSC on FT and Spacer models	$0.2M
Tooling	Advance Spacer Retrieval Tooling (ASRT) adaption for SFCR	$0.5M	Spacer Retrieval Tooling for extended life conditions	$1.5M
Other Work	OPG and COG Project management activities, development of the next BCS release in 2015 etc.	$1.7M	OPG and COG Project management activities, project close-out etc.	$2.8M

Table 2 below explains the differences between FCLMP (#62444) and this project (#80014) on the Core R&D scope items:

Item	FCLM Scope (Proj. #62444)	FCLE Scope (Proj. #80014)	Explanation
1. Fracture Toughness - Burst Tests	14 BTs have been completed with which Rev. I of the New Fracture Toughness (FT) Models have been established. 6 more BTs will be completed as part of the final BCS release.	A test matrix is being developed with initial recommendation ranging from 17 to 50 BTs (including 6 from FCLMP that will be credited towards the matrix). This BCS assumes funding for 14 BTs.	Additional BTs are required under higher [Heq], broader range of Chlorine concentrations and higher hoop stress conditions which would exist during the extended life. CNSC is closely scrutinizing the BT Matrix in evaluating the acceptance of the new FT Models.
2. PT Crack Initiation - Hydriding Techniques Development	High Pressure Hydriding targeting 150 ppm [Heq] was included.	Electrolytic Hydriding in parallel with HPH and Low Pressure Hydriding to 130 ppm [Heq] by 2015, and 150 ppm by 2017.	HPH repeatability has been poor and may not achieve the target [Heq]. Alternative processes are required to achieve ~130 ppm [Heq] by 2015 to support DNGS refurbishment planning.
3. Spacer HFIR Irradiation	HFIR piloting i.e. reactor set up, material procurement, shipping and testing of the samples removed from the first interval.	Irradiation (Neutron) cost of subsequent samples and ex-service spacers retrieved during SFCRs.	Oak Ridge National Laboratories (ORNL) did not charge for neutrons during FCLM scope which was considered R&D work. Significant neutron charges will now be levied for future OPG commercial orders.
4. Spacer Empirical & Structural Modelling	Initial development of the models	Refinement of the models and acceptance by CNSC	These models are required to predict the life of the DNGS tight fitting spacers.

The Fracture Toughness Models developed under FCLMP have not yet received CNSC acceptance. Discussions with the CNSC so far indicate that significant additional testing and analysis will be required, beyond what is scoped in the FCLM Project, to validate and to expand the models for the later life conditions at Pickering (beyond 247k EFPH) and Darlington (beyond 210k EFPH).

The protocol agreement between CNSC and OPG "Additional Protocol For Development Of Probabilistic Leak Before Break Assessments And X-750 Annulus Spacers" commits OPG to R&D, inspection and material surveillance activities that extend beyond the scope and timelines of FCLMP.

PROJECT DELIVERABLES FUNDED BY THIS RELEASE (2014-2015)

FRACTURE TOUGHNESS

- Surveillance Testing of PT from D1321
- Validate the new fracture toughness model and obtain acceptance by the CNSC.
- Third party reviews of CNSC technical submissions on Fracture Toughness

SPACERS

- Removal of the PT and spacers from P1561 SFCR, and shipping to the testing facility
- HFIR irradiation, and Empirical and Structural models refinement to achieve understanding of spacer degradation at extended life.
- Mobility and PT/CT contact assessment to support the fitness-for-service assessment of the spacers
- Submissions to the CNSC according the Darlington Long Term Spacer management plan.

PROJECT COMPLETION

Project is targeted for completion and close-out by June 2018. A PIR will be completed by June 2019.

Deliverables under this release (2014-2015):

Deliverables:	Associated Milestones (if any):	Target Date:
Flaw Assessments Completed for both Pickering and Darlington Units		Dec. 30, 2014
Contact Assessments completed for Pickering 5-8		May 31, 2015
D1321 PT Surveillance Testing Report Issued		Nov. 30, 2015
Electrolytic or alternative method to achieve hydriding to 130 ppm [Heq]		Dec 30, 2015

Part C: Other Alternatives

Base Case: Status Quo – No Project and Achieve 247k EFPH for Pickering and 210k EFPH for Darlington

NOT RECOMMENDED:

In this alternative, OPG would not fund the FCLE Project and would complete only the scope of work included in the FCLMP, which concludes in 2015. The Fracture Toughness Models developed under FCLMP have not yet received CNSC acceptance. Discussions with the CNSC so far have indicated that significant additional testing and analysis will be required, beyond what is scoped in FCLM Project, to validate and to expand the models for the later life conditions at Pickering (beyond 247k EFPH) and Darlington (beyond 210k EFPH).

The protocol agreement between the CNSC and OPG "Additional Protocol For Development Of Probabilistic Leak Before Break Assessments And X-750 Annulus Spacers" requires R&D, inspection and material surveillance activities that extend beyond the scope and timelines of the FCLMP. These activities would be funded by the project if it proceeds, otherwise they would have to be funded from other sources.

This alternative would not allow OPG to achieve its business objectives of operating Pickering to the end of 2020 and of operating the Darlington units to their currently planned refurbishment dates without incurring idle time or significant life management outages, and would significantly curtail OPG's planning flexibility with respect to the operation of Pickering and Darlington.

For example, removal of the overlap between the first and second unit refurbishments at Darlington (as is currently planned) would require the last unit to operate to approximately 230 - 235k EFPH before entering its refurbishment outage. High confidence in operating up to approximately 235k EFPH cannot be achieved with this alternative, which would also foreclose the option of operating the Darlington units for an even longer period prior to refurbishment, if it were economical to do so.

Alternative 2: NOT RECOMMENDED - Achieve 247k EFPH for Pickering and 210k EFPH for Darlington with Life Management of Darlington Units

This alternative was considered but rejected. Given the currently contemplated Refurbishment Schedule for the Darlington units, this alternative would imply either idle time of 8 months on Darlington Unit 1, 19 months on Darlington Unit 3, and 30 months on Darlington 4 prior to refurbishment, or life management of these units during 2014 to 2021/2022 to mitigate this significant idle time threat immediately prior to refurbishment, or other mitigating activities such as SFCRs, or non-standard operating configurations in the most-at-risk fuel channels.

Similarly this alternative would require life management of Pickering Unit 7 to achieve the end of 2020 along with Pickering Unit 8, and would see Pickering Units 5 and 6 cease operation in early 2020 and 2019 respectively.

While the costs of the FCLE project would be saved as well as a portion of consequential costs, significant system economic value would be forsaken. This alternative would foreclose the option of operating the Darlington units for a longer period prior to refurbishment, if it were economical to do so.

Alternative 3: NOT RECOMMENDED - Achieve 247k EFPH for Pickering and Do only R&D work to Achieve 217k EFPH for Darlington with Possible Life Management of Darlington Units

This alternative was considered but rejected. Given the currently contemplated Refurbishment Schedule for the Darlington units, this alternative would imply idle time of 7 months on Darlington Unit 3 and 18 months on Darlington Unit 4 prior to refurbishment, or life management of these units in the period 2014 to 2021/2022 to mitigate this significant idle time threat immediately prior to refurbishment or other mitigating activities, such as SFCRs or non-standard operating configurations in the most-at-risk fuel channels.

The opportunity to extract addition economic value for the system by operating all Pickering units to the end of 2020 would also be lost. This alternative would foreclose the option of operating the Darlington units for an even longer period prior to refurbishment, if it were economical to do so.

Alternative 4: NOT RECOMMENDED - Do Not Extend Pickering Fuel Channel Life Past 247 k EFPH, but Extend Darlington to 235k EFPH

The opportunity to extract addition economic value for the system by operating all Pickering units to the end of 2020 would be lost. Some of the testing which would provide high-confidence in Darlington achieving 235k EFPH also provides a benefit to Pickering and there is economic value and operational flexibility gained by operating Pickering units to the end of 2020. Thus, for a relatively small incremental cost, the FCLE project can achieve the target business objectives for both Pickering and Darlington; therefore, this alternative is not preferred.

Part D: Project Cash Flows

M$	LTD	2014	2015	2016	2017	2018	2019	Future	Total
Currently Released									
Requested Now	-	8.5	32.7						41.2
Future Required	-			37.6	26.5	0.6			64.6
Total Project Cost		8.5	32.7	37.6	26.5	0.6			105.8
Ongoing Costs	-		22.0		4.5	63.6	53.5	3.1	146.7
Grand Total		8.5	54.7	37.6	31.0	64.1	53.5	3.1	252.5

Estimate Class:	Class 4	**Estimate at Completion:**	[redacted]	**OAR Approval Amount:**	252.5

Additional Information on Project Cash Flows (optional):

Project Cash Flows, Estimate at Completion, and OAR approval amount show in the table above assumes no co-funding by any other party. The Estimate at Completion does not include contingency of [redacted]

Ongoing Costs are composed of Consequential costs and contingency Single Fuel Channel Replacements (SFCR):

$M	To Enable 261k EFPH for Pickering	To Enable 235k EFPH for Darlington	Total
Consequential Costs*	52.0	23.6	75.6
Contingency repeat CT-LISS nozzle inspection	5.1		5.1
Contingency SFCR (including material surveillance)		66.0	66.0
Total	57.1	89.6	146.7

*Consequential costs are composed of: material surveillance of pressure tubes and annulus spacers post the FCLE project, incremental station OM&A for fuel channel inspection and maintenance, incremental major components (Feeders, Steam Generators) life cycle management costs.

With another CANDU operator co-funding the R&D effort at 50%, OPG's forecast expenditure would be the following:

($M)	2014	2015	2016	2017	2018	Total
Base	[redacted]					
Contingency						
Total	5.7	21.0	24.9	15.3	0.6	67.4

*Associated with OPG-STD-0076, Developing and Documenting Business Cases

Type 3 Business Case Summary

Part E: Financial Evaluation

M$	Preferred Alternative	Base Case	Do Less	Alternative 3	Alternative 4
Project Cost	105.8	0	N/A	N/A	
NPV (after tax)	1100	N/A	N/A	N/A	

Summary of Financial Model Key Assumptions (see Guidance on this Type 3 BCS Form):

The value to the electricity system if the Fuel Channel Life Extension (FCLE) Project is pursued and successfully achieves high confidence in fitness-for-service of the fuel channels to 261k EFPH at Pickering and to 235k EFPH at Darlington is estimated at $1.1 B (PV 2013$). This value is based on the assumption that the Darlington units are indeed operated to 235k EFPH or to their planned refurbishment dates (whichever is earlier) and that the Pickering units are operated to the end of 2020 (261k EFPH allows all units to operate to at least the end of 2020). The amount contributed by Pickering and Darlington to the overall value is shown in Table 3. As can be seen, the majority of the value arises from the elimination of the idle time on the Darlington units, which would occur if these units are refurbished on their currently planned refurbishment schedules, but fitness-for-service of the fuel channels beyond 210k EFPH were not achieved. However, there is approximately $220M (PV 2013$) in value created by the longer operation of the Pickering units. The estimated value is net of the estimated $64 M (PV 2013$) cost of implementing the FCLE project, as well as net of the estimated $77 M (PV 2013$) of consequential costs associated with longer operation and increased life cycle management work on both Darlington and Pickering.

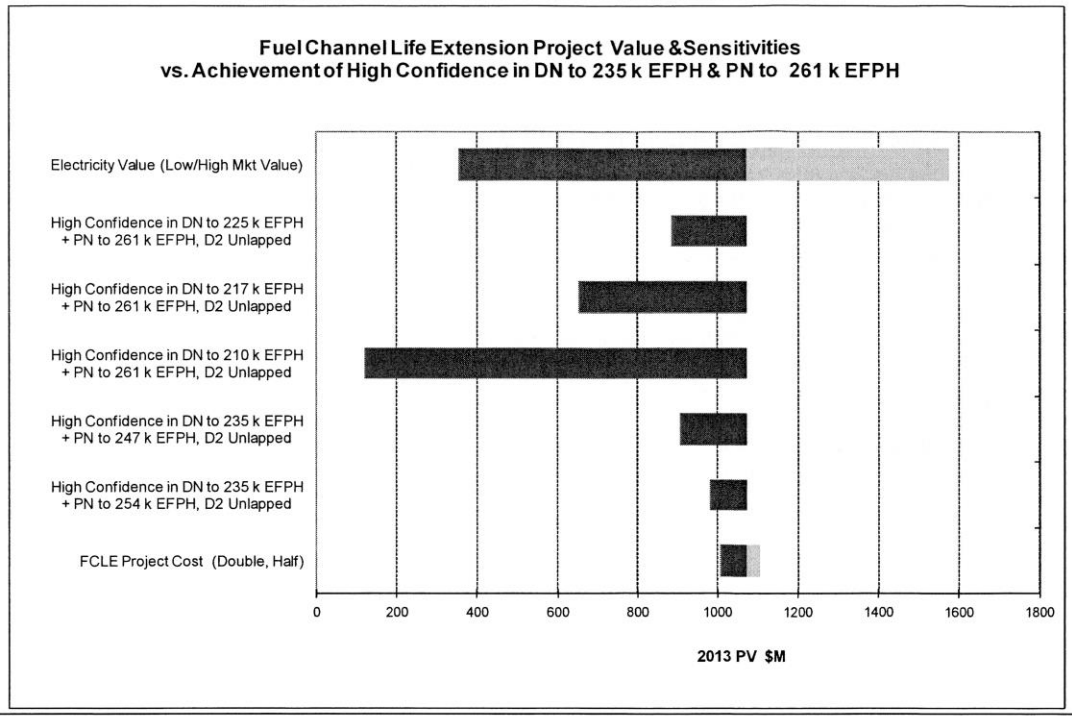
Table 3: Summary of Value Enabled by Recommended Alternative Versus Do Nothing (No project)

	No FCLE Project	Implement FCLE project	Impact	Value $B (PV 2013$)
Pickering	High Confidence in 247k EFPH achieved. Units Assumed Operated to 247k EFPH with Life Mgmt Outages on Unit 7	Tools and methodologies established to determine technical confidence in 261k EFPH achieved. Units Assumed Operated to 261k EFPH or end 2020, whichever is sooner.	Would allow all Pickering units to operate until end 2020, and would eliminate life mgmt outages on Pickering Unit 7.	0.2
Darlington	High Confidence in 210k EFPH achieved* and Units operated to 210k EFPH or start of refurbishment outages, whichever is sooner	Tools and methodologies established to determine technical confidence and Units operated to 235k EFPH or start of refurbishment outages, whichever is sooner	Would allow elimination of all idle time prior to start of refurbishment on all units, given current planning schedule. Also allows flexibility to start refurbishment of the first unit later if readiness issues arise.	0.9
			Total Median Estimated Value	**1.1**

*Some additional funding above base programs and beyond the Fuel Channel Life Management Project would be required to achieve high confidence in 210k EFPH at Darlington.

Results of the economic assessment were tested for sensitivity to key inputs such as the assumed electricity value, the degree of success in achieving high confidence in additional fuel channel life, and therefore the amount of additional station operating life achieved, the cost of the FCLE project and the level of consequential costs. In summary, the results indicate that, provided some additional life on Darlington is achieved, even if only to 217k EFPH, there would be a positive value to the electricity system, given the current planned refurbishment schedule (i.e. no overlap of the first two units to be refurbished), because of the reduction in idle time which is achieved. The following tornado diagram shows the key sensitivity results.

Figure 1: Sensitivity of Value to Key Uncertainties



The following provides additional details on the sensitivity analysis:

i. Assumed Electricity Value: The estimated value of FCLE is extremely sensitive to the assumed electricity value. In a high value regime the estimated value of eliminating potential idle time on Darlington and operating all of Pickering to end 2020 could be as high as approximately $1.6 B (PV 2013$). In a low value regime the value could be approximately $0.4 B (PV 2013$). A low priced regime could result from low or declining electricity demand growth (which could result, for example, from a prolonged economic slowdown) and low or declining gas prices, and /or high conservation which could result in a prolonged period of significant surplus base load generation.

ii. Length of Operating Life Achieved: The value is somewhat sensitive to the additional fuel channel life which can be achieved with high confidence:

- If the FCLE project were to enable the Pickering units to operate until end 2020, but only allowed Darlington to operate to 225k EFPH the value would be reduced by approximately $200 M (PV 2013$) to approximately $0.9 B (PV 2013$), as approximately 7 months of idle time would result for the last unit refurbished.
- If end 2020 operation were achieved for the Pickering units, but only 217k EFPH were achieved for Darlington the value would be reduced by approximately $425 M (PV 2013$) to approximately to $0.65 B (PV 2013$), as approximately 23 months of idle time would result on the last two units refurbished.
- If end 2020 were achieved for the Pickering units, but the FCLE project was unsuccessful and the Darlington fuel channel lives could not be extended beyond 210k EFPH, the value would be reduced by approximately $1.0B (PV 2013$) to $0.1 B (PV 2013$), as approximately 57 months of idle time could be incurred on the last three units refurbished.
- If the FCLE project achieved 235k EFPH for Darlington (no idle time) but only achieved 254k EFPH for Pickering the value would be reduced by approximately $100M (PV 2013$) to approximately $1.0 B(PV 2013$).
- If 235k EFPH were achieved for Darlington, with Pickering life remaining at 247 k EFPH, the value would be reduced by approximately $200 M (PV 2013$) to $0.9 B (PV 2013$).

iii. Project Costs: The value is insensitive to FCLE Project Costs. An approximate doubling of these costs reduces the value by $64 M (PV 2013$) to approximately $1.0 B (PV 2013$). A halving of these costs increases the value by $32 M (PV 2013$). Given the magnitude of the consequential cost the value would also be insensitive to consequential costs.

Part F: Qualitative Factors

The completion of the scope in the preferred alternative of this project is critical to the Continued and Extended Operations of Pickering, Refurbishment of Darlington. Since OPG operates the first CANDU units to be impacted by the fuel channel degradation mechanisms being investigated, our R&D findings may present financial opportunities when other CANDU units in the world are approaching their end-of-life.

Part G: Risk Assessment

Risk Class	Description of Risk	Risk Management Strategy	Post-Mitigation	
			Probability	Impact
Cost	Burst Test matrix not finalized and reviewed with CNSC. Additional BTs may be required (in excess of 14 included in the scope)	Contingency has been included for moderate scope addition	Medium	Medium
Scope	Same as above	to be finalized in the next BCS release	Medium	Low
Schedule	Same as above	Schedule extension - to be finalized in the next BCS release	Medium	Medium
Resources	Delay in project schedule may occur due to unavailability of specialized resources who cannot be easily replaced. Reasons may include labour disputes or commitment to other work programs in the vendor company	Mitigate - Obtain resource commitment from vendors Accept risk if resource unavailabiliy is due to labour disputes	Low	Medium
Quality/ Performance	If the empirical and structural modelling work conducted at Oak Ridges National Laboratory cannot provide predictive capability of spacer material degradation, the confidence in spacer material conditions may be uncertain.	Mitigate - Insufficient prediction capability will need to be made up by additional spacer material surveillance, with contingent Darlington SFCR's required	Medium	Medium
Technical	Results of R&D or field inspection may not support operations to the targeted fuel channel lives (235k EFPH for Darlington and 261k EFPH for Pickering)	Mitigate - Phased release strategy and continuous assessments of the R&D and inspection results to minize the cost of the project should this risk materialize	Medium	Medium

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Cost	Increase in cost due to R&D vendor switching their cost model for full cost recovery - future quotes from R&D vendor may be higher than anticipated	Specific contingency [redacted] contingency and a general contingency has been included in the project has been included	Med	Low
Scope	Increase in cost due to discovery work scope, indeterminate results or unexpected results. This also affects cost and schedule.	Mitigate - Set aside contingency on COG Joint Project Work.	Med	Med
Scope	Unexpected scope cuts from the outage will cause the project to have insufficient information to perform assessments on fuel channel fitness-for-service	Mitigate - Communicate to the outage planning organization that work is essential to the continued operation of the stations	Low	Med
Quality	Insufficient pressure tube test material available - may reduce confidence in fracture toughness models	Specific contingency [redacted] has been set aside for procurement of ex-service tubes from other CANDU plants	Low	Med

Additional Risk Analysis:

Long term business risk to demonstrate fuel channel fitness-for-service (post project):
Management of fuel channel fitness-for-service must continue even after the completion of this project. As units age, CNSC is expecting that there would be sufficient inspection and surveillance data to support the projections that the units are safe to operate to their targeted service lives. An expansion of fuel channel inspection scope has been proposed to the outage organization with the potential for outage extension. A Darlington "Long Term Spacer Plan" has also been submitted to CNSC, stating OPG's plan to retrieve and test intact spacers from Single Fuel Channel Replacement campaigns in outages, as well as during Darlington's 1st Unit Refurbishment.

Part H: Post Implementation Review (PIR) Plan

Type of PIR	Target Project In Service Date	Target PIR Completion Date
Simplified	2018-06-30	2019-06-30

Measurable Parameter	Current Baseline	Target Result	How will it be measured?	Who will measure it? (person/group)
Expanded fracture toughness curves covering the hydrogen concentrations at extended life	FCLMP may obtain CNSC acceptance of the new fracture toughness models, but will not cover the later life conditions	Expanded fracture toughness curves reflecting effects of hydrogen concentration, covering lower-shelf and transition temperature region	Acceptance of the expanded fracture toughness curves by the CNSC.	MCED
Structural model to project Darlington Spacer life limits	No model available	Model developed and available for use	Acceptance by CNSC	MCED
Confidence in fitness-for-service of the Pickering fuel channels to 261k EFPH is established	Confidence statement not available	Level of confidence established and statement available	Fuel Channel experts concur with High Confidence	MCED
Confidence in fitness-for-service of the Darlington fuel channels to 235k EFPH	Confidence statement not available	Level of confidence established and statement available	Fuel Channel experts concur with High Confidence	MCED

Part I: Definitions and Acronyms
ASRT - Advanced Spacer Retrieval Tool
BT - Burst Test
CT - Calandria Tube
EFPH - Equivalent Full Power Hours
FCLE(P) - Fuel Channel Life Extension (Project)
FCLM(P) - Fuel Channel Life Management (Project)
FT- Fracture Toughness
HFIR - High Flux Irradiation Reactor
HPH- High Pressure Hydriding
PM - Project Management
SFCR - Single Fuel Channel Replacement
SLAR - Spacer Location and Repositioning

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Type 3 Business Case Summary

Appendix A: Summary of Estimate			
Project Number:	10-80014	**Facility:**	Nuclear
Project Title:	Fuel Channel Life Extension Project		

Estimated Cost in M$

	LTD	2014	2015	2016	2017	2018	20--	Future	Total	%
OPG Project Management		0.6	0.6	0.8	0.8	0.4			3.3	4.5
OPG Engineering		0.3	0.7	0.6	0.4	0.1			2.1	2.8
Permanent Materials			0.5	2.2	0.5				3.2	4.3
Design and Construction										
Consultants		[redacted]							[redacted]	
Other Contracts/Costs										
Interest										
Subtotal without Contingency		[redacted]							[redacted]	
Contingency										
Grand Total		**8.5**	**32.7**	**37.6**	**26.5**	**0.6**			**105.8**	

Notes

Project Start Date	2014-01-02	**Project Completion or In-Service Date**	2018-06-30 (FCLE Project Completion)
Interest Rate	5.00%	**Escalation Rate**	2.0%
Definition Cost Included	$0 k	**Estimate at Completion**	[redacted]

Prepared by:		**Approved by:**	
John Xiao Section Manager, FCLMP	2013-10-28 YYYY-MM-DD	Kathy Charette Director (Acting), FCLMP N.C. VAN DEN BREKEL ACTING FOR K. CHARETTE	2013-10-28 YYYY-MM-DD

Appendix B: Comparison of Total Project Estimates

Phase	Release	Date (YYYY-MM-DD)	Total Project Estimate in M$ (by year including contingency)						Later	Total Project Estimate
			2014	2015	2016	2017	2018	2019		
Definition & Execution	Partial	2013-11-11	8.5	32.7	37.6	26.5	0.6			105.8

Type 3 Business Case Summary

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Project Variance Analysis					
Estimated Cost in M$					
M$	LTD	Total Project		Variance	Comments
		Last BCS	This BCS		
First release – Project Variance Analysis not required					

Appendix C: Financial Evaluation Assumptions

Key assumptions used in the financial model of the Project are (complete relevant assumptions only):

Project Cost:

(1) Incremental Project Costs are [redacted] for the Preferred Alternative.

(2)

(3)

Financial:

(1) Discount rate is 7% for regulated assets.

(2)

(3)

Project Life:

(1)

(2)

(3)

Energy Production:

(1)

(2)

(3)

Operating Cost:

(1)

(2)

(3)

Other:

(1)

(2)

(3)

Attach further detail as appropriate from the Financial Evaluation spreadsheet.

Appendix D: References

1. N-CORR-00531-06249, Fuel Channel Life Management Project - Additional Protocol For Development Of Probabilistic Leak Before Break Assessments And X-750 Annulus Spacers

2. NK38-PLAN-31160-10000, Long Term Darlington Life Management Plan for Inconel X-750 Spacers