
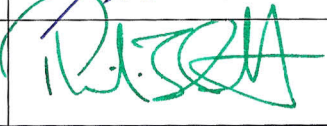

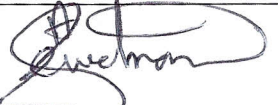

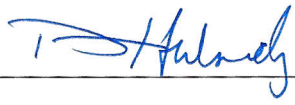
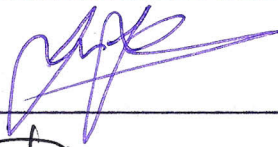
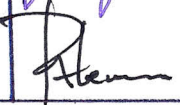


Business Case Summary

Fuel Channel Life Management Project 10 - 62444 (OM&A)
& Spacer Retrieval Tool Project 28 - 66567 (Capital)
Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000

<u>Name / Title / Phone</u>	<u>Location</u>	<u>Action</u>	<u>Signature</u>	<u>Date</u>
EXECUTING ORGANIZATION - FCLMP				
Imtiaz Malek Director, Fuel Channel Life Management Project	P82-6	Review BCS		July 4, 2011
Mark Elliot SVP, Nuclear Engineering & Chief Nuclear Engineer	P82-5	Review BCS		2010712.
PROJECT SPONSORS				
Wayne Robbins Chief Nuclear Officer	P82-6	Submit BCS		2011-07-20
Albert Sweetnam EVP, Nuclear Projects	H17-G25	Submit BCS		20 July 11
BCS APPROVAL				
Don Power Vice President, Corporate Investment & Asset Planning	H07-G05	Approve BCS		Aug 3/11
Donn Hanbidge SVP & Chief Financial Officer	H19-F27	Approve BCS		Aug 12/11
Tom Mitchell President & Chief Executive Officer	H19-A24	Approve BCS		
Carolyn Sicard Nuclear Investment Management 702-4082	P82-3B6.2	Return for Distribution		
Jamie Lawrie Director, Investment Management Nuclear Finance	P82-3	Review BCS		July 22/2011
Randy Leavitt VP, Nuclear Finance	P82-3	Review BCS		July 22, 2011.

Business Case Summary**Fuel Channel Life Management Project 10 - 62444 (OM&A)
& Spacer Retrieval Tool Project 28 - 66567 (Capital)
Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000****1/ RECOMMENDATION:**

We recommend a third **Partial Release** of an **additional \$18.6 Million Capital and OM&A** (including a contingency of [REDACTED] Million) to fund the following work:

- 1) \$16.4 Million **OM&A** to fund **additional research & development (R&D) activities, plus new scope of oversight of supporting activities and increased regulatory interface activities** for the Fuel Channel Life Management Project (10-62444).
- 2) \$2.2 Million **Capital** to fund **design, procurement, and commissioning activities** for the Spacer Retrieval Tool Project (28-66567), which started in 2011.

Approval of this request will bring the total funding released to date to **\$37.5 Million**, including a contingency of [REDACTED]. This work is jointly funding by OPG and industry partners, and only OPG's share of the project costs is presented in this business case. This release will fund work activities through to the end of 2012. R&D activities will be completed and a high confidence statement of the service life of pressure tubes at Darlington and Pickering B will be made at the end of 2012, as per the original schedule.

The OM&A project completion date has been extended to June 30, 2015 to accommodate the **new** additional scope of interfacing with the Regulator, providing licensing support, incorporation of R&D results into business and generation plans, as well as project close out activities.

The total project is estimated to cost **\$43.1 Million**. This represents an overall increase of \$12.9 Million for the OM&A work with the breakdown as below:

- a) \$5.0 Million for new funding to allow OPG to enter into negotiations with Bruce Power to obtain critical spacer degradation data for Darlington FFS (Fitness-for-Service) demonstration through a Bruce Power SFCR project in 2012.
- b) \$4.5 Million for the added R&D to obtain CNSC concurrence based on 18 technical submissions per agreed CNSC Protocol.
- c) \$3.4 Million for added new scope to oversee supporting projects (e.g. Gap and Spacer Retrieval Tooling), supporting activities, and to confirm integration of R&D work into surveillance programs.

The final release of the remaining funding on this estimate will be requested in August 2012.

The Business Objectives of these **Sustaining** projects are:

10-62444 Fuel Channel Life Management Project (OM&A):

OPG plans to refurbish the Darlington units starting in October 2016. Following this schedule, the last two units to be refurbished will reach or exceed their original planned life of 210k EFPH (Unit 3 in 2019; Unit 4 in 2021). However, due to Darlington's higher operating temperatures and pressure, OPG can only demonstrate with high confidence that the Darlington units can operate to 187k EFPH using current available methodologies. The recently observed new Inconel X-750 spacer degradation mechanism (embrittlement due to nickel transmutation under irradiation) may threaten current operations. Thus, critical information is required from the COG R&D project. OPG will work with Bruce Power to establish the material property degradation rate sooner by using spacers retrieved from a Bruce Unit in 2012 in addition to spacers retrieved from Darlington in 2013.

Pickering B units are not to be refurbished. However, to manage the power supply during the Darlington Refurbishment project, OPG plans to operate the Pickering B units to mid 2020 (~247k EFPH). High confidence that these units will achieve this new planned life needs to be demonstrated prior to the final business planning decision, to be made at the end of 2012.

To demonstrate that both Darlington and Pickering B will reach these operational targets, research in the following technical areas are underway:

1. Deuterium Ingress and its Impact on Material Properties
2. Spacer Integrity and Pressure Tube - Calandria Tube (PT-CT) Contact

Business Case Summary

Fuel Channel Life Management Project 10 - 62444 (OM&A) & Spacer Retrieval Tool Project 28 - 66567 (Capital) Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000

3. Crack Initiation
4. Probabilistic Core Assessments (PCA) and Leak-Before-Break (LBB)

There are 2 critical objectives for the short term R&D work:

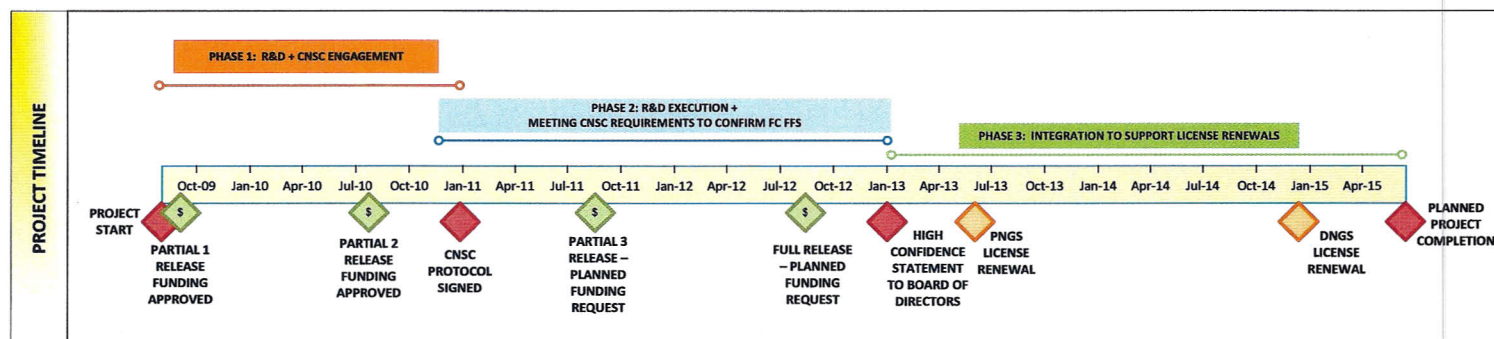
1. Enable a high confidence statement of the targeted service life of Pickering and Darlington fuel channels to be made to the Board of Directors by the end of 2012 in order to make business decisions on the continued operations of Pickering B and the refurbishment schedule for Darlington.
2. Obtain Regulator acceptance of OPG initiatives to operate Pickering B to 2020 and to provide Darlington Refurbishment schedule flexibility. The requirements for the two initiatives, specific to fuel channel technical issues, have been agreed upon and documented in N-CORR-00531-05133 ("the CNSC Protocol").

To ensure success of the two initiatives, post R&D activities need to be managed and transitioned into the base organization. This includes the following activities:

- a. Manage regulatory submissions for the application of new or improved methodologies developed from the R&D programs. These submissions are required separately for Pickering B and Darlington.
- b. Manage outstanding CNSC follow-up requirements, such as additional confirmatory R&D work and new inspection requirements to be integrated into life cycle management plans (LCMPs).
- c. Develop a long term tight-fitting spacer surveillance and management plan for Darlington.
- d. Assist in the license renewal process for Pickering B (2013) and Darlington (2014).

The project can be divided into three major phases (see diagram below):

1. The initial scope of R&D work was identified and refined through early engagement with the CNSC during the first phase (2009-2010).
2. The CNSC Protocol, which specifies the critical R&D scope that must be accomplished by December 2012, was agreed to and signed by OPG and the CNSC in February 2011 as part of the second phase activities (2011-2012). This phase will now concentrate on execution of the defined R&D program to support the delivery of a high confidence statement to the OPG Board of Directors on pressure tube end-of-life for both Darlington and Pickering.
3. The third phase, beginning in January 2013, will focus on the post R&D activities described above. Additional support to integrate R&D results into Life Cycle Management Plans (LCMPs) will be provided to 2015. The planned completion date of the project is June 30, 2015.



Business Case Summary
**Fuel Channel Life Management Project 10 - 62444 (OM&A)
 & Spacer Retrieval Tool Project 28 - 66567 (Capital)
 Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**
28-66567 Spacer Retrieval Tool Sub-Project (Capital) – Rationale of Recommendation:

All Darlington and some Pickering B replacement fuel channels are made of Inconel X-750, a material which will degrade under irradiation. In June 2009, tight-fitting spacers retrieved during a Darlington single fuel channel replacement (D3Q13) were damaged during transportation. Consequently, testing of these ex-service spacers to demonstrate on-going fitness-for-service has added challenges. To support this testing, specialized tooling that will not cause damage to the component is needed for future spacer retrieval and transportation.

The estimated total cost for the tooling development is \$3.2M. An initial release of \$0.87M was approved in 2010 and is currently being used to carry out project initiation efforts and to fund a vendor contract for the design and development of a manual-operated tool. This phase will finish at the end of 2011. A second release of \$2.2M is requested at this point to fund tool production and commissioning activities to the end of 2012. If the manual tooling is unable to deploy across the length of the channel, then an alternative new design involving automation will be developed. If this second concept is utilized, the incremental cost would be [REDACTED] (already included as a specific contingency item). Regardless of design approach, this new spacer retrieval tool will be commissioned and readied for first use in 2012. Potential increase to outage duration is estimated at 24 hours per single fuel channel replacement. This duration will be optimized during outage pre-planning. The results from testing retrieved spacers will be utilized for validating the fuel channel fitness-for-service predictive model.

\$000's (incl contingency)	Funding	Type	LTD Dec 2010	2011	2012	2013	2014	2015	Later	Total
Currently Released	Partial	OM&A	8,991	8,978						17,969
		Capital		867						867
Adjustments to Current Release	Adjustments	OM&A	(819)							(819)
		Capital								
Requested Now	Partial	OM&A		3,852	13,403					17,255
		Capital		72	2,145					2,217
Future Funding Req'd	Full	OM&A				3,332	1,861	332		5,525
		Capital				82				82
Total Project Costs		OM&A	8,172	12,830	13,403	3,332	1,861	332	-	39,930
Total Project Costs		Capital	-	939	2,145	82	-	-	-	3,166
Total Project Costs		Total	8,172	13,769	15,548	3,414	1,861	332	-	43,096
Other Costs										-
Investment Type Sustaining			Class Multi Class		NPV 2,000,000		IRR N/A		Discounted Payback N/A	

Submitted By:

(Date)

Submitted By:

(Date)

 W. Robbins
 Chief Nuclear Officer

 A. Sweetnam
 EVP, Nuclear Refurbishment Projects & Support

Financial Approval By:

(Date)

(OAR Element 1.1 Project in Budget)

Line Approval By:

(Date)

 D. Hanbidge
 SVP & Chief Financial Officer

 T. Mitchell
 President & Chief Executive Officer

**Fuel Channel Life Management Project 10 - 62444 (OM&A)
& Spacer Retrieval Tool Project 28 - 66567 (Capital)
Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**

2/ BACKGROUND & ISSUES:

The degradation mechanisms impacting pressure tube fitness-for-service described below affect all CANDU units, including Pickering A, Pickering B and Darlington units. However, they have varying degrees of impact on different stations due to station design and operating conditions.

Deuterium ingress and its impact on material properties

During hot operation, pressure tubes react with the heavy water coolant and, as a consequence of this, the concentration of hydrogen (deuterium and protium, quoted in terms of the equivalent hydrogen concentration, H_{eq}) increases over time. As well, in the pressure tube/end fitting rolled joint region, there is an additional galvanic corrosion component which makes the process in this region much more rapid. Since pressure tube material has a limited solubility of hydrogen which increases with increasing temperature, a brittle hydride phase can form - which makes fuel channel pressure tubes susceptible to an active cracking mechanism, delayed hydride cracking (DHC).

Because of the limited fracture toughness data available for high H_{eq} conditions, CSA (Canadian Standards Association) N285.8 limits the allowable H_{eq} in the main body of a pressure tube (BOT) and in the tensile portion of the rolled joint (RJ) region to 70 ppm at the inlet and 100 ppm at the outlet. These values in CSA N285.8 impose a hard limit for operation. Moreover, with limited fracture toughness data at high H_{eq} values, it is challenging to demonstrate the safe operation at H_{eq} values approaching N285.8 limits.

As a result, OPG fuel channel experts have only medium confidence (up to 70%) that the pressure tubes in Darlington will achieve the target service life of 210k EFPH or beyond. This is due to the fact that Darlington Unit 3 scrape samples in 2002 exhibited some very high uptake trends that exceeded the upper bound of the CANDU 6 model, and that Darlington pressure tubes have some of the highest initial impurity hydrogen ($H_{initial}$) values in any CANDU units. Other contributing factors include a scarcity of rolled joint H_{eq} data, a lack of scrape data from the Darlington units to support model predictions and the lack of a validated predictive rolled joint model. If the current CSA N285.8 limits are reached in Darlington earlier than 210k EFPH, then it may be necessary to advance the refurbishment schedule from the current plan of 2016. As it takes more than 5 years to properly prepare for refurbishment, the Darlington Refurbishment project, as a risk mitigation strategy, is planning to be ready to commence the refurbishment as of October 2015. It should be noted that a start earlier than October 2015 would significantly increase the risk of adequate project performance of the Refurbishment project. Additionally, there will be a significant loss in economic value if the Darlington units need to be refurbished earlier and/or if units are idled pending refurbishment. Aside from issues concerning reaching this H_{eq} limit, it should be recognized that there are little high hydrogen material property data from ex-service pressure tubes. Hence, there is insufficient data to provide the needed technical basis supporting operation of pressure tubes with H_{eq} above the current CSA N285.8 limit.

Until recently, Pickering B was not expected to exceed the CSA N285.8 limits during the pressure tube original planned life of 210k EFPH. This expectation was related to the lower operating temperatures and pressures in Pickering B. However, the hydrogen and deuterium profiles through the inlet and outlet rolled joint regions of surveillance tube P6 M14 have challenged this expectation. It appears that P6 M14 has much higher deuterium uptake in the compressive regions of the pressure tube.

In summary, the following concerns regarding deuterium ingress need to be addressed in a timely manner for OPG to make confident predictions of pressure tube life in order to optimally plan potential refurbishment activities and achieve continued operations:

- a) Pressure tube material property changes with high H_{eq} ;
- b) Kinetics of deuterium ingress (increasing H_{eq}) in the rolled joint region - to project future values and predict when fitness-for-service values will be reached; and
- c) The appropriateness of the current limits.

If it is demonstrated that there remains an adequate margin on material properties with high H_{eq} , changing the limits may be justified. Refined deuterium uptake rate prediction capability may also increase confidence that Darlington can operate to 210k EFPH or beyond and that Pickering B can operate to 240k EFPH or beyond.

**Fuel Channel Life Management Project 10 - 62444 (OM&A)
& Spacer Retrieval Tool Project 28 - 66567 (Capital)
Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**

Spacer Integrity and PT/CT Contact

Annulus spacers perform the critical function of maintaining a gap between the pressure tube and calandria tube – to assure that contact between these components cannot occur. Pressure Tube to Calandria Tube contact (PT/CT contact) led to the failure of the pressure tube in channel G16 of Pickering Unit 2 in 1983. As such, spacer integrity and the maintenance of a PT/CT gap must be demonstrated over the full operating life of the reactor.

The spacers used in Darlington are a tight-fitting design made from Inconel X-750. Removal of pressure tubes and spacers from Darlington Unit 2 Channel O18 in 2005 and from Darlington Unit 3 Q13 in 2009 has indicated that the structural integrity of this spacer design may be degrading. Although visual inspection evidence obtained during pressure tube removal indicates that the spacers were intact, after transport they arrived at testing laboratories in several pieces, which is an indication that some material properties had been degraded. Although the flasking and transportation may have led to the ultimate failure of these spacers, their degraded properties are due to operation. It is unknown at this time whether the in-service degradation in properties of spacers at Darlington has saturated or if degradation will continue. This issue is one that could result in premature shutdown of Darlington units, since failure of a spacer would lead to increased risk of PT/CT contact in the outlet region of the pressure tubes in Darlington, which could result in hydride blister formation and subsequent pressure tube rupture.

OPG technical staff and the CNSC have raised questions regarding the validity of data obtained from the damaged spacers. Testing an undamaged tight fitting spacer allows the actual properties of the irradiated spacers to be established. The next planned Darlington spacer retrieval is in the fall of 2013. However, OPG has an opportunity to obtain early X-750 material degradation data from Bruce Power spacers. Bruce B uses non-optimized Inconel X-750 spacers and may choose to conduct a single fuel channel replacement in 2012. Bruce B Unit 8 spacer properties were first examined in 1999 (82,225 EFPH), and comparing this data to the test results of Bruce B spacers retrieved in 2012 would provide OPG with the Inconel X-750 material property degradation rate.

Although the material properties of the loose-fitting Zr-Nb-Cu spacers in Pickering B are considered to be adequate for a 240k EFPH pressure tube life, the root cause investigation of the failed calandria tube in Pickering Unit 7 channel A13 revealed significant spacer wear as well as wear on the pressure tube and calandria tube surfaces. This finding calls into question whether the spacers in Pickering B are capable of maintaining an adequate PT/CT gap for a 240k EFPH pressure tube life. The root cause investigation team has produced an interim report, but additional activities are required to determine the root cause of spacer wear, the extent and severity of spacer wear in OPG reactors, and the impact of worn spacers on PT/CT contact predictions.

Currently, there is no program to periodically assess spacer integrity as they can only be examined when a fuel channel pressure tube is replaced. Moreover, spacers are not part of the normal surveillance activities associated with fuel channel replacement. Therefore, a spacer surveillance program will be developed to assure structural integrity over the full operating life of the units. Elements of this program include: a comprehensive literature survey to determine the credible degradation mechanisms and subsequent assessment methods, procedures and acceptance criteria for the results.

The CNSC has clearly indicated that actual in reactor measurements of the gap between a pressure tube and a calandria tube is required for validation of the assessment methodology. OPG has launched Project 28-66255 (Gap Measurement tooling development) to enable actual data collection. The gap data are needed to validate results of this project.

Crack Initiation

Flaws in Pickering B pressure tubes were generated during commissioning due to construction debris entrained in the Primary Heat Transport System (PHTS). These flaws can initiate cracks and lead to failure of the pressure tube. The risk level depends on the type, size, and location of a flaw. The mechanisms which may allow initiation of a crack from an existing flaw include delayed hydride cracking (DHC), transient stresses (overload), and fatigue. The CSA standard N285.4 and N285.8 specifies acceptance criteria of flaws.

Flaws that fail to satisfy the acceptance criteria provided in CSA N285.4 must be evaluated for acceptability and the condition must be dispositioned with the regulator. CSA N285.8 provides the recognized and accepted means of assessing flaws. One requirement is to demonstrate that crack initiation will not occur from DHC, fatigue and hydrided region overload. Pickering B currently has a number of flaws where crack initiation criteria are not satisfied. This has resulted in the imposition of limits on the number of heat up/cool down cycles on operation and a requirement for re-inspection to

**Fuel Channel Life Management Project 10 - 62444 (OM&A)
& Spacer Retrieval Tool Project 28 - 66567 (Capital)
Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**

assure that there has been no crack initiation and propagation. Although crack initiation has never been observed, these flaws continue to be monitored with a decreasing number of available cycles due to increasing deuterium concentration in the pressure tubes. Procedures currently used to assess flaws carry a significant degree of conservatism which is becoming increasingly limiting.

Test programs are underway to address the conservatism in modeling flaw behavior involving the use of more realistic flaw geometries, H_{eq} and sample conditioning. Initial results have shown much greater resistance to crack initiation in pressure tubes using these conditions than the assumptions used in the original model. However, test programs are proceeding at a pace that would not produce the desired results by 2012 as required by OPG to better plan possible refurbishment activities.

A recent attempt to modify the evaluation procedure for fatigue crack initiation was not accepted by the CNSC based on limited data to support the proposed changes. Following this, an 'interim approach' was adopted with a commitment to produce more data in the next few years to support the original request. This would include work to capture any environmental (reactor water) effects.

Additional testing to support changes to all crack initiation mechanism evaluation procedures would increase the acceptable flaw size envelope (especially for Pickering B) by showing that pressure tubes currently in service have a higher resistance to crack initiation than they are currently given credit for in assessments.

Probabilistic Core Assessments and Leak-Before-Break

CSA N285.8 requires that probabilistic core assessments be conducted to demonstrate that the probability of pressure tube rupture remains acceptably low, and that leak-before-break capability remains.

In addition to evaluating flaws found during inspections, the condition and acceptability of the pressure tubes in the reactor core as a whole must be evaluated using a Probabilistic Core Assessment (PCA). Among other input information, data from crack initiation experiments and the subsequent evaluation methodologies in the PCAs which impact on the probability of pressure tube rupture are to be evaluated against an acceptance criterion. The current state-of-the-art understanding of crack initiation is not captured in the current PCA code and, for this reason, the results are considered to be conservative. As well, the tool is not qualified to the industry standard of CSA N286.7. This exposes OPG to some regulatory risk.

Leak-before-break refers to the scenario where a postulated through-wall crack in a pressure tube results in a leak into the Annulus Gas System which is detected and subsequent operator actions are taken to place the reactor in the cold and depressurized safe state prior to reaching the extent of crack propagation when a pressure tube would fail catastrophically. Assurance of this capability is becoming increasingly difficult as the pressure tube properties degrade with time, and a change in methodology and/or input parameters can have a significant impact on the margin.

Regulatory Engagement

To facilitate the upcoming license renewal activities, a protocol was signed between OPG (in partnership with Bruce Power) and the CNSC in February 2011 (N-CORR-00531-05133). The CNSC and the FCLM project have agreed to two critical issues ("Propositions"), for which OPG requires a positive response from the Regulator by the end of 2012 to facilitate license renewal for Pickering and Darlington sites. License renewal is the first critical step to allow continued operation of Pickering B and to provide schedule flexibility for the Darlington Refurbishment Project. These Propositions are as follows:

1. Establish a fracture toughness model of upper/transition/lower shelf behaviour for $H_{eq} > 100$ ppm.
2. Demonstrate that PT/CT gap is maintained to 2014 for each station

The CNSC Protocol specifies eighteen documents to be submitted by the FCLM project to the Regulator. Acceptance of these submissions will support the resolution of the two Propositions listed above. Additionally, the FCLM project is providing regular updates to the CNSC regarding technical issues.

The CNSC recognizes that OPG has adequate capabilities in the Crack Initiation Assessment and Probabilistic Core Assessment areas at present and hence did not include these issues in the Protocol. The CNSC also indicated that they will not have the resources before 2012 to review submissions on these two areas. However, the FCLM project anticipates that the improved methodologies for Crack Initiation Assessment and Probabilistic Core Assessment will be required

**Fuel Channel Life Management Project 10 - 62444 (OM&A)
& Spacer Retrieval Tool Project 28 - 66567 (Capital)
Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**

toward the end of planned operations. Hence, it is proposed that the FCLM project timeline be extended to allow the project staff to submit the technical basis for these improved methodologies starting in 2013.

While the CNSC Protocol addresses the license renewal process, the application of new methodologies must follow the established Regulator process. Thus, starting in 2013, submissions to the CNSC for application of new methodologies at specific sites must be done to ensure these approaches can be used in the later years of planned continued operations.

Oversight of Supporting Activities

In early 2011, OPG Internal Audit made recommendations to FCLM project to include or strengthen the following activities to ensure success of Continued Operations at Pickering B and the Refurbishment Project at Darlington:

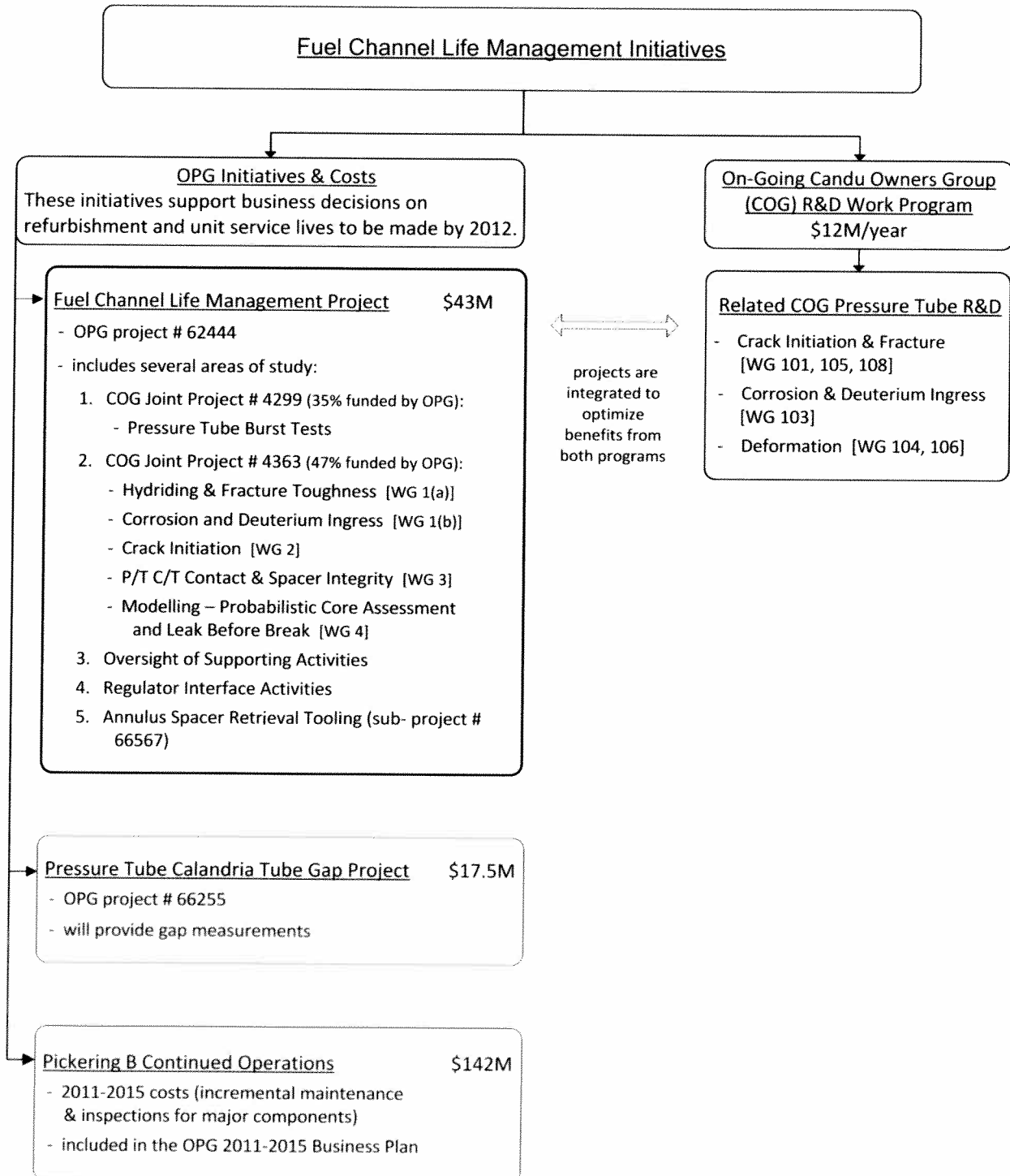
1. Finalize the Regulatory Strategy
2. Identify risks of the supporting activities and oversee management of these risk items
3. Identify and oversee critical OPG supporting activities and ensure that controls are established to effectively manage the interdependencies
4. Develop a standard suite of project reports to ensure alignment of all business units and up to date briefing of senior management
5. Appoint a senior manager to oversee the "broader picture"

Corrective action plans were developed and accepted by Internal Audit. All corrective actions were completed by May 2011, and the audit has since been closed. However, the implementation of the plan has added scope to the FCLMP for the duration of the project. This additional scope includes the following on-going activities:

1. Development and maintenance of a project risk management plan (N-PLAN-31100-10007) and risk register
2. Engagement of OPG stakeholders
3. Engagement of CNSC – technical and licensing personnel
4. Communication of project and/or activity progress between supporting departments and the FCLM project
5. Integration of R&D results into long term strategic planning to support Pickering Continued Operations and Darlington Refurbishment

**Fuel Channel Life Management Project 10 - 62444 (OM&A)
 & Spacer Retrieval Tool Project 28 - 66567 (Capital)
 Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**

OPG's Fuel Channel Life Management Initiatives can be summarized by the following figure:



ONTARIOPOWER GENERATION	OPG Confidential	Page: 14 of 30
	Business Case Summary	
Fuel Channel Life Management Project 10 - 62444 (OM&A) & Spacer Retrieval Tool Project 28 - 66567 (Capital) Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000		

3/ ALTERNATIVES & ECONOMIC ANALYSIS:

Major Assumptions	Base Case	Alternative 1 (Recommended)
FCLM Project costs (includes spacer retrieval program)	None	\$43.1M
PT/CT Gap Measurement Project costs	None	\$17.5M
Pickering B Continued Operations Project costs	None	\$142M
Pickering A Unit End of Life (EOL) Date	Shutdown with 2 nd last PB unit	Shutdown with 2 nd last PB unit
Pickering B Unit EOL Date	210k EFPH assumed (2014–2016); P7 life managed	240k EFPH assumed (2018–2020; P7 life managed
Darlington Unit EOL Date before refurbishment: unit EOL date based on 92% capacity factor	187k EFPH assumed or Refurb Outage Start Date if earlier	210k EFPH assumed or Refurb Outage Start Date if earlier
Darlington Refurbishment Outage Schedule with 36 month unit outages and 16/19 month overlaps	First unit outage begins Oct 2015	First unit outage begins Oct 2016
Station Operating Costs	Based on 2011–2015 Business Plan and extrapolated	Based on 2011–2015 Business Plan and extrapolated

Base Case: × *Not Recommended* - **Continue with current COG R&D program to support Fuel Channel FFS (Do nothing)**

At the pace with which fuel channel R&D was proceeding under COG, the results of testing and associated analyses would be not be completed in time to demonstrate high confidence (>70%) in fitness-for-service beyond 210k EFPH for Darlington and beyond 240k EFPH for Pickering B by 2012. This could result in Darlington units reaching their end-of-life as early as 187k EFPH with the refurbishment advanced from 2016 to 2015 with a substantial increase of refurbishment project risks and a substantial reduction in economic value due to shorter life and/or idle time pending refurbishment. For Pickering B, support for the technical basis for operation of fuel channel components to 240k EFPH will likely not have the required confidence by 2012 if the work were not accelerated.

Alternative 1: ✓ *Recommended* - **Prioritize R&D and provide oversight to supporting activities**

Completing the key R&D activities, as specified and committed to in the CNSC Protocol, in conjunction with executing planned inspections and maintenance under OPG's fuel channel inspection program before the end of 2012 will help demonstrate whether there is high confidence (>70%) that Darlington units can operate to 210k EFPH or beyond and Pickering B can operate to 240k EFPH or beyond.

It is anticipated that a significantly reduced but continued effort will be required in 2013 and beyond to complete non-critical and discovery R&D work. Support for regulatory interface activities, including license renewal and delivery of outstanding CNSC commitments, will be provided to the end of 2014. Oversight of supporting activities, including the integration of R&D results into Life Cycle Management Plans, will be provided by FCLMP to mid-2015. Completion of the proposed work will allow refurbishment activities to be planned effectively at Darlington. The operation of Pickering B to 2020 would realize greater economic value from these units.

Business Case Summary

**Fuel Channel Life Management Project 10 - 62444 (OM&A)
& Spacer Retrieval Tool Project 28 - 66567 (Capital)
Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**

Alternative 2: ** Not Recommended* - Conduct a portion of the work proposed (Do Less)

This alternative is a reduction in scope over the recommended Alternative 1. R&D work that is not committed to in the CNSC Protocol would be removed from the scope. However, the capability to provide a high confidence statement by the end of 2012 would be impaired. In addition, methodologies required to validate fitness for service in later years would not be available.

This alternative is not recommended based on the need to support high confidence (>70%) projections of operating Darlington units to 210k EFPH or beyond (from 187k EFPH) and Pickering B units to 240k EFPH or beyond (from 210k EFPH). OPG will not be able to make a business decision on continued operations based on critical technical information.

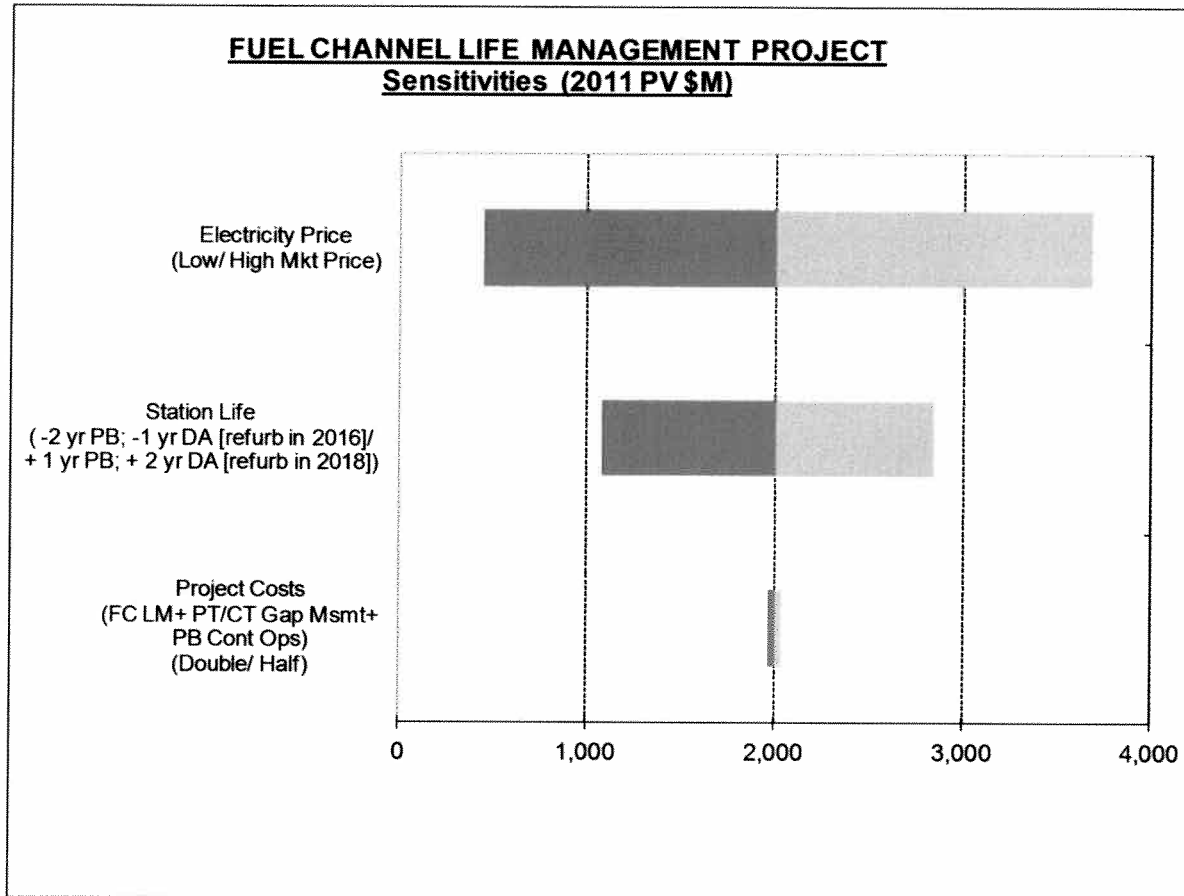
Alternative 3: ** Not Recommended* - Request Regulatory Relief on Life Limiting Issues

In the area of pressure tube fitness-for-service, several submissions to revise the fitness-for-service methodologies (or inputs to these methodologies) have not been completely accepted by the regulator and 'interim approaches' have been utilized which include commitments to conduct additional work to justify the original submissions. By requesting relief in areas where commitments have been given (including some cases with formal plans) to justify previous submissions, the regulator may lose confidence in OPG since the regulator may already consider the 'interim approaches' to be a form of relief. Moreover, technical experts in the industry share most of the concerns of the regulator, and it would be prudent to get the appropriate answers rather than requesting relief.

**Fuel Channel Life Management Project 10 - 62444 (OM&A)
& Spacer Retrieval Tool Project 28 - 66567 (Capital)
Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**

Economic Analysis

Alternatives 2 and 3 were not analyzed economically as they are not considered to be feasible in achieving the desired objectives. The value to the provincial electricity customers of Alternative 1 compared to the Base Case is estimated at \$2 Billion. The following graph shows the key sensitivities of the results.



Results of the economic assessment were tested for sensitivity to key inputs such as assumed electricity price, length of additional station life achieved, and project costs, and indicate the following:

- i. **Assumed Electricity Price:** The value is extremely sensitive to the assumed electricity price. In a high price regime, the value would be approximately \$3.7 Billion and in a low price regime, the value would be approximately \$0.45 Billion. A low price regime would result from low electricity demand and low gas prices (such as during a prolonged economic slowdown) and/or high conservation.
- ii. **Length of Additional Station Life Achieved:** The value is sensitive to the station life that can be achieved with high confidence. If Pickering B units achieve only 225k EFPH and Darlington units achieve only 202k EFPH with Darlington refurbishment starting in 2016, then the value would be \$1.1 Billion. If the Pickering B units achieve 248k EFPH and the Darlington units achieve 225k EFPH with Darlington refurbishment starting in 2018, then the value would be \$2.8 Billion.
- iii. **Project Costs:** The value is insensitive to project costs. Project costs include the costs of the integrated fuel channel life management project, the PT/CT gap measurement project and the Pickering B Continued Operations costs. The sensitivity analysis shows that a doubling of these costs has a minimal impact on the expected PV.

Business Case Summary

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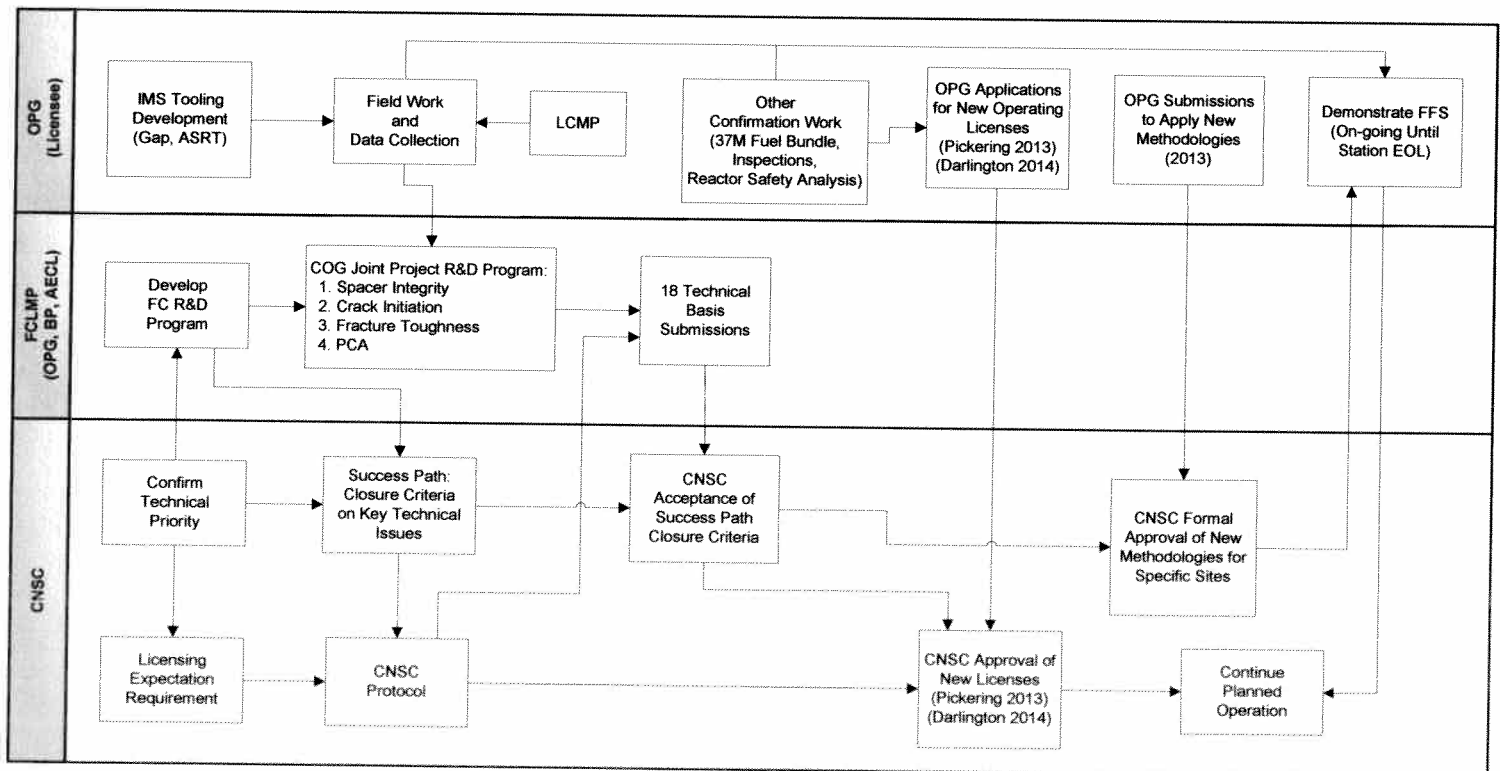
4/ THE PROPOSAL

Overall Approach

It is proposed that funding be made available to continue to execute a fuel channel life management project. This project will be characterized primarily by an accelerated research program, to be substantially completed by end of 2012, which allows integration of information from existing programs (COG R&D programs and OPG fuel channel inspection programs) to formulate a new technical basis and refined methodologies to allow justification of continued operations. By this approach, the refined methodologies and new acceptance criteria will be incorporated into current inspection techniques to support the confirmation of extended fuel channel life predictions. The development of specialized tooling (Gap Measurement and Spacer Retrieval) is required to enable the collection of data mandated under the inspection program as input or validation data for the new technical basis and methodologies.

The research program deliverables are guided by the CNSC Protocol. Expectations for each R&D activity will be measured against defined closure criteria, which have been identified and agreed to by OPG and the CNSC. Additional research work will be conducted in order to support the update of the fuel channel fitness-for-service assessment model and methodologies. Formal submissions will be made to the CNSC to request regulatory acceptance to apply the new technical basis and to use the refined methodologies and new acceptance criteria.

The relationships of the programs/project mentioned are shown in the diagram below.



**Fuel Channel Life Management Project 10 - 62444 (OM&A)
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Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**

Project Objectives and Scope

The objectives of this project are listed below. The original project objective, as described in the previous BCS Partial Release, has been expanded in order to satisfy the recommendations of Internal Audit.

1. Provide a high confidence statement of the targeted service life of Pickering and Darlington fuel channels to the Board of Directors by the end of 2012.
2. Complete and submit to the CNSC the R&D deliverables that are critical to CNSC's licensing decisions for Pickering and Darlington stations by December 2012.
3. Manage post R&D activities for transition into the base organization.

To accomplish these objectives, the project scope includes the activities listed below. Additional scope has been added to this release to satisfy the recommendations of Internal Audit and is denoted by an asterisk (*).

1. Monitor and control project cost and schedule
2. Liaise between COG project manager and OPG management on technical progress and risk management
3. Maintain continuous engagement with the CNSC
4. Support license renewal process at Pickering B and Darlington
5. * Execute the project risk management plan, including risk monitoring and performing risk mitigation actions
6. * Provide oversight to the development of the Annulus Spacer Retrieval Tooling (ASRT)
7. * Support the integration of new technical basis and refined methodologies into LCMPs

The project will be executed in three major phases, which are outlined as follows:

- **Phase 1 (Sept 2009 – Dec 2010): R&D Definition and CNSC Engagement (*Completed*)**

The initial scope of R&D work was identified and refined through early engagement with the Regulator. The CNSC Protocol, which specifies the critical R&D scope that must be accomplished by December 2012, was agreed to and signed by OPG and the CNSC in February 2011.

- **Phase 2 (Jan 2011 – Dec 2012): R&D Execution and Meeting CNSC Requirements to Confirm FC FFS**

Execution of R&D scope is in progress and the project is currently providing oversight to the development of the ASRT. The closure criteria for critical R&D activities have been agreed to by the CNSC and OPG. The project will deliver R&D submissions to the Regulator according to the CNSC Protocol and a high confidence statement to the OPG Board of Directors on pressure tube end-of-life for both Darlington and Pickering by December 2012. The project will begin to prepare specific license submissions to support Pickering B continued operations in 2012.

- **Phase 3 (Jan 2013 – Jun 2015): Integration of R&D to Support License Renewals**

All R&D results will be integrated into Life Cycle Management Plans (LCMPs) in order to confirm fuel channel Fitness for Service (FFS). Specific license submissions will be prepared ahead of Pickering B license renewal in July 2013, and a long term spacer management plan will be developed ahead of the Darlington license renewal in 2015. The planned completion date of the project is June 30, 2015. Continuous engagement of the CNSC and stakeholders will be maintained throughout this stage.

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Partial Release Business Case Summary N - BCS - 31100 - 10006 - R000**

Technical Program Plans

The following work includes the total current project work scope to be conducted between 2011 and 2012 as a joint project between OPG and industry partners. The first two areas of work (Deuterium Ingress and its Impact on Material Properties & Spacer Integrity and PT/CT Contact) have been identified as critical by the CNSC in the Protocol.

Deuterium Ingress and its Impact on Material Properties (Critical R&D)

Two methods of adding hydrogen (called "hydriding") to irradiated pressure tubes in a manner that does not affect existing irradiation damage are currently being tested. In September 2011, one method will be selected to produce hydrided pressure tube samples which will be tested to determine fracture toughness at proposed end-of-life conditions. These tests will be conducted as proposed in the COG Joint Project 4299. Information from full scale tests will be integrated with data from the standardized small sample tests to produce engineering fracture curves.

Other activities to support deuterium ingress projections will be conducted including: developing detailed requirements for rolled joint H_{eq} model to ensure that the modification of current code addresses concerns over the lack of predictability; updating the body-of-tube deuterium ingress model to improve the accuracy of long term predictions; and using existing and new data/models to calculate the time to reach specified H_{eq} values for all units.

Spacer Integrity and PT/CT Contact (Critical R&D)

The properties of tight fitting spacers used in Darlington fuel channels and Pickering replacement fuel channels (made of Inconel X-750), may degrade under a radiation field. The irradiated properties need to be established from retrieved spacers that did not suffer from damage in the retrieval process or the subsequent transportation. Testing of broken spacer casts doubt on whether the actual properties have been captured and the CNSC has raised similar questions. It is critical to have confidence that these spacers will carry out their designed functions for their target service life. As such, this work has been identified by the CNSC as critical R&D which must be completed by December 2012. Development of tooling capable of retrieving spacers without inducing any damage is an important step to establish spacer properties for continued operations at Darlington.

To address concerns over tight-fitting spacer integrity, the major scope of work includes: determination of the mechanism of degradation of Inconel X-750 spacer material, development of a comprehensive program of condition monitoring, including evaluation methods and acceptance criteria for examination of ex-service spacers, and pursuing the implementation of PT-CT gap measurements to assure spacer integrity and capability to maintain an appropriate gap. A literature review to identify the knowledge has been a key input to the work program just described. Also, the feasibility of an experimental program to irradiate Inconel X-750 to determine the rate of degradation in early life for extrapolation and projection to late life operation is being undertaken.

To address the concerns over loose-fitting spacer wear, the major scope of work includes: completing the actions identified by the root cause investigation for P7A13 calandria tube leak, determination of the impact of spacer wear on PT-CT predictions, and examination of other available ex-service spacers to determine the possible extent of spacer wear in OPG reactors.

The key deliverable from this work program is to provide assessment on spacer integrity and mobility, and to identify spacer surveillance requirements. Also, the predictive capabilities for PT/CT contact will be assessed, and upgraded by comparing gap predictions from contact models with PT/CT gap measurements obtained from reactors.

Crack initiation

Tests using more realistic sample geometries and conditioning cycles will be conducted to quantify increased crack initiation resistance. This will allow most known flaws in Pickering pressure tubes to pass fitness-for-service evaluations in the future as well as support Probabilistic Core Assessments.

The work includes: quantifying the positive benefit of reduced pressure shut down on crack initiation, increasing the variability and H_{eq} validity range on the non-ratcheting factor, and crediting the benefits of finite length flaws and angled volumetric flaws. Preliminary assessments of this type of work has indicated that pressure tubes are more resistant to crack initiation than current methodologies credit and, with the data to be acquired from these tests, the technical basis to modify fitness-for-service methodologies can be achieved.