# UNIT 2 PERFORMANCE

## 1.0 OVERVIEW

This exhibit provides an update on the refurbishment of Darlington Unit 2, with a focus on OPG's cost and schedule performance. It concludes by discussing OPG's proposed treatment of the IR term rate base as it relates to the variance against the EB-2016-0152 approved in-service additions for the Darlington Refurbishment Program ("Program" or "DRP") and associated balances in the Capacity Refurbishment Variance Account ("CRVA"). As noted in Ex. D2-2-1 and further explained in this exhibit, in this application, OPG is not seeking inclusion of variances against the EB-2016-0152 approved DRP-related in-service additions in rate base and is also not seeking recovery of the related CRVA balances accumulated to date.[1]

OPG started the refurbishment of Unit 2 as planned on October 15, 2016 and returned Unit 2 to service on June 4, 2020, just over three months later than its committed schedule. Of note, the final two-and-a-half months of the Unit 2 refurbishment outage were completed under the state of emergency declared in Ontario on March 17, 2020 as a result of the COVID-19 pandemic. OPG captured thousands of Lessons Learned[2] during the course of the Unit 2 refurbishment. These Lessons Learned as well as a number of Strategic Improvements[3] have been incorporated into the planning and execution of the refurbishments of Units 3, 1, and 4 (the "Remaining Units"), and are expected to result in unit-over-unit cost and schedule duration improvements.[4]

---

[1] Other than the D2O Storage Project (Ex. D2-2-10) and the impacts of capital cost allowance deductions arising from changes in income tax legislation since EB-2016-0152 (Ex. F4-2-1). OPG also did not seek recovery of DRP-related CRVA balances in its EB-2018-0243 application for disposition of deferral and variance account balances, meaning that none of DRP-related CRVA balances accumulated since January 1, 2016 have been sought for clearance to date.

[2] "Lessons Learned" refers to specific and detailed knowledge and experience gained during a process, project or activity which, when applied to the same or similar processes, projects or activities in the future, results in improved performance.

[3] "Strategic Improvements" are new approaches and/or innovative methods for planning and executing the Remaining Units' refurbishments that are being implemented in addition to Lessons Learned.

[4] Ex. D2-2-3 (Remaining Units Planning), Sections 4 and 5, for a detailed discussion of the Lessons Learned program and Strategic Improvements.

Relative to the OEB approved amounts in EB-2016-0152 of $5,177.4M for the refurbishment of Unit 2 (including the Definition Phase), Early-In-Service projects, Facilities and Infrastructure Projects ("F&IP") and Safety Improvement Opportunities ("SIO"),[5] there is a forecast variance of $132.7M or 2.5%. See Section 5.0 for further discussion of variances against the amounts approved for Unit 2 and for the Early-In-Service projects, F&IP and SIO.

Compared to the Unit 2 Execution Estimate ("U2EE"), which is discussed below, the refurbishment of Unit 2 itself was completed on budget at $3,417M.[6]

## 2.0 UNIT 2 EXECUTION ESTIMATE

Cost estimating is a process that is repeated and refined at different stages of a program or project, particularly as a project progresses through its project life-cycle. With each iteration a cost estimate is expected to become more accurate. The OEB approved OPG's revenue requirement in EB-2016-0152 based on the RQE for the Program, which was approved by the OPG Board of Directors in November 2015 and reflected in OPG's evidence submitted in the application.[7] Two months prior to the start of the refurbishment of Unit 2, as planned, OPG completed the "final check" of the forecast cost and schedule for the refurbishment of Unit 2, which resulted in the U2EE.[8] The U2EE was approved by the OPG Board of Directors in August 2016 and established the Unit 2 project baselines for cost and schedule monitoring. Therefore, OPG tracked its Program performance through the execution of the Unit 2 refurbishment both internally and to the public against the U2EE.

---

[5] Early-In-Service projects are those that provide benefit to the station prior to the return-to-service date of the nuclear unit under refurbishment. Examples include in-plant modifications which are of immediate benefit to multiple or all units.
F&IP are projects that do not involve the refurbishment of units but which are necessary to enable execution of the unit refurbishments and are expected to be useful to OPG's current and future nuclear operations independent of the DRP. A number of the F&IP involve upgrades to Darlington site infrastructure to ensure it can effectively support continued operations for 30 or more years. To meet required in-service dates, OPG commenced the F&IP work early in the Definition Phase of the Program.
SIO are initiatives which OPG committed to in the Environmental Assessment ("EA") for the DRP, primarily to address beyond-design-basis or four-unit events. The need for this work was established through the EA, which was filed with the Canadian Nuclear Safety Commission ("CNSC"). To meet required in-service dates, OPG commenced execution of SIO work early in the Definition Phase of the Program.

[6] Of the $3,417M final cost of Unit 2, $3,340.5M represents the capital in-service amount.

[7] EB-2016-0152, Ex. D2-2-8, Section 1 and Attachment 1.

[8] EB-2016-0152, L-04.3-1 Staff-055.

Compared to the RQE, the U2EE was a more highly developed estimate in the following ways:

1. A larger percentage of the U2EE was at Class II or Class III compared to the RQE.
2. Base cost estimates had been updated to reflect the further development of comprehensive work packages, which led to an enhanced understanding of the effort and cost to execute the work and updates to contingency and residual risks.
3. The overall schedule to execute Unit 2 had been revisited, including the elimination of a planned two-month overlap with Unit 3, which was the plan at the time of the RQE.[9]
4. Cash flows, interest and escalation had all been updated.
5. Regulatory certainty had been achieved and regulatory hold points during execution agreed to with the Canadian Nuclear Safety Commission ("CNSC").
6. OPG's role as General Contractor had been reviewed and adjustments were made to the size of OPG functions (i.e., OPG's Program Management and Execution Management and Support organizations) based on Lessons Learned from the prerequisite projects.

Excluding the Definition Phase, the U2EE estimate to complete the refurbishment of Unit 2 itself was $3,417M. The High Confidence Schedule duration for Unit 2 remained at 40 months, as it was in the RQE. The U2EE also continued to forecast total Program costs at $12.8B and total Program duration at 112 months, as was the case in the RQE.

OPG's cost performance relative to the OEB approved amounts, which were based on the RQE, and also relative to the U2EE is further discussed in Section 5.0.

## 3.0 QUALITY PERFORMANCE

The refurbishment of a nuclear unit requires a constant focus on the quality of the construction to meet or exceed all required specifications. The refurbishment of Unit 2 involved many thousands of removal and installation activities, which required a high degree of precision. Completion of work on Unit 2 required co-ordination, and detailed scheduling of,

[9] Per the Long Term Energy Plan, the Province of Ontario required demonstrated success on the first unit prior to commencing the Remaining Units' refurbishments.

the activities of multiple trades, e.g., boilermakers, welders, millwrights, pipefitters, carpenters, electricians, painters, field engineers and radiation protection technologists in concert with the activities of OPG operations and maintenance staff.

OPG's Quality Management program monitored quality issues and OPG worked collaboratively with its contractors to resolve all quality events and to ensure mitigation measures were implemented to prevent recurrence. As a result, the quality of the work completed on Unit 2 was excellent.

## 4.0 SCHEDULE PERFORMANCE

As discussed in Ex. D2-2-5, and extensively in EB-2016-0152, OPG measures progress against two schedules:

1. A Working Schedule; and
2. A High Confidence Schedule.

The difference between these two schedules is that the High Confidence Schedule includes contingency durations based on detailed analyses of risks. These contingency amounts are expected to be utilized over the course of the Program. Thus, the High Confidence Schedule is the basis of OPG's public commitments and the approvals sought from the OEB. The Working Schedule is used to calculate performance metrics, e.g., Schedule Performance Index ("SPI"), and manage day-to-day activities, allowing for early escalation of issues. The use of a Working Schedule and a High Confidence Schedule is an industry leading best practice for large and complex projects.[10]

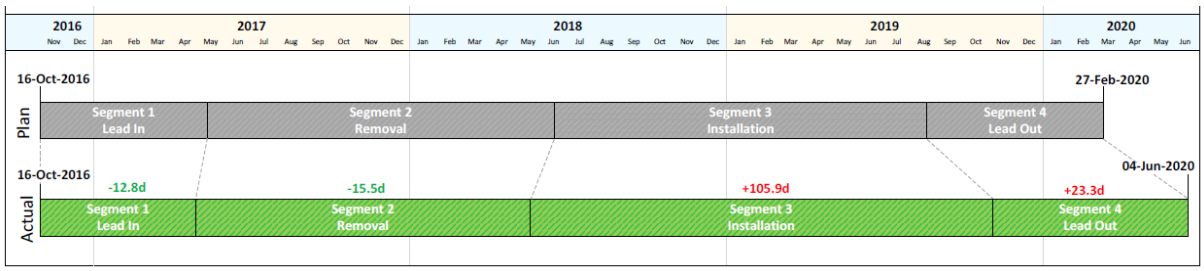
OPG commenced the Unit 2 refurbishment outage on October 15, 2016. At the time of the RQE, OPG had developed both a Working Schedule and a High Confidence Schedule for the Unit 2 refurbishment outage. Following the RQE, these schedules were refined over the next 10 months as the U2EE was completed. OPG then used the U2EE Working Schedule to

[10] This strategy provides an early indication of potential risks or issues and allows OPG to proactively manage Program performance.

drive the work on Unit 2 to completion. OPG monitored progress against both the U2EE Working and the High Confidence Schedules.

The refurbishment outage of Unit 2 was completed in four major segments. Figure 1 shows a comparison of the actual execution performance versus planned performance (per the U2EE High Confidence Schedule) for each segment.

**Figure 1: Comparison of Actual versus Planned Performance on Critical Path**




In the first segment, the unit is de-fuelled and physically isolated from the three operating units; this segment was completed in 12.8 fewer days than planned in the High Confidence Schedule.

In the second segment, the reactor is disassembled and existing reactor components removed; this segment was completed in 15.5 fewer days than planned in the High Confidence Schedule.

OPG began the third segment ahead of the High Confidence Schedule by approximately 28 days. The third segment involves the installation and reassembly of reactor components, and includes the installation of feeder pipes. This segment was completed in 105.9 more days than the planned duration. Thus, at completion of this segment, the U2 refurbishment outage was 78 days behind the High Confidence Schedule. Challenges experienced with the procurement and installation of feeder pipes affected the refurbishment schedule. Additional discussion of feeder pipe procurement and installation is provided in Section 4.1. In August 2019, the Working Schedule and High Confidence Schedule return-to-service dates for Unit 2 were reforecast to May 20, 2020 and June 25, 2020, respectively.

The fourth major segment of the Unit 2 refurbishment outage, which involved the loading of new fuel, removal of isolation from the other units, completion of the return to service of all systems and the restarting of Unit 2, was completed in 23.3 more days than the planned duration in the High Confidence Schedule. The refurbishment of Unit 2 was completed on June 4, 2020, with the declaration that the unit had returned to commercial service. This date was just over three months behind the U2EE High Confidence Schedule, and three weeks ahead of the date projected in the August 2019 re-forecast the High Confidence Schedule. Overall, the Unit 2 refurbishment outage was completed within 8% of the U2EE High Confidence Schedule.

As discussed in greater detail in Section 4.1 below, feeder pipes are installed in three sequential work programs, upper feeder pipe installation, followed by middle feeder pipe installation, followed by lower feeder pipe installation. The design of a CANDU nuclear unit means that only lower feeder pipe installation must be planned as a critical path activity, although installation of lower feeder pipes can be impacted by delays in installation of upper and middle feeder pipes. Analysis of the Unit 2 schedule performance shows that without the challenges experienced on lower feeder pipe installation, the Unit 2 refurbishment outage would have been completed on schedule.

Given the impact of the lower feeder pipe installation work on the Unit 2 schedule and the importance of improving performance on this work for the Remaining Units, the following sections provide an explanation of the function of feeder pipes, the procurement and installation process for these components, and briefly summarizes key Lessons Learned and Strategic Improvements that will be implemented for the procurement and installation of feeder pipes on the Remaining Units. Attachment 6 of Ex. D2-2-3 provides more details on the specific actions and Lesson Learned, which have been implemented to provide confidence that the procurement and installation of feeders will go according to plan for the Remaining Units.

## 4.1 Unit 2 Feeders – Function, Procurement and Installation

### 4.1.1 The Function of Feeder Pipes

Feeder pipes are a part of the heat transport system of a CANDU nuclear reactor. The feeder pipes transport heated heavy water from the fuel channels in the reactor to the steam generators, where steam is produced to turn the turbine-generator set. After passing through the steam generators, the heat transport heavy water is recirculated back to the fuel channels in the reactor to start the cycle all over again. Figure 2 shows a simplified schematic of the heat transport system in a Darlington unit.

**Figure 2: Simplified Schematic of the Heat Transport System of a Darlington Unit**

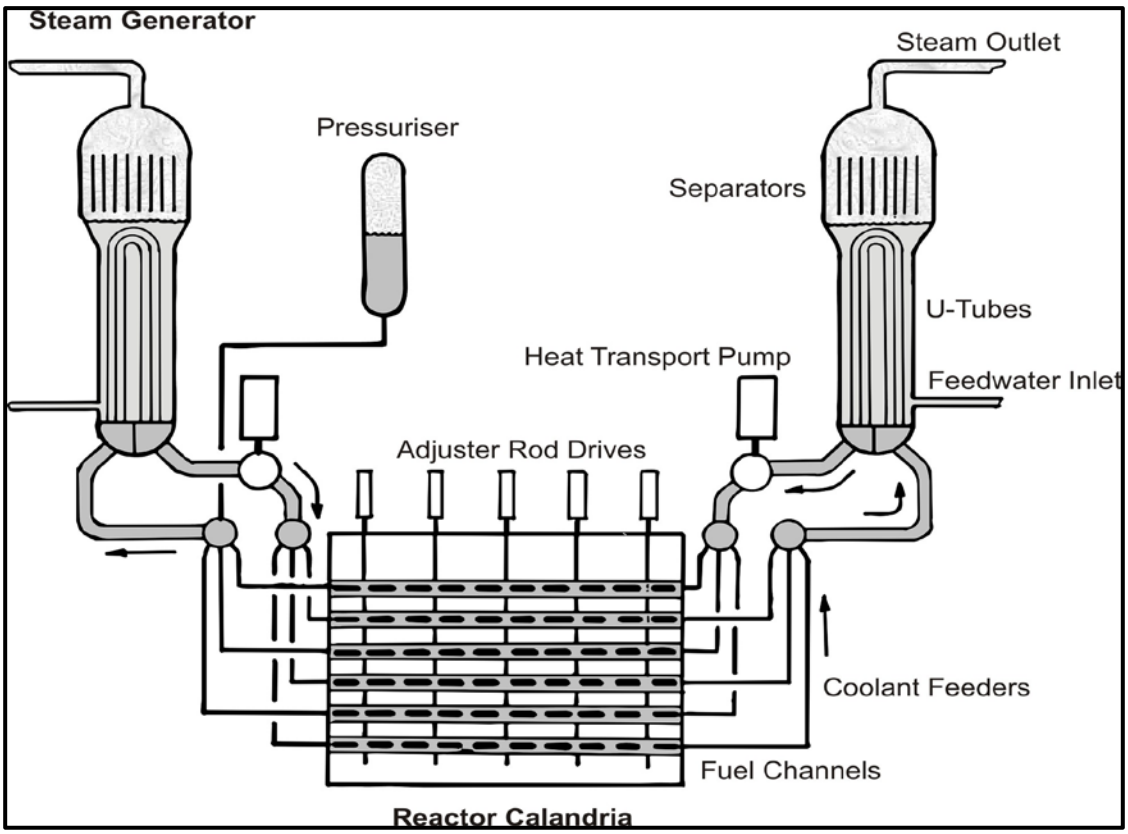
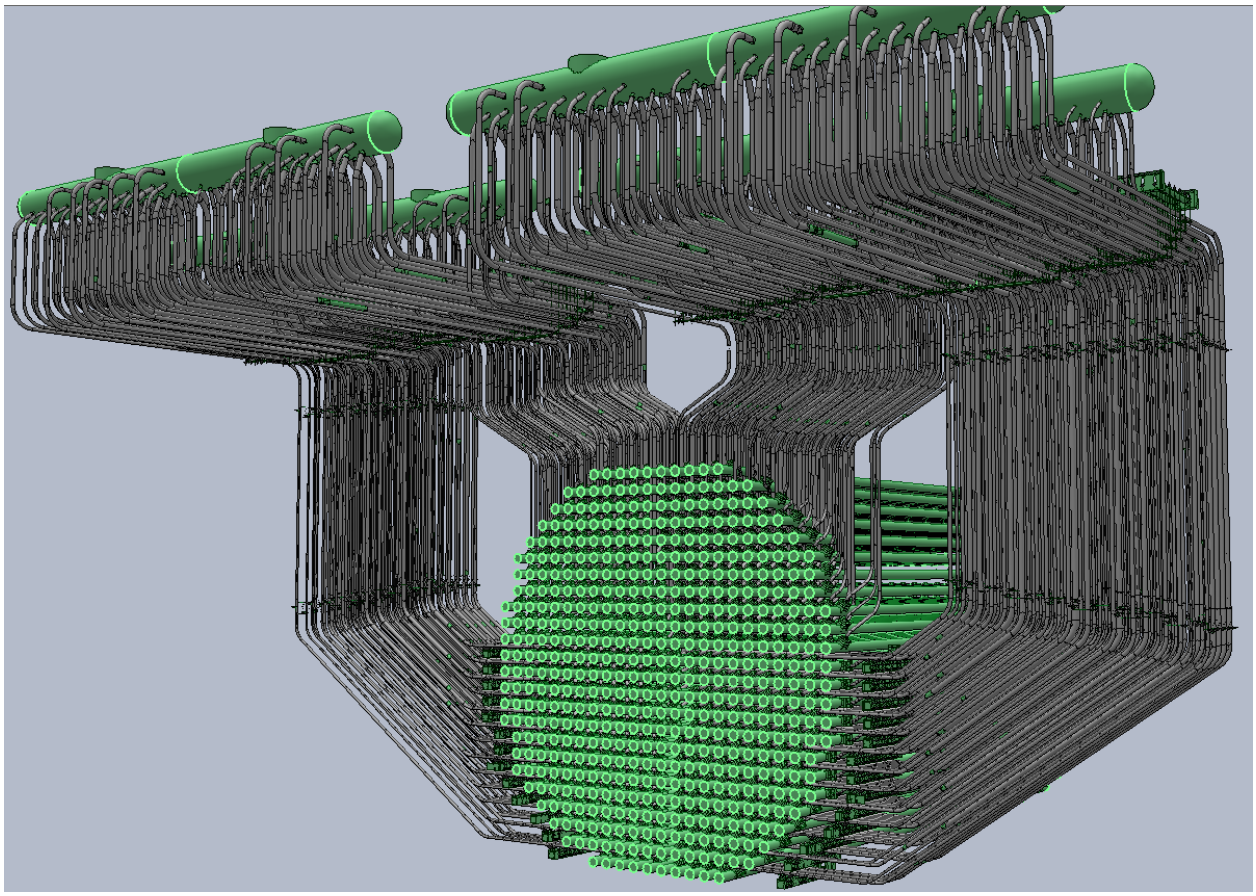



Figure 3 below is an illustration of a Darlington nuclear reactor showing the organization of the feeder pipes. Each Darlington nuclear unit has 960 feeder pipes (480 inlet pipes and 480 outlet pipes) connected to the inlet and outlet ends of each of the 480 fuel channels in the reactor and to the inlet and outlet feeder headers.

**Figure 3:**

**Darlington Reactor Showing Feeder Pipes and Feeder Inlet and Outlet Headers**



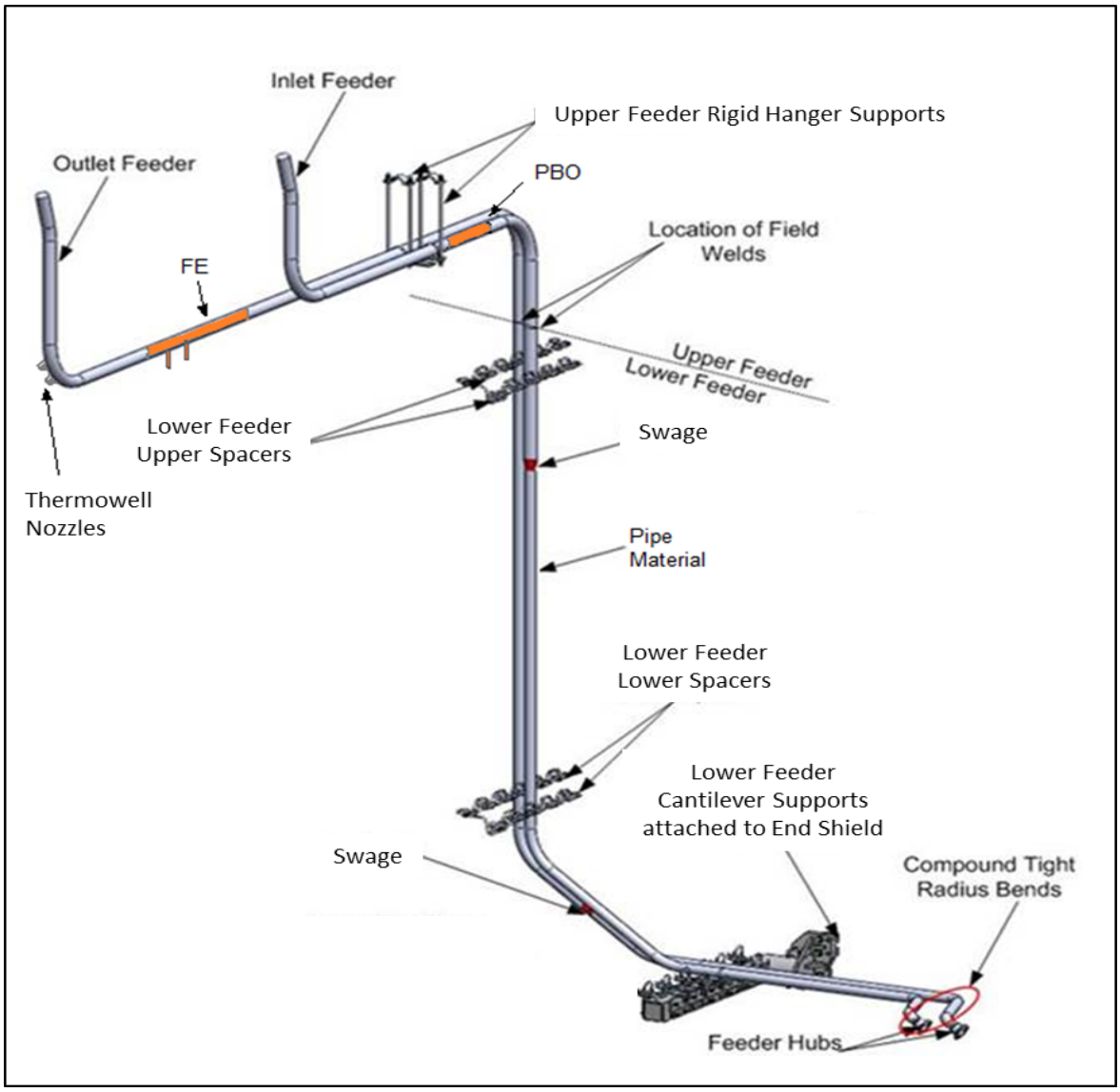
4.1.2 Feeder Pipe Procurement

Feeder pipes are fabricated off-site under strict quality requirements, then delivered to a warehouse facility where the quality documentation is verified and final preparation and quality checks are performed, before being shipped, in the required sequence, to the Darlington site for installation.

As can be seen from Figure 4, each individual run of feeder piping has its unique geometric shape to connect from the feeder headers to the fuel channels. In addition, each feeder pipe is fabricated from a number of components, including: straight pipe runs; angled sections to meet the geometric shape required to permit connection to the feeder headers and the fuel channels; and elements to facilitate the measurement of flow, temperature and pressure.

**Figure 4:**

**Feeder Schematic Showing Feeder Pipes, Flow Elements, Supports and Spacers**




1. FE = Flow Element; PBO = Pressure Breakdown Orifice;
2. A swage, also known as a reducer, is used to connect two sections of pipe of different diameters.

### 4.1.3 Feeder Pipe Installation Approach

As previously mentioned, feeder pipes are installed in three sequential campaigns. First, upper feeder pipes, which are welded to the feeder headers, are installed. Second, middle feeder pipes are welded to the upper feeders for 25% (248 of the 960) of the feeders which

have longer pipe runs, in order to facilitate connection to the lower feeders. Finally, lower feeder pipes are installed mechanically at the fuel channel and then welded to the already installed upper/middle feeders.

The installation of feeder pipes involves the execution of high-precision work, in a prescribed sequence, while working in very cramped conditions. For example, 960 high quality welds must be completed to attach the upper feeder pipes to the feeder headers. In addition, as seen in Figure 4, there are a large and varied number of pipe supports and other hardware to be installed. Proper alignment of upper/middle feeders is critical to achieving a proper connection to the lower feeders. Misalignment could lead to difficulty welding the two sections, unacceptable welds, residual stresses, and a resultant inability to meet the strict quality requirements.

Lessons Learned on the feeder series during the execution of Unit 2 included:

- Delays were experienced in the receipt of the new feeders due to the required qualification of fabrication welding specifications, inspection of fabrication, and welding, fabrication and delivery issues. Quality non-conformances, found upon inspection, needed to be resolved. Thus, planning for the Remaining Units includes longer procurement lead times to ensure that feeders are received at the station at least 12 months prior to the installation window. The qualification of fabrication welding specifications, which impacted Unit 2, is approved for all four units, thereby eliminating this source of delay in subsequent units.
- Higher than expected weld failure rates were experienced in field welds. As a result of Lessons Learned, welding on the Remaining Units will utilize improved welding condition setup, training processes, and the use of specialty welders with deep experience.[11] These changes, among others, are expected to improve productivity and reduce weld-failure rates.
- Congestion was experienced on the reactor face, particularly as regards to scaffolding. Thus, the Remaining Units will employ a streamlined scaffolding approach to reduce

[11] See Ex. D2-2-3, Section 5.1.5 regarding Training Program Improvements and Ex. D2-2-8, Section 2.2.1.1 for a discussion of the implementation of components of the Organizational Evolution Strategic Improvement, which includes the Project Centric Organization and Workstream Specialization.

congestion, and facilitate transitioning from one work site to another on the reactor face. The use of smaller, more highly trained work crews, trained for proficiency in the entire work series, is also expected to contribute to reduced congestion.

- Installation of the upper feeder pipes to the inlet feeder headers will be simplified for the Remaining Units by leaving short pieces of feeder pipe in place on the inlet feeder headers, thereby simplifying the machining process in advance of welding the new pipes into place.

As indicated above, Lessons Learned from Unit 2 are being applied to the planning of the Remaining Units to enable unit-over-unit efficiencies. Many challenges faced on the Unit 2 refurbishment have been resolved and improvements to methods and tooling have been made, all of which are expected to lead to significant execution improvements for the Remaining Units. See Ex. D2-2-3 for a detailed discussion of planning for the Remaining Units including the incorporation of Lessons Learned and Strategic Improvements.

## 5.0 COST PERFORMANCE

In EB-2016-0152, the OEB approved a total in-service amount of $5,177.4M, consisting of $4,800.2M ($4,799.8M in 2020 and $0.4 in 2021) for the refurbishment of Unit 2 (including the Definition Phase) and $377.2M for Unit 2 Early-in-Service projects, F&IP, and SIO. Relative to the total approved in-service amount of $5,177.4M, there is a forecast variance of $132.7M or 2.5%.

Focusing on performance relative to the $4,800.2M approved in-service amount for Unit 2 (including the Definition Phase), OPG is forecasting an amount of $4,761.8M for 2020 and $0 for 2021, for a variance of $-38.5M. This negative variance is due to placing $70.3M of projects, which had been approved as part of the $4,800.2M, in-service earlier than Unit 2 because they provided immediate benefit to the Darlington station. This reduction of $70.3M to the Unit 2 in-service amount (including Definition Phase) was offset by an increase of $31.8M in the Unit 2 in-service amount (including the Definition Phase) due to higher spend, resulting in the net variance of $-38.5M (see D2-2-9, Section 4).

For the Unit 2 Early-In-Service projects, F&IP and SIO, compared to the OEB approved amount in EB-2016-0152 of $377.2M, there is a forecast total over-variance $171.2M. This variance is the result of increased costs of $100.9M for these projects, and declaring in-service $70.3M for new Unit 2 Early-In-Service projects, as discussed above. Further information on in-service amounts is provided in Ex. D2-2-9.

Compared to the U2EE, OPG completed the refurbishment of Unit 2 itself (i.e. excluding the Definition Phase) on budget at $3,417M.[12]

The final two-and-a-half months of the Unit 2 refurbishment outage were completed under the state of emergency declared in Ontario on March 17, 2020 as a result of the COVID-19 pandemic. The COVID-19 pandemic did not materially impact OPG's safety, quality, cost, or schedule performance for the refurbishment of Unit 2. Further discussion of the COVID-19 impacts on the schedule and costs of the Remaining Units is provided in Ex. D2-2-5 (Remaining Units Schedule) and Attachment 1 to Ex. D2-2-7 (Remaining Units Cost).

The successful completion of the Unit 2 refurbishment on budget and reasonably on schedule represented a significant achievement in mega-project execution for OPG. A picture showing the completed Unit 2 reactor face is provided in Figure 5. A panoramic view of the Unit 2 turbine hall is provided in Figure 6.

[12] See footnote 6.

**Figure 5: Close-up of the Finished East Face of the Unit 2 Reactor**

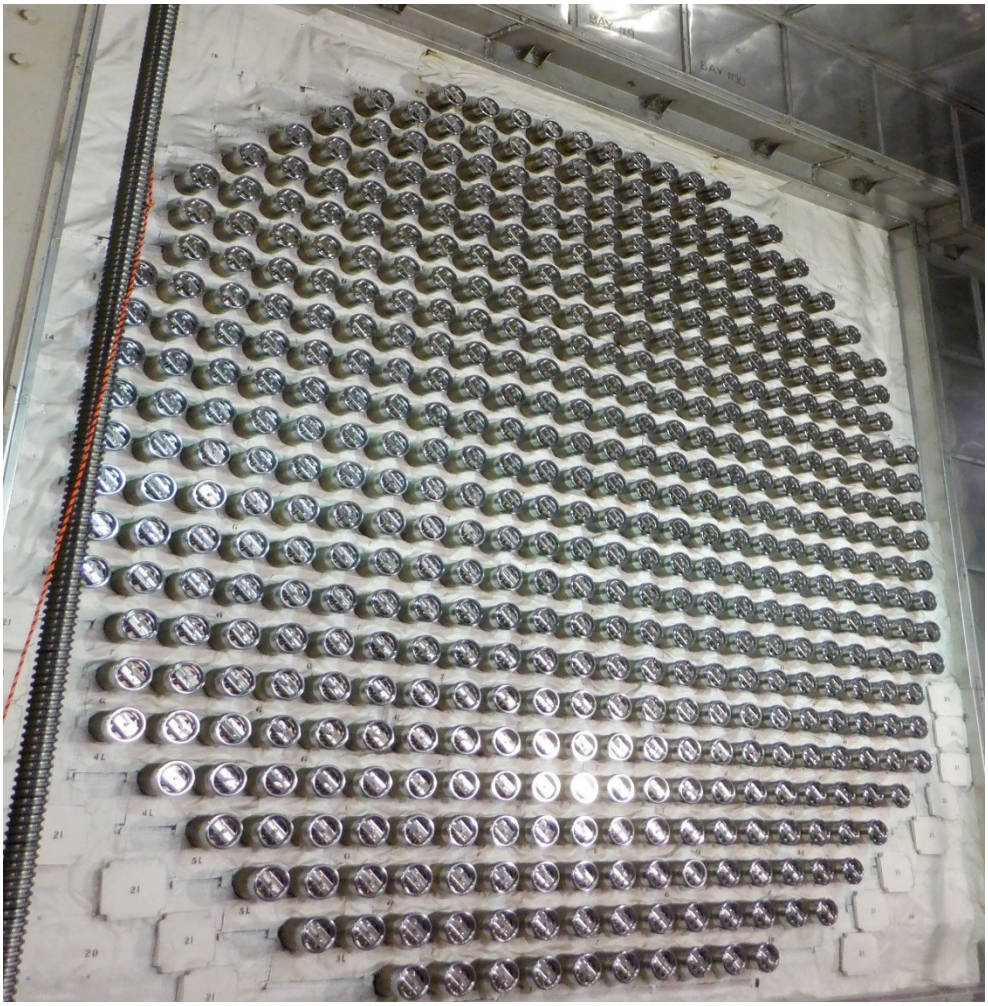
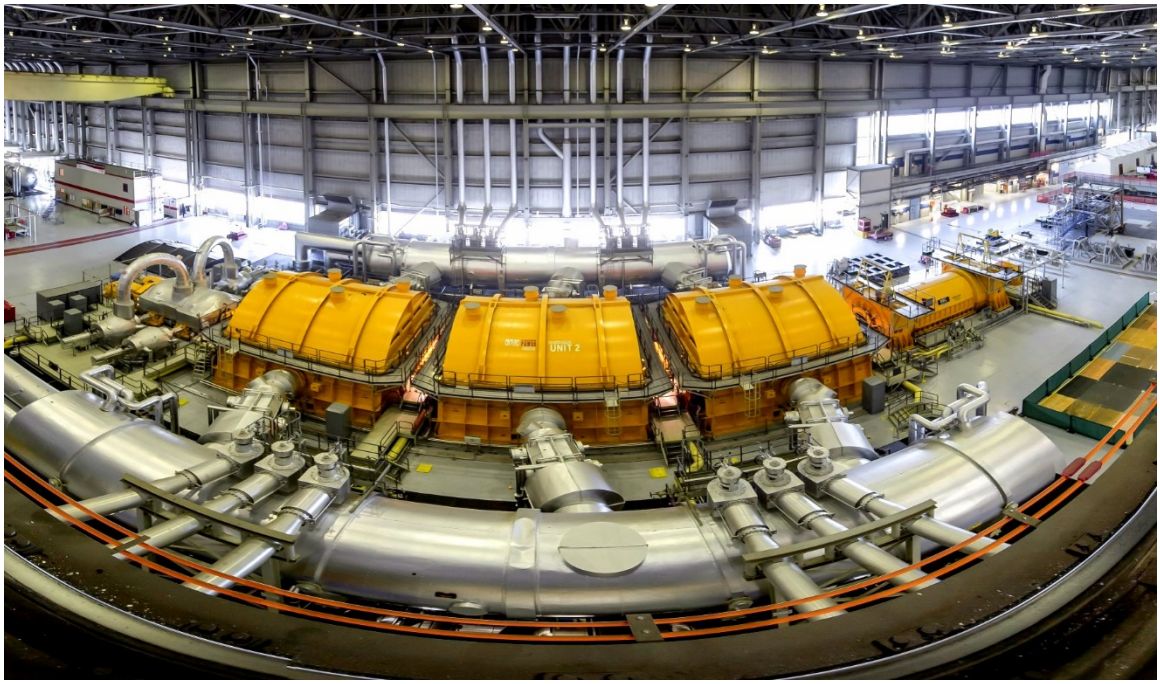


**Figure 6: A Panoramic View of the Unit 2 Turbine Hall**




## 6.0 OVERSIGHT

During the execution of the Unit 2 refurbishment, OPG had implemented an assurance plan comprised of several layers of oversight.[13] This oversight structure effectively helped OPG and its contractors meet safety, quality, cost and schedule expectations by identifying issues and aiding in their expeditious resolution. OPG's oversight structure for the Remaining Units is discussed in Ex. D2-2-8.

For Unit 2, the Refurbishment Construction Review Board ("RCRB") supported Program-level oversight for OPG's Chief Project Officer, Chief Nuclear Officer, and Chief Executive Officer, and Burns McDonnell/Modus Strategic Solutions ("BMcD/Modus") was engaged by the OPG Board of Directors to provide independent oversight of the DRP. These two independent advisors provided regular and effective reviews of Unit 2 execution progress.[14]

[13] See EB-2016-0152, Ex. D2-2-9 Program Execution, Section 8, for discussion of the forms of oversight in place at the beginning of the execution of the Unit 2 refurbishment.
[14] See Ex. D2-2-8 Oversight, Section 5, for more detailed descriptions of the RCRB and BMcD/Modus roles.

The RCRB delivered 14 reports over the course of Unit 2 refurbishment. In general, the RCRB provided overall findings on Unit 2 progress as well as more specific observations regarding the current and upcoming scopes of work.

BMcD/Modus reported to the OPG Board of Directors on a quarterly basis over the course of the Unit 2 refurbishment. BMcD/Modus delivered detailed reports regarding OPG's Unit 2 execution performance as well as on all other major scopes of work being executed.

## 7.0 REPORTING

In accordance with the OEB's Decision and Order in EB-2016-0152,[15] OPG produced annual reports on the DRP in each of 2018, 2019 and 2020 which summarized Program performance, including the refurbishment of Unit 2. Copies of the 2018 and 2019 reports are provided in Attachments 1 and 2.

## 8.0 RATE BASE AND CAPACITY REFURBISHMENT VARIANCE ACCOUNT TREATMENT

The revenue requirement impact of the difference between the OEB approved amounts and actual in-service additions (and associated timing) to rate base for DRP is recorded in the CRVA. Clearance of balances in the CRVA is predicated on the OEB determining the prudence of any in-service amounts over the approved amounts prior to disposition. The CRVA includes capital and non-capital costs and firm financial commitments incurred in respect of the DRP, which is forecasted to be completed in 2026.

As noted above, OPG provided the U2EE in EB-2016-0152 and used the U2EE as the baseline against which to track its Program performance through the execution of the Unit 2 refurbishment. OPG did not update its EB-2016-0152 revenue requirement as a result of the U2EE and instead requested that any variance against the originally proposed (and ultimately approved) in-service amounts be recorded in the CRVA. The OEB agreed with this approach, stating as follows in the EB-2016-0152 Decision and Order:

[15] EB-2016-0152 Decision and Order, pp. 44-45.

> The OEB is of the view that it is not necessary to use the Unit 2 Execution Estimate as the basis for its approvals. The OEB notes that the CRVA will operate to capture any revenue requirement impacts of changes to in-service dates and in-service amounts between OEB-approved and actual. Therefore, using the in-service amounts and dates as proposed by OPG is reasonable.[16]

As noted in Section 5.0, there is a forecast variance of $132.7M, or 2.5%, against the total EB-2016-0152 approved in-service addition of $5,177.4M (which was comprised of in-service additions of $4,800.2M for Unit 2, including the Definition Phase, and of $377.2M for the Unit 2 Early In-Service projects, F&IP and SIO); the revenue requirement impact corresponding to this variance is recorded in the CRVA.

In this application, OPG is not seeking inclusion of the variance against the EB-2016-0152 approved in-service additions in rate base for the purposes of setting payment amounts for the IR term. Under OPG's proposal, the revenue requirement impact of the variance would continue to be recorded in the CRVA. Further details regarding the proposed rate base treatment can be found in Ex. B1-1-1, Section 2.

OPG also is not seeking clearance of DRP-related amounts in the CRVA in this application, except for certain amounts related to the D2O Storage Project.[17] OPG proposes to defer the clearance of DRP-related amounts recorded in the CRVA to a future application, which would assess of the recoverability of any DRP-related variances in the context of the overall performance of the four-unit refurbishment, including the effectiveness of Lessons Learned and Strategic Improvements from the earlier unit refurbishments. OPG's proposed treatment of the variances is consistent with the DRP being a single mega-program as opposed to a collection of smaller projects. The CRVA is discussed further in Ex. H1-1-1, Section 5.6.

[16] EB-2016-0152 Decision and Order, p 39.
[17] Ex. H1-1-1, Section 5.6 and see, footnote 1.

## ATTACHMENTS

Attachment 1: Darlington Refurbishment Program 2018 Annual Report

Attachment 2: Darlington Refurbishment Program 2019 Annual Report