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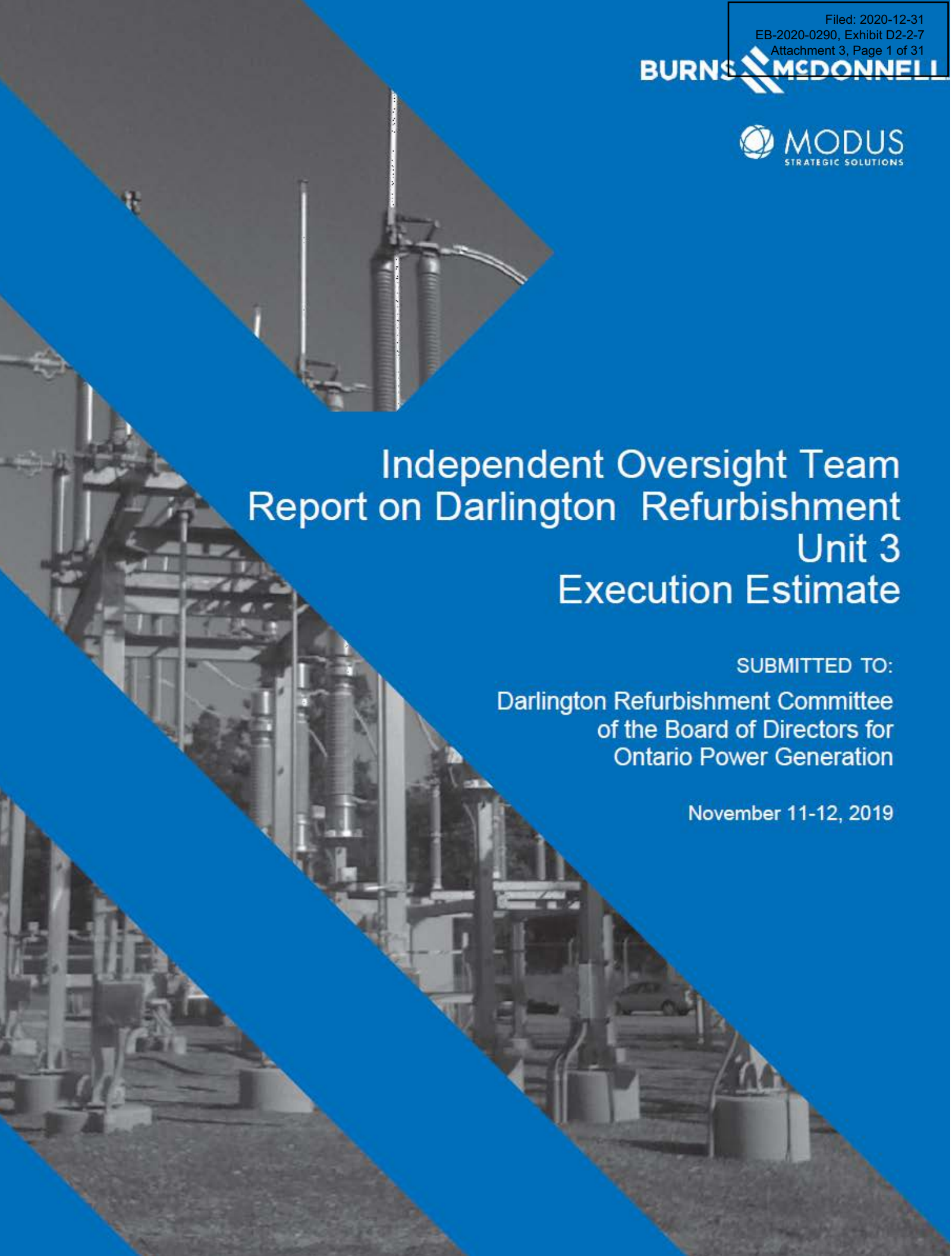


# Independent Oversight Team Report on Darlington Refurbishment Unit 3 Execution Estimate

SUBMITTED TO:

Darlington Refurbishment Committee
of the Board of Directors for
Ontario Power Generation

November 11-12, 2019

# I. Executive Summary

The Darlington Refurbishment Committee ("DRC") of the Ontario Power Generation Board of Directors has requested Burns & McDonnell Canada and Modus Strategic Solutions Canada Company ("Burns/Modus") to provide the following report regarding the process used by the Darlington Refurbishment Project ("DR Project") to develop the Control Budget and Schedule for the refurbishment of Darlington Unit 3. This report reflects the DR Project's progress since the Unit 3 Execution Estimate Forecast that was presented to the DRC and the BOD in March 2019 (the "March DRC Meeting") and which was the subject of our report to the DRC (the "March 2019 Report").

Since the March DRC Meeting, CanAtom has completed the Fuel Channel Installation, Upper and Lower Feeders and has begun restoring the vault. The current Unit 2 forecast completion of June 25, 2020 is 119 days (9%) longer than the High Confidence Schedule duration though the cost is within the Unit 2 execution estimate of $3.417B. Based on recent nuclear and non-nuclear megaproject results, the expected result for Unit 2 should be considered a success, and Unit 2 has effectively served as a laboratory for injecting immediate improvements into the planning for Units 3/1/4.

The DR Team's U3EE was a snapshot of the then-current Unit 3 budget and schedule that was presented as a progress report to the DRC in the March DRC Meeting. The current estimate and schedule are intended to form the "Unit 3 Control Budget" and "Unit 3 Working Schedule" which OPG will use for measuring Unit 3's performance. The DR Team's Unit 3 Control Budget is an updated forecast of the Unit 3 portion of the DR Project's $12.8 Billion Release Quality Estimate ("RQE") approved by the Board of Directors in November 2015. Since the March DRC Meeting, the DR Team has been working to build confidence into the Unit 3 Control Budget and Working Schedule. The following is a comparison to RQE and Unit 3EE snapshot:

**Chart 1** — **Summary of Unit 3 Control Budget and Schedule**

| | RQE (2015) | Unit 3EE (March 2019) | Unit 3 Control Budget | Variance from Unit 3EE |
|---|---|---|---|---|
| Unit 3 Base Cost Estimate ($) | $2.408B | $2.487B | $2.559B | + $72M |
| Unit 3 Contingency ($) | $ 0.524B | $ 0.305B | $0.257B | ($48M) |
| Unit 3 Working Schedule (Days) | 1071 | 1028 | 1099[1] | +71 Days |

As Unit 3's planning has matured, the base cost estimate has increased while contingency has decreased. In the period since the March DRC Meeting, Unit 3's base cost has increased by $72M (2.8%), contingency has been reduced by $48M and the Working Schedule has been extended to 1099 calendar days (930 working days). A significant portion of the growth in the base estimate since the March DRC in the Unit 3 base estimate is to compensate for the Unit 2 performance on the Upper and Lower Feeder work which were over-budget and schedule; Lower Feeders were only recently completed on October 23. Since the March DRC Meeting, the DR Team led challenge sessions over the last several months have resulted in over $150M of estimate reductions based on lessons learned, Unit 2 OPEX and application of programmatic efficiencies. Burns/Modus attended many of these challenges and found them to be effective. The result of those challenges is a better defined and detailed Unit 3 estimate and schedule.

[1] Due to the 24/5 shift schedule, 1099 calendar days equates to 930 working days.

The Unit 3 Working Schedule has been modified to incorporate a revised shift schedule whereby the head count of Direct Field Labour ("DFL") can be reduced along with overtime, shift premiums and Project Management Team ("PMT") as part of a two shift per day, five (and sometimes six) day per week calendar (referred to as the "24/5" shift). The 1099 calendar day/930 working day Working Schedule incorporates this strategic change, which is intent on increasing worker productivity. The DR Team believes the revised estimate and schedule reflect increased certainty and confidence in Unit 3's performance.

Based on the maturity of the DR Project, the Unit 3 estimate can be classified on the lower range of a Class 2 (+5% to +20%) and upper range of Class 1 (+3% to +15%) estimate as measured by the AACEi Classification System adopted by OPG for the DR Project.[2] Unit 3 has to date expended $437M. The Unit 3 Control Budget has $257M contingency for the remaining cost, which calculates to **12.0%** of the current Estimate to Complete ("ETC") of $2.122B.

## A. Burns/Modus Summary Evaluation

As with the March 2019 Report, Burns/Modus has focused on the reasonableness of the process and assumptions OPG has used to develop the Unit 3 Control Budget, and in particular how OPG and its vendors have utilized the operational experience ("OPEX") and lessons learned from the Unit 2 refurbishment to benefit Unit 3. We were also mindful of how the process used by the DR Team's Unit 3 Control Budget compares to industry practices for similar projects. Based on our review of the DR Team's development of the Unit 3 Control Budget and Schedule, Burns/Modus finds that:

- The DR Team's process for developing the Unit 3 Control Budget is consistent with the methods OPG has used to date on the DR Project, starting with RQE, and conforms to best practices used in the industry for developing cost estimates. The Unit 3 Control Budget is an updated, unitized forecast based on estimates that have progressively matured since RQE, including the reflection of nearly all of Unit 2's actual cost and schedule history and lessons learned. The revised Unit 3 estimate is largely based on production rates previously achieved for periods during Unit 2's work.
- Since the March DRC Meeting, while Unit 2's execution of Fuel Channel Installation and Upper and Lower Feeders continued, CanAtom iterated its Unit 3 estimate for RFR that reflected lessons learned and OPEX from Unit 2. Through the 2Q and 3Q, the DR Team worked with CanAtom on series by series challenge sessions to identify the variances, question CanAtom's cost and schedule estimates, and increase overall confidence. As a result of these challenge sessions, the CanAtom estimate was reduced by over $150M and the schedule was reduced by 100 days Working Days.
- Unit 3's scope is bounded and certain key external issues (notably supply of materials, logistics and tooling) that impacted work on Unit 2 that have been resolved should not be repeated on Unit 3/1/4. These would be considered "One Time Events".
- The Unit 3/1/4 Working and High Confidence schedules were developed in deliberate stages with key stakeholder involvement and the schedule was updated to account for Unit 2 OPEX, modified resourcing strategies and innovations to produce a reasonable and achievable plan.
- The DR Team has reasonably considered Unit 3's overlaps with Unit 1 and Unit 4 for purposes of reducing and allocating cost, achieving economies of scale, and rationalizing PMT cost and optimizing DFL in anticipation of future expected resource challenges. Unit 3's Breaker Open has been shifted to May 6, 2020 to reduce potential impacts from the overlap of Unit 2.

[2] AACE International Recommended Practice No. 18R-97, COST ESTIMATE CLASSIFICATION SYSTEM – AS APPLIED IN ENGINEERING, PROCUREMENT, AND CONSTRUCTION FOR THE PROCESS INDUSTRIES TCM Framework: 7.3 – Cost Estimating and Budgeting

- Units 1 and 4 have base estimates of $2.115B and $2.193B, respectively. Unit 1 will be the beneficiary of the most resource overlaps and opportunities for economies of scale with Units 3 and 4, thus its lower estimate. Achieving the level of cost reduction on Unit 1 and 4 will depend in part on the timely transference of lessons learned. The current Unit 1 schedule appears to be optimally timed to use craft from Unit 3 with minimal gaps that will reduce training time and utilize direct experience. In addition, there are costs for D3IP that are being picked up by Unit 3. Unit 1 currently has 17% contingency while Unit 4 has 11.5%.
- The DR Team's ongoing process for collecting, vetting and interpreting lessons learned from Unit 2 is consistent with best practices we have observed in other multi-unit projects (including OPG's Pickering A Return to Service), and the DR Team has a strong basis for planned improvements for Units 3/1/4. These lessons learned have led the DR Team to re-plan a significant portion of the work on the basis of: (1) production rates that CanAtom can meet and sustain for each repetitive work series; (2) a revised 24/5 based work schedule that is expected to increase craft productivity and proficiency while reducing the total number of craft required, overtime, shift premiums, weekend work, and other costs; (3) PMT reductions and insertion of OPG personnel into the OneTeam approach.
- The development of the Unit 3 Control Budget's contingency has followed the same basic process as used for RQE and was confirmed using OPG's risk management system and quantitative assessment techniques (i.e. Monte Carlo). The 1099 calendar day Unit 3 Working Schedule (930 working days) is an aggressive Working Schedule that is based on improvement from Unit 2. In addition, the change in the shift schedule to the 24/5 driven critical path will allow Unit 3 to utilize weekends for catching up as necessary, though there would be cost associated with direct cost, overtime and shift premiums for working those days.
- In light of the work that has occurred since the March DRC Meeting, the $257M of contingency is 12% of the remaining Unit 3 ETC and is appropriate for a Class 2/1 estimate. OPG is prudently maintaining contingency for the discrete risks for Unit 3, including potential limits to trades labour, Ontario supply chain support, overlaps of units for the first time, potential impact on labour availability from Bruce Power's simultaneous MCR Program and other project risks.
- Feeder work was the largest source of increased cost and schedule on Unit 2 and poses a risk to the Unit 3 Control Budget and Schedule. The Unit 2 manhour overrun on the Feeder work was 60% of CanAtom's total manhour overrun on RFR and 35% of the total DR Project overrun. As discussed in detail in Section C.1. below, numerous issues impacting progress on Feeders are being examined at this time, including identification and impact of One-Time Events from Unit 2. CanAtom's Unit 3 Feeder estimate was increased by 47% over the RQE budget to account for Unit 2 lessons learned and to correct aspects of its original estimate. CanAtom believes this current estimate is bounding based on the re-planning and other actions it has taken to date. Burns/Modus recommends the DR Team complete the recently started Feeder lessons learned program and provide other means such as partial check estimates and thorough schedule analysis to ensure these estimates are complete.

Based on the results OPG has achieved to date on Unit 2 relative to RQE and the preparations OPG is making for Unit 3, Burns/Modus has confidence the current Unit 3 Control Budget and Schedule have been developed with a robust process. Burns/Modus's current confidence level should only increase once the Feeder work and the remainder of Unit 2 is complete and is subjected to the same rigorous process. The charts below identify Burns/Modus' Confidence Level in the Unit 3 Estimate and Schedule. The cost of each element of the Unit 3 budget is represented in $M proportionally below and is shaded according to our confidence level:

**Figure 1**

**Unit 3 Estimate – $2,559M – Confidence Level**

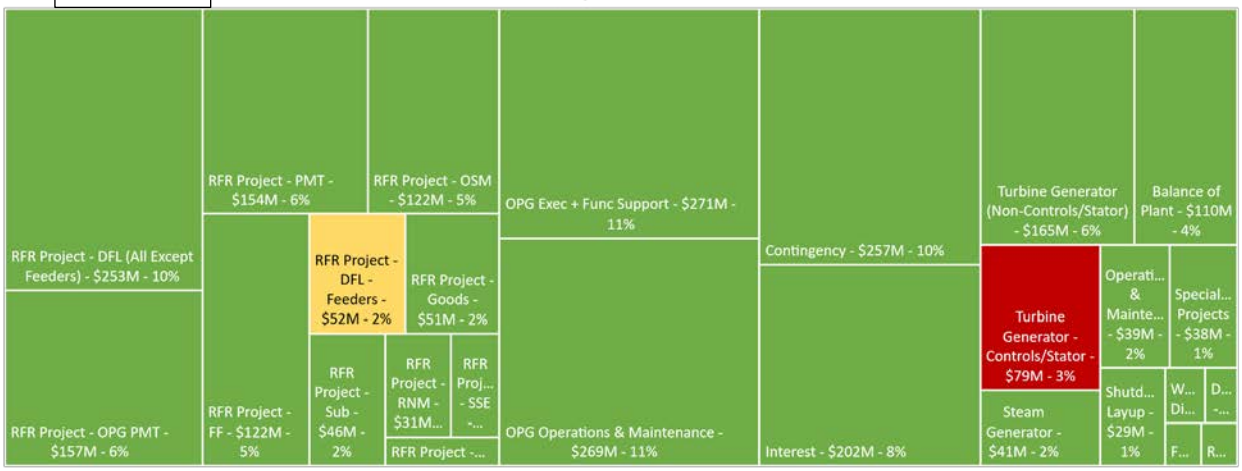
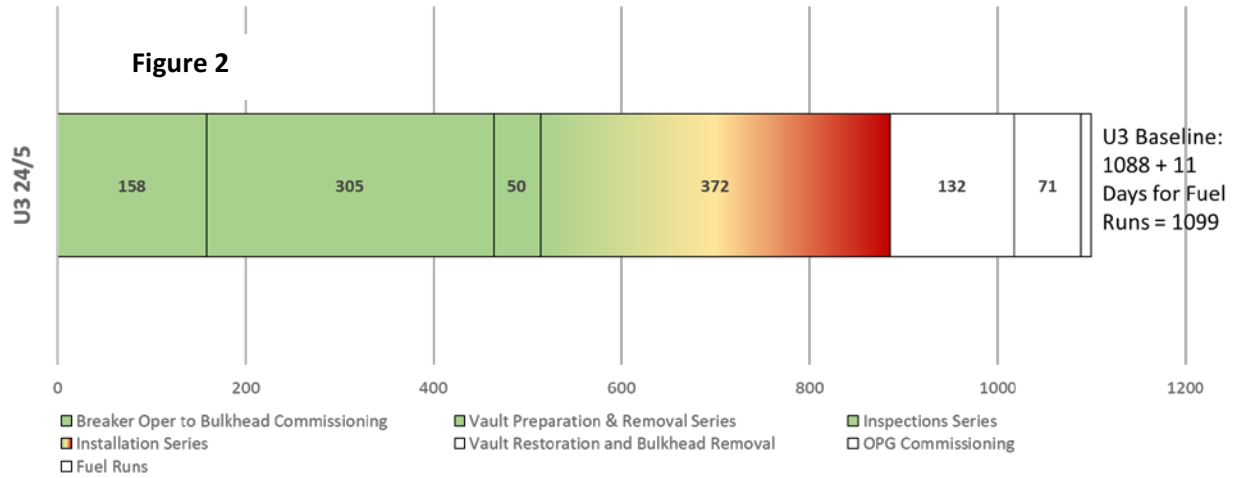



**Figure 1&2 Color Coding**:
The above graphic depicts the entire Darlington Unit 3 budget including OPG costs. Each rectangle represents a cost element proportionally sized ($M) in relation to the total Unit 3 budget and assigned a color code based on Burns/Modus's confidence in that cost element. Similarly, the below chart represents the major schedule segments and our confidence (in calendar days) in that segment of the overall Unit 3 schedule.
Green –represents high-confidence in the estimated cost / schedule resulting from an estimate that meets an AACE Class 2 or better; represents work that was performed on Unit 2; and lessons learned are incorporated into the base estimate, schedule, and workplans.
Yellow – represents moderate confidence in the estimated cost / schedule resulting from an estimate that meets an AACE Class 2; will have critical path impact; lessons learned from Unit 2 have not been fully incorporated into the plan
Red – represents low-confidence in the estimated cost / schedule resulting from an estimate for work that exceeded cost and schedule on Unit 2; or work that will be performed for the first time on Unit 3.
White – Work that has not been performed yet on Unit 2.

Burns/Modus has evaluated the major schedule segments for Unit 3 are represented below are shaded according to our confidence level:

**Figure 2**




In summary, Burns/Modus finds the process used in preparation of the Unit 3 Control Budget and Schedule consistent with a Class 2/1 estimate under the AACEi Classification guidance and conforms to industry good practice. The reduced risk that comes from repeating the work should provide confidence that Unit 3 can complete within the total RQE envelope, thus increasing the certainty of maintaining the total $12.8B RQE budget. The DR Team's work also sets a good course for continuous improvement of the budget and schedule for Units 1 and 4.

# II. Unit 3 Planning Since March 2019

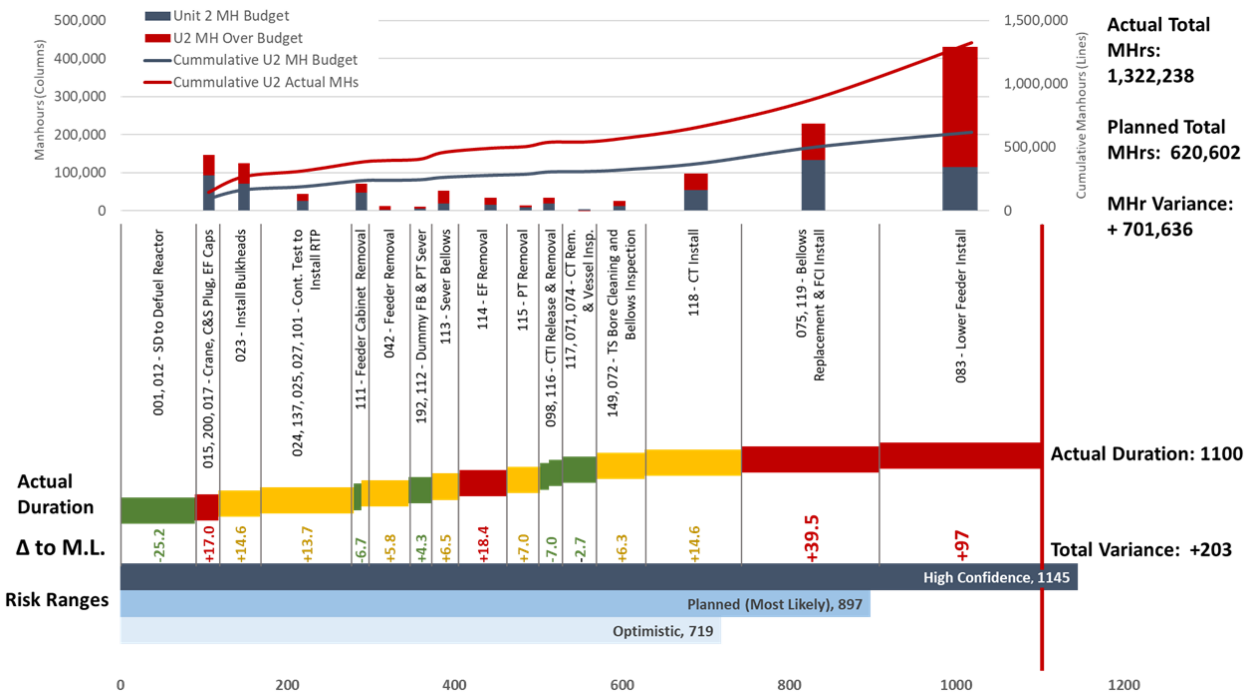
Since the March 2019 Unit 3EE forecast and in further development of the Unit 3 Control Budget and Working Schedule, the DR Team has focused on establishing a reasonable, achievable and repeatable work plan that accounts for Unit 2 OPEX and lessons learned. The following is a detailed summary of the DR Team's progress in developing the Unit 3 Control Budget and Schedule since the March 2019 Meeting.

## A. Unit 2 Progress Since March 2019

In our March 2019 Report, we prepared an analysis of the Unit 2 Performance versus the Unit 2 Working Schedule and Budget with comparison to the Monte Carlo simulation used for Unit 2 at RQE. As of the March 2019 Report, the critical path series performed to date were 27 days behind the Planned (Most Likely) and 3-4 months ahead of the High Confidence Schedule. The activities on critical path work had experienced manhour overruns of +289,800 hours over Unit 2 Working Schedule. We have updated that same chart (Figure 3 below) to include the work series that have been completed since the March 2019 Report, namely Fuel Channel Installation and Lower Feeder Installation. As depicted below, these last two work series were +39.5 and +97 days longer than the Unit 2 Working Schedule. In addition, these two work series accounted for more than 30% of the overrun of manhours on the critical path, resulting in contingency drawdowns.

## Unit 2 Performance v. Working Schedule and Manhour Budget

**Figure 3**




As of the completion of Calandria Tube installation in December 2018, CanAtom was +32.6 days ahead of the High Confidence Schedule and -69.4 days behind the Working Schedule. Fuel Channel Installation and

Lower Feeders accounted for -136.5 days of delay over their Working Schedule durations[3]. At the completion of the Lower Feeder Installation, Unit 2 was forecast to complete +209 days beyond the High Confidence Schedule. Therefore, CanAtom appeared to be comfortably within the High Confidence Schedule but for these last two series, which suggests that the key to restoring the baseline schedule for Unit 3 would be eliminating or mitigating the issues that caused these and the other "red" series in Figure 2 to extend beyond their original schedule. The Unit 3 re-planning effort has focused on these and other critical areas to achieve improvements.

## B. Lessons Learned Process

The DR Team has executed a robust plan for extracting critical OPEX from Unit 2's actual performance. As each work series completed, the DR Team immediately held lessons learned sessions with the performing contractors who worked on or near the critical path. These meetings are attended by the field superintendents, engineers, project management staff and others as necessary, during which they review the schedule, actual performance, sequence of work and identified issues for further review and disposition. The contractor representatives use the information gathered in these sessions to modify their schedules, budgets and corresponding Comprehensive Work Packages ("CWPs"). CanAtom has assigned a team leader to develop reports that show the results of this analysis, summarize the impact of One Time Events and assess the extent of delays in both days and hours. We sampled the information from these sessions and attended some of the meetings and found them to be well organized and substantive. **Attachment A** summarizes select key work series on the critical path that have been performed on Unit 2, reviewed for lessons learned and re-planned for Unit 3. This chart summarizes how the DR Team has utilized this information for planning the schedule duration, shift pattern and other process changes for Unit 3.

### 1. RFR Lessons Learned

The most significant advances in the RFR critical path lessons learned process since the March DRC Meeting have been: (1) CanAtom monetizing some of the major delay impacts caused on Unit 2 by One Time Events, first of a kind ("FOAK") and issues that can be mitigated in future performance; and, (2) the DR Team's focus on identifying sustainable production rates for each of the repetitive series in RFR that can be used as the basis of the revised Unit 3 estimate.

As of the March DRC Meeting, Unit 2 was approximately 80% complete overall and CanAtom was actively working on Fuel Channel Installation and Upper Feeder Installation, each of which were being impacted at the time by ongoing production challenges and One Time Events. Since the March DRC Meeting, CanAtom has partially monetized the impact of the One Time Events in both days and work hours. The following chart depicts the 141 days and over 3,000 hours on critical path impacted by these one-time and FOAK events for key series as assessed by CanAtom in its lessons learned reports to date[4]:

[3] Planned duration for Fuel Channel Installation was 125 days and Lower Feeder Installation was 96 days; actuals for these were 160 days and 193 days, assuming an October 22, 2019 date for Lower Feeders.

[4] CanAtom's work monetizing the lessons learned is ongoing. Chart 2 depicts only those work series CanAtom has completed its review to date. The remaining critical path series and Feeders are being examined as the work is completed. Appendix A further identifies how lessons learned are being applied.

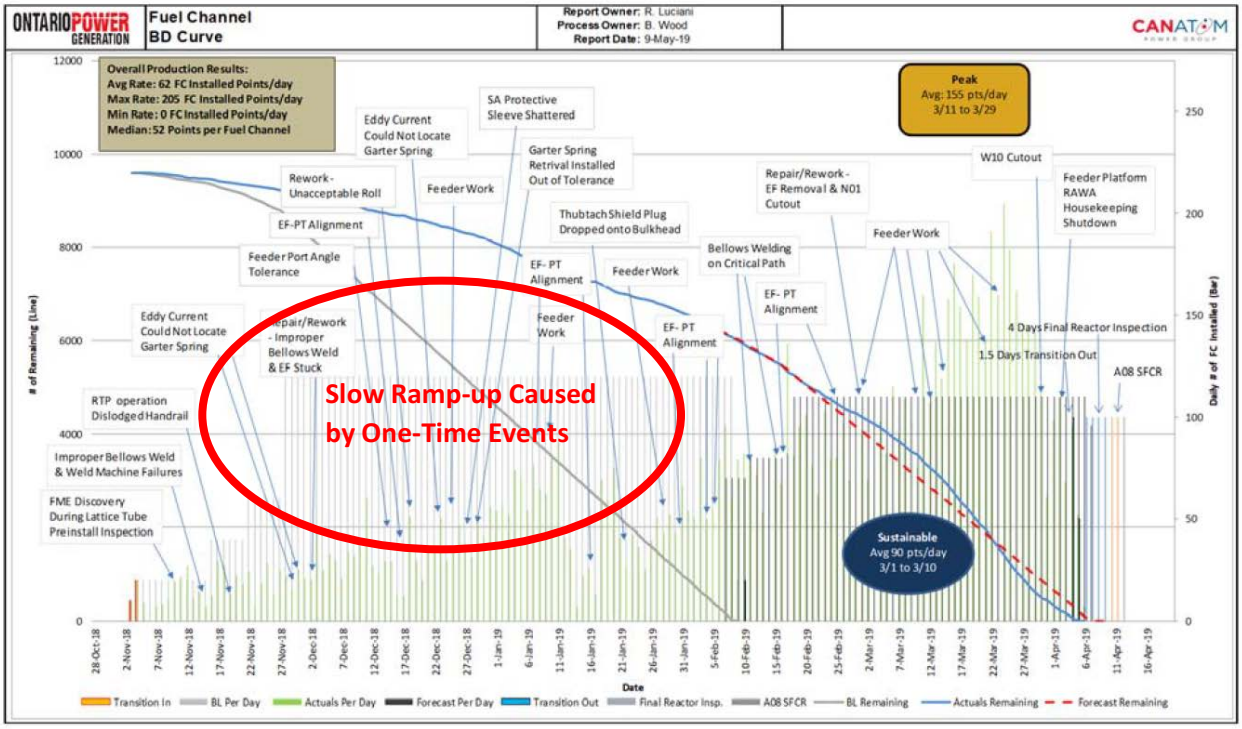
| Lessons Learned Assessed Impacts – Unit 2 | | | | |
|---|---|---|---|---|
| Chart 2<br>CWP | Work Series | Worker Hours | Work Days | Critical Path Hours |
| 2172 | Fuel Channel Installation | 43,853 | 46.2 | 1,075 |
| 2183 | Calandria Tube Installation | 16,430 | 39.1 | 893 |
| 2180 | CTSB Inspection | 14,535 | 14.7 | 344 |
| 2169 | PT Removal | 10,032 | 12.6 | 284 |
| 2168 | End Fitting Removal | 10,022 | 10.37 | 244 |
| 2177 | CT Removal | 9,132 | 10 | 212 |
| 2176 | CTI Removal | 3,773 | 4.32 | 103 |
| 2179 | LT and Bellows Inspection | 3,791 | 2.51 | 22 |
| 2178 | Calandria Vessel Inspections | 547 | 0.67 | 16 |
| 2141 | Feeder Coupling Disconnect | 229 | 0.2 | 4 |
| | **Total** | **112,344** | **141** | **3,197** |

The results from the lessons learned process were transacted directly into the Unit 3 cost estimate and schedule (See Appendix **A** for examples). From this history, CanAtom has calculated performance trends that have become the basis of its Unit 3 estimate. CanAtom has transacted the impact of all One Time Events and other OPEX-based adjustments as part of the revised Unit 3 cost estimate and schedule. This analysis also allowed the DR Team to examine other alternatives for performing the Unit 3/1/4, including altering the shift pattern for the critical path work. As discussed below, the 24/5 shift pattern has been adopted for approximately half of the critical path work for Unit 3.

Chart 3 below reflects the work that the DR Team's lessons learned for the two series that occurred after the March DRC Meeting, both of which had challenges on Unit 2:

| Series<br>Chart 3 | Unit 2 Planned Duration | Unit 2 Actual Duration | Unit 2 CPI | Unit 2 Budget Manhours | Unit 2 Actual Manhours | Unit 3 Estimated Manhours |
|---|---|---|---|---|---|---|
| **Fuel Channel Installation** | 125 Days | 161 Days | 0.41 | 132,304 | 228,238 | 154,983 |
| Unit 2 Events | • CanAtom calculated delays at 43,853 work hours and 46.2 days; if these delays and related manhour overruns could have been avoided, the series could have completed on-time<br>• Key Causes included: (1) Human Performance; (2) Coordination with Feeders; (3) Bellows Welding; (4) End Fitting/Pressure Tube Alignment; (5) Coordination of resources<br>• CanAtom's progress recap in its lessons learned Report provides details regarding the impact of the issues encountered on Unit 2 Fuel Channel | | | | | |

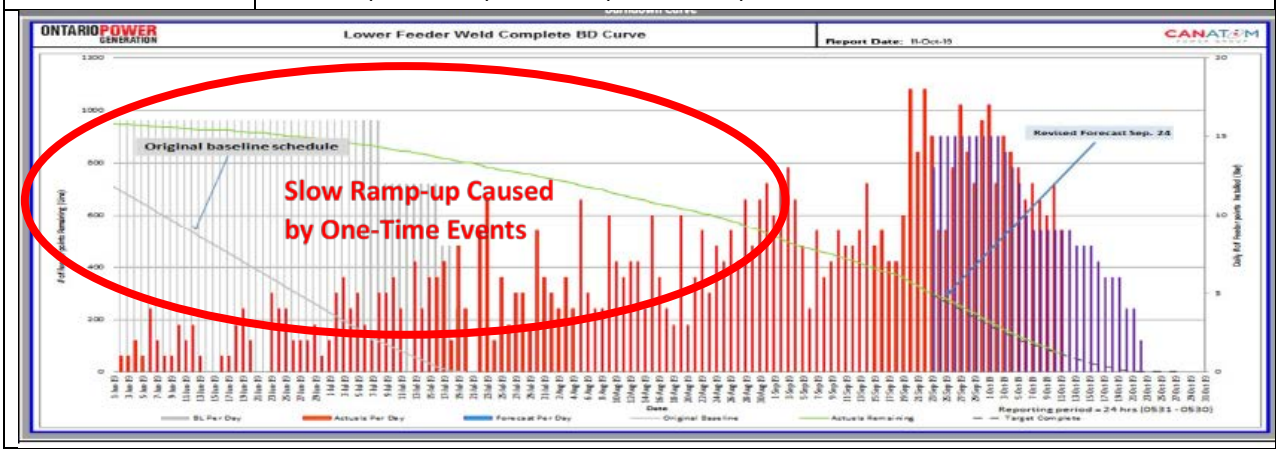
| | |
|---|---|
| | Installation that contributed to the slow ramp-up to sustainable production rates<br>• Based on the data assembled and reviewed, CanAtom was able to determine a sustainable production rate once the upfront issues were resolved; that production rate has been used for calculating the duration, hours and resources for Unit 3 estimate |
| Unit 3 Improvements | • Unit 3 basis of estimate for Fuel Channel Installation assumes:<br>  ○ Training for proficiency prior to series will accelerate the ramp-up<br>  ○ Ramp-up will occur over 1-2 weeks based on logistics and efficient access to the reactor face<br>  ○ Fuel Channel Installation will reach a sustainable peak of 5 /day<br>• Duration range for Unit 3 is estimated at 123 (planned/most likely), 119.5 (best case) and 134 (worst case) |




| Series | Planned Duration | Actual Duration | CPI | Unit 2 Budget Manhours | Unit 2 Actual Manhours | Unit 3 Estimate Manhours |
|---|---|---|---|---|---|---|
| Lower Feeder Installation | 96 days | 193 days | 0.25 | 114,098 | ~430,000 (forecast) | 176,383 |

| | |
|---|---|
| Unit 2 Events | • CanAtom has recently initiated the formal lessons learned process for the entirety of the feeder work (upper and lower)<br>• Upper and Lower Feeders were impacted by significant One Time Events and other identified issues including:<br>  ○ Inconel 690 material change<br>  ○ Vendor supply issues<br>  ○ Nozzle preparation and inspection<br>  ○ Welding procedures required modifications |

| | |
|---|---|
| | ○ Logistics, scaffolding and field management<br>○ FME incursions<br>○ Lower Body Tubing and instrumentation on critical path<br>○ Cantilever supports<br>○ Craft absenteeism<br>○ High weld rejection rates<br>• CanAtom has committed to significant changes for Unit 3 based on the Unit 2 performance<br>• Lower Body Tubing installation was initially planned to be concurrent with Upper and Lower Feeder installation |
| Unit 3 Improvements | • Unit 3 basis of estimate for Lower Feeder Installation assumes:<br>○ Continuous effort on the Feeder work with a smaller, well trained crew working 24/5 will improve productivity<br>○ Elimination of One Time Events<br>○ Ramp-up will occur over 1-2 weeks based on logistics and efficient access to the reactor face<br>○ Lower Feeder Installation will reach a sustainable peak of 10 /day<br>• Duration range for Unit 3 is estimated at 117 (planned/most likely), 96 (best case) and 137 (worst case) |




CanAtom's Unit 2 performance of the Feeder work yielded the largest cost variance from the base RQE estimate. The following chart identifies the manhour overrun CanAtom experienced on Unit 2 and the increased Unit 3 budget for this work:

| Feeder Work Craft (DFL) Manhour Comparisons | | | | | |
|---|---|---|---|---|---|
| Chart 4 | Unit 2 | | | Unit 3 | |
| | Planned | Actual | Variance | Planned | Variance from Plan |
| Upper Feeders[5] | 203,000 | 721,000 | +355% | 474,000 | +58% |
| Lower Feeders | 158,000 | 467,000 | +296% | 176,000 | +10% |
| Total - Feeder Work | 361,000 | 1,188,000 | +329% | 650,000 | +45% |

[5] The Upper Feeder cost code includes: Nozzle Inspection and Weld Preparation, Feeder Instrumentation, Feeder Scanner install and Lower Body Tubing.

CanAtom has updated the base estimate for Unit 3 planned production rates, resulting in a 45% increase in DFL hours over RQE. The full RQE Feeder estimate was $27.8M, while Unit 3's estimate for Feeders is now $52.11M (+47%). As shown above, the Upper Feeder work series slow ramp-up was impacted by One Time Events, performance issues, supply and logistical issues that have been addressed and should not be repeated. The schedule has been revised for Lower Body Tubing work and there an opportunity to plan to perform work concurrent to Feeder installation. The formal lessons learned process for the Feeder work has recently begun; however, the DR Team has been addressing and mitigating issues on the Feeder work on an ongoing basis throughout Unit 2. The Feeder estimate should be thoroughly reviewed, challenged and refined further based on completion of the lessons learned.

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### 2. Lessons Learned – BOP and Major Systems

The lessons learned process was not exclusive to RFR and critical path activities. The DR Team has also conducted lessons learned sessions and recorded results for Balance of Plant ("BOP"), Turbine Generator and other specialized projects.

- **Balance of Plant/ES Fox**: ES Fox utilized lessons learned in developing the Unit 3 BOP estimate by quantifying one-time events and delays and deducting them from the Unit 2 actual costs to form the basis of the Unit 3 estimate. The lessons learned process identified $14.3M and 279 total non-critical path days of potential savings for Unit 3, which provides float to Units 3/1/4 and reductions to PMT cost. The lessons learned review also determined that productivity could be improved by 5%, and therefore the DFL hours were reduced accordingly. In addition, the scope of BOP is different for Unit 3. For example, some of the BOP work on Unit 2 was planned to be performed once for the entire program, and other scopes (adjuster rods, flux detectors) have been moved to other bundles for performance. The lessons from this project are being applied across all bundles on Unit 3 as a model for improved performance. The following areas of improvement have been identified:
    - Update CWPs to incorporate lessons learned
    - Improve and standardize the lessons learned process
    - Vendor engagement in constructability review
    - Utilize same work force involved in previous unit (e.g. VVRS)
    - Improved response to Field Initiated Changes ("FICs")
    - Retaining qualified field resources to reduce learning curve
- **Major Systems**: The lessons learned process on Major Systems identified a number of One Time Events and opportunities for improvement. As a result, the One Team approach was implemented with OPG and vendor PMT to improve communication, coordination and accountability. A major lesson currently being implemented is the addition of a lunchroom in the turbine hall to reduce nonproductive time. Through this and other changes, the Turbine Generator team is planning on

a 36% increase in productivity compared to Unit 2. Due to the manhour overrun on Unit 2 and the additional turbine controls change out for Unit 3, the Turbine Generator work merits close watching. The changes initiated within the DR Team to place this work in the Major Systems bundle should provide the additional oversight needed for this work. Moreover, it will be critical for the Turbine Generator team to accurately record, document and disposition lessons learned for Unit 3. Unlike Unit 2, when the Turbine Generator work was far off the critical path, Unit 3's schedule will require a definitive completion and roll-over to Unit 1, as there are less than 3 months of float between the units.

## C. Unit 3 Schedule Development

Since the March DRC Meeting, the Unit 3 schedule has evolved to reflect maturation of planning assumptions, Unit 2's actual performance and lessons learned. As noted in the March 2019 Report, the DR Team's analysis of Unit 2 has continued to result in an increase of the base estimate cost for Unit 3, though with a correspondingly narrower range of project risks (and contingency requirements). This narrowing of project risk and reduction of contingency is a result of the elimination of the One Time Events and the opportunities presented by second-time performance, mitigation of Unit 2 issues and innovations.

RQE assumed a 40-month (1217 days) planned High-Confidence duration for each of Unit 2 and Unit 3. Unit 2 proceeded with a Working Schedule of 1071 days and is currently forecast to complete in 1249 days. At the March DRC Meeting, the Unit 3 forecast was 1028-days, an overall improvement of 43 days v. Unit 2's 1071-day planned Working Schedule.

Starting before the March 2019 Unit 3EE forecast, the Unit 3 DR Team was working to understand the reasons for Unit 2's outcome and rationalize the Unit 2 result to determine high confidence Unit 3/1/4 schedule durations. The DR Team used a deliberative process with multiple iterations and challenges, with CanAtom's full participation. The result is a 1099 calendar day (930 working day) schedule, the difference being that many weekend days are not planned to be full work days with the 24/5 schedule. The following summarizes the process the DR Team used to develop the Unit 3 Working and High Confidence Schedule durations.

### 1. Rev. C Schedule

After more than 6 months of review, vertical slice meetings, challenge sessions and reviews of OPEX, the DR Team agreed on a working schedule on July 10, 2019 known as the Unit 3 Rev. C Schedule, which was 1064 calendar days for Unit 3. This schedule was based on a 24/7 critical path schedule with no "credit" for the D3IP innovations, including the second heavy worktable and simultaneous Pressure Tube and Calandria Tube removal. While the Rev. C schedule did account for the lessons learned through Calandria Tube Installation, it did not account for the Unit 2 experience with the Fuel Channel Installation and Lower Feeder Installation series, which were underway or just completed. Therefore, the DR Team has always assumed there would be an update to the Rev C Schedule.

### 2. 24/5 v. 24/7 Shift Pattern

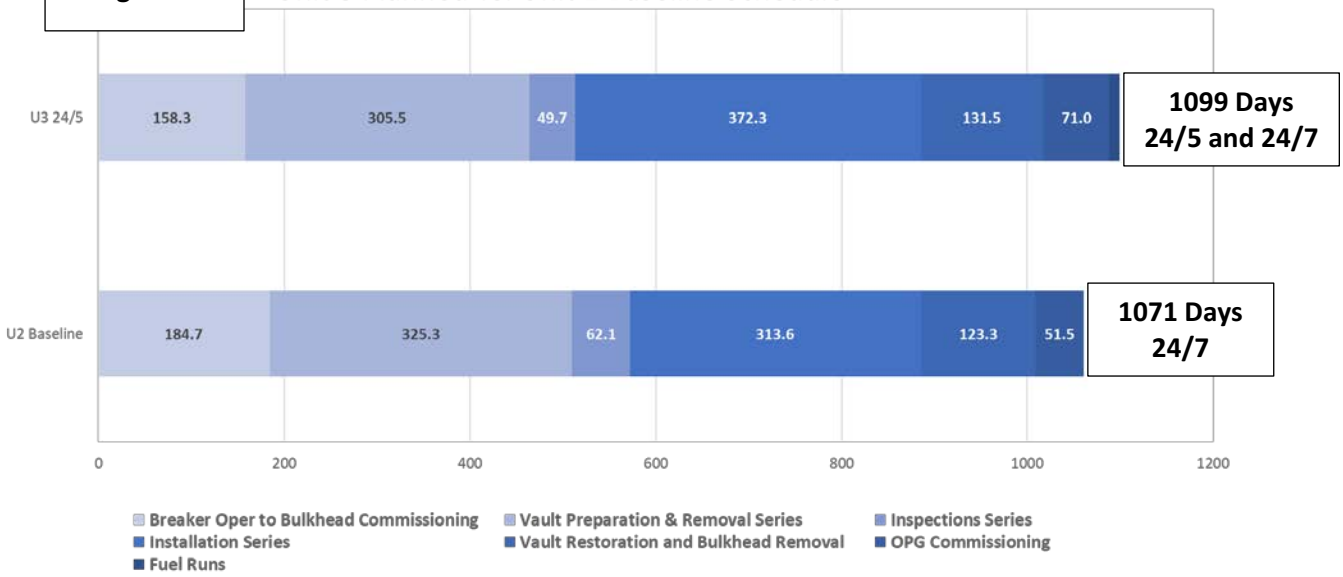
As the Rev. C schedule was being completed, the DR Team began exploring with CanAtom a different shift structure for working the critical path activities. Unit 2's Working Schedule was built using a round-the-clock, 24/7 shift pattern on the critical path with the field craft workers working continuously in a "4 on/4 off" shift pattern. To maintain this shift regime, CanAtom has to employ four different shifts of workers staggered around the clock and weekends. As Unit 2 progressed and each critical path work series closed in on its completion, the field work switched to a "safe sprint" during which it began employing two shifts each working 6 to 7-day weeks at extended hours with smaller, select crews of the top performing craft.

While the 4 on/4 off and 24/7 safe sprint allowed the Project to progress, this had the impact of drawing contingency for overtime and shift premiums.

As a result, CanAtom proposed moving certain work series to a 24/5 schedule, with two 10-hour, five-day-per-week shifts and using 24/7 for only shorter duration work series that are tool intensive. The potential benefits of the 24/5 shift pattern are: a reduction in headcount to fill two shifts vs. four shifts of qualified workers; increased productivity; a reduction in payment of shift premiums and overtime; a reduction in worker burn-out; the availability of weekends to perform clean-up, planning and logistics, and spot overtime if necessary; reduction of PMT to manage the work; among other reasons. The potential downside is not progressing the critical path two days a week. The DR Team weighed the relative benefits for Unit 3 and concluded that the benefits of the 24/5 shift were substantial.

For the Unit 3 baseline schedule, CanAtom has recalibrated its estimate to incorporate 24/5 shifts into ~53% of the critical path activities, comprising 13 of the 97 series on the critical path. Those activities that are short in duration (less than 1 week), are typically focused on the use of a tool and have limited manpower, or where the primary skill is general construction work may remain on the 24/7 shift pattern. Conversely, labour intensive series that rely on training and skill of the trades were deemed candidates for 24/5. As a result, CanAtom reduced its Unit 3 estimate by approximately $70M, based on using the 24/5 shift for approximately half of the work.

**Figure 4** Unit 3 Planned vs. Unit 2 Baseline Schedule




The overall differences by segment between Unit 3 24/5 and the Unit 2 Baseline schedule are as follows:

- **Breaker Open to Bulkhead Commissioning**: The 26-day reduction accounts for a 23-day reduction for defuel and 19 days reduction for descoping the bulkhead shielding from Unit 2 OPEX. These reductions were partially offset by longer durations for Accessibility Platform Trolley ("APT") install, containment testing, and vault vapor recovery configuration.
- **Vault Preparation and Removal Series**: The 20-day reduction is largely due to the consolidation of the PT and CT removal series into one activity, saving 30 days. This savings is offset by longer and shorter durations for a variety of activities that net to approximately 10 additional days.
- **Inspection Series**: The shorter durations for the tube sheet bore cleaning and bellows inspections series result in 12.5 days reduction. These reflect OPEX from Unit 2.

- **Installation Series**: The 59-day increase in the schedule is due to longer durations for Lower Feeders, support scaffolding, and the cantilever installation, and 24/5 durations for Calandria Tube installation, Fuel Channel Installation and Lower Feeder Installation. These changes amount to more than 50 days with additional minor changes adding 9 days increase in schedule duration.
- **Vault Restoration and Bulkhead Removal**: An increase of 8 days to the schedule for vault restoration and bulkhead removal is the net result of several activities that were added and shorter durations for other activities. Activities that were added or are longer duration include Lower Body Tubing, +31 days; Reactor Tooling Platform ("RTP") removal, +17 days; and removal of lower body supports, + 7 days. Activities that were removed or are shorter include replacing the Reactor Accessibility bridge, -20 days; removal of bulkheads and shielding, -17.5 days, and installing feeder cabinets, -9 days.
- **OPG Commissioning**: The 20-day increase in the schedule duration is due to longer durations for OPG activities including hot commissioning, run-up and synchronization, and high-power testing.

As shown above, the first three segments, from Unit 3's breaker open through Removal and the Inspection series, are shorter by a combined ~59 days. This reflects a greater confidence in the work that is both highly mechanized (removals) and more predictable for Unit 3 due to the completion and incorporation of lessons learned from Unit 2. The latter half of the schedule, from the Installation series to Commissioning, represents work that is either underway or only recently completed on Unit 2. Based on the Unit 2 experience, the current Unit 3 schedule reflects 86 calendar days longer for the installation and commissioning portion of the schedule and is overall 28 calendar days longer than the Unit 2 baseline.

With the shift to the 24/5 schedule, there will be ~60 "non-working" Saturdays, of which approximately half are available for catch-up days if the work gets behind schedule. Working these Saturdays would impact direct cost but would not cause a schedule extension. As noted, these are the series CanAtom has not yet completed and incorporated lessons learned into the planning and scheduling of the work in this portion of the schedule. There is an opportunity for further refinement of this portion of the schedule which should be a focus for the DR Team as this work concludes.

### 3. Additional Schedule Challenges

There were additional and multiple challenges by the DR Team to the overall duration of the Unit 3 schedule that CanAtom included in the formation of the Project schedule:

- **3-Point Range Challenges**: As part of establishing the schedule, CanAtom developed a 3-point range that accounted for the base assumptions for each series' Planned/Most Likely, Best Case and Worst-Case scenarios. CanAtom prepared a detailed analysis that identified: basis for each of the 3 points; comparisons to Unit 2 planned and Unit 2 actual durations and assumptions; summary of production levels; and other details that allowed for a granular examination of CanAtom's basis of schedule. This analysis was thoroughly vetted during the Q2/Q3 2019 Unit 3 challenge sessions. This 3-point range analysis should be updated with recent changes to the schedule as well as any further changes that will ultimately be incorporated into the Execution Schedule.
- **Production Rates**: As noted, one of the primary goals for the lessons learned reports was for CanAtom to identify from Unit 2 reasonable and achievable production rates for each of the repetitive work series that could be used as a basis of the Unit 3 estimate and schedule. The lessons learned process produced the initial groundwork for the revised production rates; as part of the recap of each series, the review team examined the point at which the Unit 2 series achieved a sustainable production rate. Based on this analysis, CanAtom adjusted its Unit 3 targets. The DR Team reviewed and challenged each of the major series' production rates to

confirm that they were appropriately calculated and could be repeated in successive units. The result for each such series is based on CanAtom's assessment of reasonable and achievable production rates.

- **Ramp-up and Proficiency Training**: As noted, one of the key lessons learned from Unit 2's performance was the quality and proficiency of craft training prior to entering the vault, which resulted in slower than expected ramp-up rates for certain work series. CanAtom has committed to improve the content and quality of training in the mock-up with a focus on increasing worker's proficiency at the start of the series. CanAtom's training budget for Unit 3 is $51.7M. This investment in training should reduce ramp-up periods for long series such as Calandria Tube Installation, Fuel Channel Installation and Feeders. CanAtom has updated its training process though given the importance attached to it, they should provide demonstrable and measurable evidence that the planned training improvements are materializing.
- **Work Efficiency Factors**: CanAtom provided a series of opportunities to reduce the impact of operational constraints that may improve productivity in the remaining units. These challenges included: reducing previous requirements for wearing plastics in the vault, performing radiological surveys off-shift and other potential improvements. OPG has accepted some of these issues and is working to eliminate identified barriers to the contractors' performance.
- **Incomplete Work Series**: The work series on Unit 2 that have not been completed or for which the full analysis of OPEX and lessons learned has not been performed present an opportunity for further refinement to the overall Unit 3 cost and schedule. These incomplete work series include critical activities: Upper Feeder Installation (off-critical path), Lower Feeder Installation, Lower Body Tubing, vault restoration and start-up. CanAtom has made reasonable assumptions regarding these series, factoring in the 24/5 shift schedule and potential changes based on level of assumed improvement from Unit 2 to Unit 3. As the work and lessons learned process is completed for these series, the results should be monitored as they are incorporated into the schedule and budget.

### 4. Final Execution Schedule

The current agreed 1099 calendar day/930 working day Unit 3 schedule has been approved for planning purposes as the Working Schedule. As with the Rev C Schedule, the Unit 3 Working Schedule will need to undergo additional detailed analysis and challenges in order to finalize the Unit 3 Execution Phase Schedule. The DR Team will need to perform vertical slice reviews to ensure that the schedule can be supported at the granular, day-to-day field operation. The team expects this process to complete in late 4Q.

## D. Risk and Contingency

Throughout the Unit 3 schedule development process, the DR Team has incorporate lessons learned and refined the planning to increase the confidence in the schedule. As a result, the 40 month schedule continue to be a high-confidence duration. As noted, the 24/5 driven critical path will allow the Unit 3 project to utilize some non-working Saturdays for catching up when and if necessary, though there would be cost associated with direct labour, overtime and shift premiums. The DR Team has identified and monetized a discrete risk for use of Saturdays during the 24/5 periods for catch-up when needed.

Unit 3 is holding $257M in total contingency inclusive of $115M in contingency for discrete risks, the most notable of which are:

- Assumed ramp rates are not achieved due to lack of training;
- Retention of trades;

- Vendor performance;
- Turbine Generator controls – first time installation.

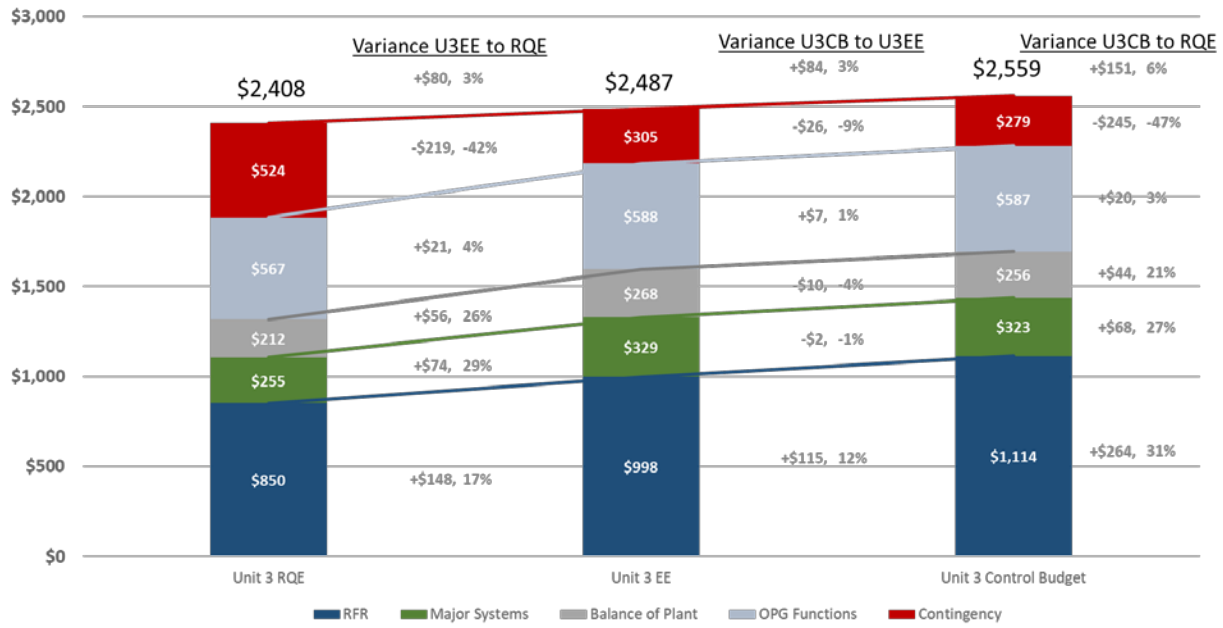
Over the course of Unit 2, the DR Team has increased the effectiveness of the risk management. Currently these and the other articulated discrete risks are being appropriately managed.

## III. Unit 3 Control Budget

The following is a summary of the process the DR Team and the vendors have utilized for development of the Unit 3 Control Budget. In this section, we provide a brief summary of how the estimate for each of the major project bundles has evolved over time. Below is a comparison of the overall variances from RQE to the Unit 3 Control Budget by major estimate component.

### A. Overall Unit 3 Budget Comparison

**Figure 5** Unit 3 Estimate Variances from RQE to Control Budget




[6]

### B. RFR Cost Estimate

RFR is the largest cost component on the DR Project and its activities represent the majority of the critical path. CanAtom's Unit 3 cost estimate is essentially a duration-based estimate derived from unitized production rates, utilizing the updated Unit 3 schedule durations, revised crew sizes, multiple shift patterns and rates to determine the base cost of the direct work. From this DFL base cost of the work, CanAtom built out the project management team including utilizing OPG resources consistent with the OneTeam approach and eliminating redundancy, support services, engineering, and other indirect costs based on their experience from Unit 2 to build a complete estimate. Although not a bottom up re-estimate for Unit 3, this CanAtom estimate does incorporate detailed analysis and revisions based on the

[6] The $202M of Interest for Unit 3 is allocated proportionally to each cost element represented in the chart.

lessons learned on Unit 2 and expected unit-over-unit improvement. This represents a best practice for updating the RQE estimate with actual experience from Unit 2 execution.

The Unit 3 estimate's overall variance from 2016 RQE is an increase of 22% but a decrease from the Unit 2 estimate at completion of 19%. The largest variances in magnitude from the Unit 3 RQE budget to the current Unit 3 estimate are due to changes in the Direct Field Labour and Project Management Team costs. These changes result in $115M of the $157M overall increase in the Unit 3 budget since U3EE.

After the cost estimate was assembled, the RFR DR Team and Burns/Modus performed a series of challenge sessions over the months of July, August, and September with the CanAtom Unit 3 estimating team. The challenge sessions addressed all areas of the estimate from DFL and PMT to Support Services and Goods. The result of these challenge sessions was more than $150M of reductions to the CanAtom estimate. Senior management of OPG and CanAtom were directly involved in these challenges. These and other budget decreases were a direct result of these challenge sessions that occurred between OPG and CanAtom since the March DRC Meeting. The details of each section of the final RFR estimate are further addressed below.

### 1. Direct Field Labour (DFL)

The DFL estimate is based on the duration of the work to be performed, daily production rates, the crew size, and a blended crew labor rate. For the critical path series work, the duration from Unit 2 was used as the starting point and adjusted to remove One Time Events, add savings from lessons learned, and other factors to obtain the duration for the Unit 3 series. In addition, CanAtom determined the optimal shift schedule (24/7, 24/5 or 24/6) for the work based on the length of the series and the nature of the work. For each series, the CanAtom team analyzed the Unit 2 performance and incorporated lessons learned to develop an appropriate crew size. The total estimate for each series then becomes a simple multiplication of duration times crew size times the blended labor rate. The non-critical path series estimates were calculated in a similar manner.

The Unit 3 DFL estimate is $304.7M, a 47% increase from the Unit 3 RQE Budget of $206.7M and a 30% decrease from the Unit 2 Estimate at Completion (EAC) of $432.8M. The largest components of the variance from the Unit 3 budget to the current Unit 3 estimate are due to: Upper Feeders ($26M), PHT and Moderator Drying ($17M), Training and Bridging ($15.6M), Feeder Cabinet Removals ($7M), a variety of smaller changes of up to ~$3M apiece, and the further definition of Site Support within the estimate. These changes reflect the refinement of the crew sizes and durations from Unit 2 OPEX.

### 2. Project Management Team (PMT)

The PMT estimate is based on CanAtom's experience on Unit 2, adjusted to incorporate the unit-over-unit approach. This approach aligns the PMT with each of the three main phases of work: removal, installation, and feeders. The PMT was developed utilizing position requirements and organization charts to determine the headcount and staffing plan for the duration of the work. CanAtom aligned its PMT organization to include key positions from OPG's PMT to reduce duplication and cost. The Unit 3 PMT estimate is $154M, 12% higher than the Unit 3 budget of $138M though 28% lower than the Unit 2 EAC of $213M.

### 3. Subcontracts

CanAtom's subcontract estimate for Unit 3 is $46M, 50% higher than the Unit 3 budget of $30.5M and 50% lower than the Unit 2 EAC of $91M. For the replication of the work on future units, CanAtom has reduced its reliance on technical staff from tooling subcontractors and will rely on its own staff. In addition, shorter durations for the feeder work will reduce the Non-Destructive Examination ("NDE")

subcontract value. Further reductions to the critical path from Unit 2 durations will reduce miscellaneous subcontract costs that are based on overall duration.

### 4. Support Services and Equipment (SSE)

CanAtom's SSE estimate for Unit 3 is $22M, 80% higher than the $11M budget and 51% lower than Unit 2's EAC of $46M. This is a result of CanAtom implementing a small tools management system and purchasing of plant / tools for reuse.

### 5. Owner Supplied Materials (OSM)

The OSM estimate for Unit 3 has increased by 4% to $122.5M from the $117M budget. The increase is due to budget transfers from the Definition Phase to Unit 3 for OSM that will be installed for Unit 3.

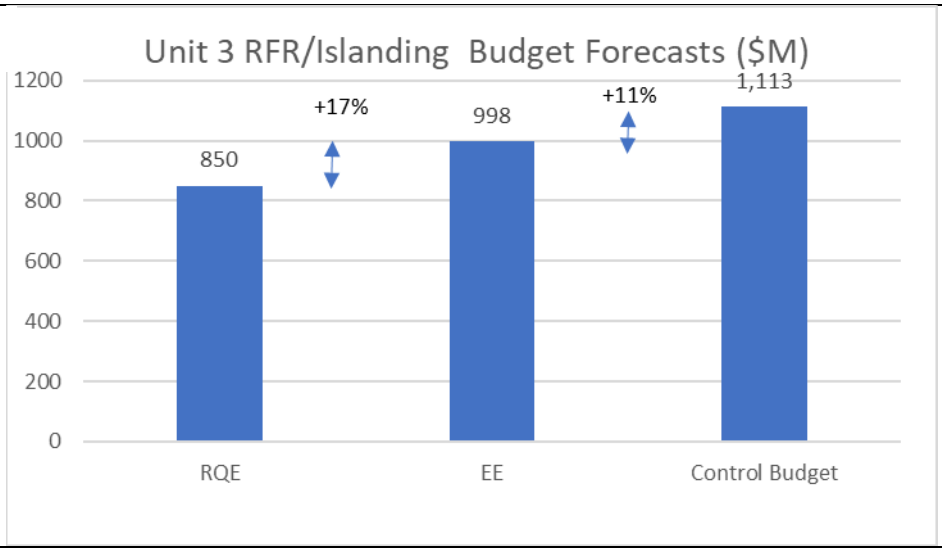
### 6. Goods

CanAtom's Unit 3 Goods estimate has increased from a budget of $10.7M to $50.8M. This represents a revised Goods strategy to purchase and reuse equipment over all units rather than rent equipment. This will reduce rental costs, which results in lower SSE above than Unit 2's EAC. This reuse of goods for Units 1 and 4 justifies lower costs per last two units.

### 7. Reimbursable Non-Markup (RNM), Non-Target Cost (Non-TC), and Fixed Fee (FF) and Markups

The remaining categories of the Unit 3 estimate have increased a collective $3M from the Unit 3 budget of $165M to $168M in the current estimate. This reflects and adjustment based on the Unit 2 experience for the living out allowance for travelling workers.

**Figure 6**




Summary of Major Cost Drivers from RQE to Unit 3 Control Budget:

- Reduction in DFL and PMT due to shift change from 24/7 to 24/5 increased productivity through more training, decreased ramp up time, decreased overtime, reduction in CanAtom PMT org -$100M
- Reductions in Interest, Escalation and Contingency due to retired risks based on Unit 2 lessons learned -$58M.

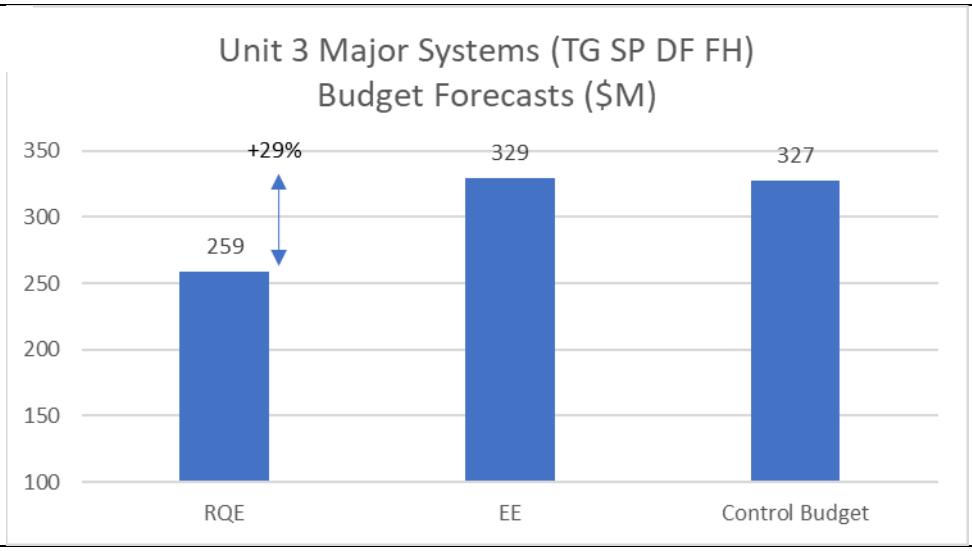
## C. Major Systems

For the Turbine Generator project, CanAtom used the Unit 3 RQE budget as the starting point, adjusting the budget to reflect Unit 2 lessons learned, scope additions, and productivity, though as with RFR, Unit 2 actual costs were not used, except as a reference. One-Time Events were "removed" by using the Unit 3 budget at Unit 2EE as the estimate starting point. OPG oversight costs are based on the start and finish date of the approved OPG resources as per the organizational chart. This is optimized for the multi units overlapped schedule. CanAtom has forecasted a 36% improvement in CPI from Unit 2 of 0.50 to 0.68 for Unit 3. The two scopes of work on the Turbine Generator project that will receive the most attention – digital control change out and stator replacement – appear to have appropriate risks identified and detailed plans for execution. The Digital Controls change out is considered FOAK for Darlington, and the lift planning for the stator will require focus given the issues that occurred on Unit 2.

The other part of the Major Systems bundle is the small Specialized Projects transferred work from BOP, Defueling and Fuel handling Projects. The scope transferred from BOP is to be performed by the Inspection and Reactor Innovation (IRI) division of OPG Operations and Maintenance. OPG oversight is being performed and estimated based on assignment of resources documented in the team's organizational chart. The Major Systems bundle went through multiple challenge sessions associated with Gate 3a.

The following summarizes the Major Systems portion of the Control Budget and changes since RQE.

**Figure 7**




Summary of Major Cost Drivers from RQE to Unit 3 Control Budget:

- Flux detectors, adjuster rods and fission chambers transferred from BOP +$42M
- Reduction in risk and contingency -$18M
- CPI of 0.50 (Unit 2) improving to 0.68 (Unit 3) -$11.1M

## D. Balance of Plant

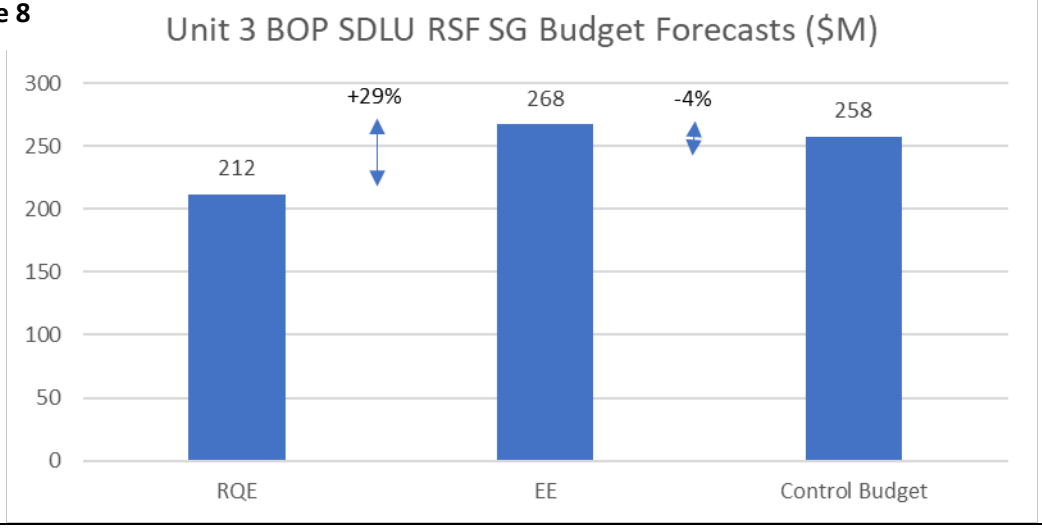
For the Unit 3 estimate, ES Fox used Unit 2 actual costs as a starting point, and removed those costs associated with One Time Events and delays, then applied lessons learned and an efficiency factor of 5%. Where Unit 2 actual costs were not available, because the work was not performed on Unit 2, ES Fox estimated the work on a bottom-up basis with quantities/hours and unit rates. Major differences from Unit 2 include: (1) scope was transferred to Operations and Maintenance and Major Systems; (2) Project-

specific PMT is now consolidated into a single ES Fox PMT organization, and (3) OPG has assumed the design responsibility for this and future units for BOP work, which has reduced cost for design work, as the replication for all three remaining units from Unit 2 was done simultaneously. BOP went through multiple challenge sessions associate with Gate 3a.

ES Fox's Unit 3 performance of the pre-requisite Vacuum Vapour Recovery System ("VVRS") project illustrates how the application of Unit 2 lessons learned can immediately improve upon the performance of Unit 3 work. The VVRS Project is the first Unit 3 project to be completed incorporating lessons learned from Unit 2. On Unit 3, ES Fox attributed the improved results on VVRS to training and continuity of using the same field personnel and removing impediments so the crews could perform. In addition, One Time Events identified on Unit were eliminated for Unit 3. The results from VVRS showed a 50% reduction of cost and schedule the second time it was performed.

The following is a summary of the overall change to BOP:

**Figure 8**




Summary of Major Cost Drivers from RQE to Unit 3 Control Budget:

- Unit 3 valve scope to be performed by Ops and Maintenance within DR Project budget-$46M
- Unit 3 transfer of projects to Specialized Projects under Major Systems -$42M

## E. Functional Support Areas

The Unit 3 Control Budget for the Functions is based on organization charts and a bottom-up assessment of project management and function support needs. The Functional Groups have been through challenge sessions associated with Gate 3a.

Based on Unit 2 lessons learned, the following opportunities have been identified for Unit 3:

- 24x5 shift change will result in lower monthly burn rate
- Reduction in management/oversight costs
- One Team concept will improve communication and coordination
- Align the shift patterns for Operations and Maintenance and Radiation Protection Personnel to match ongoing construction work, and ensure resources are part of scheduled tasks in P6.

**Figure 9**

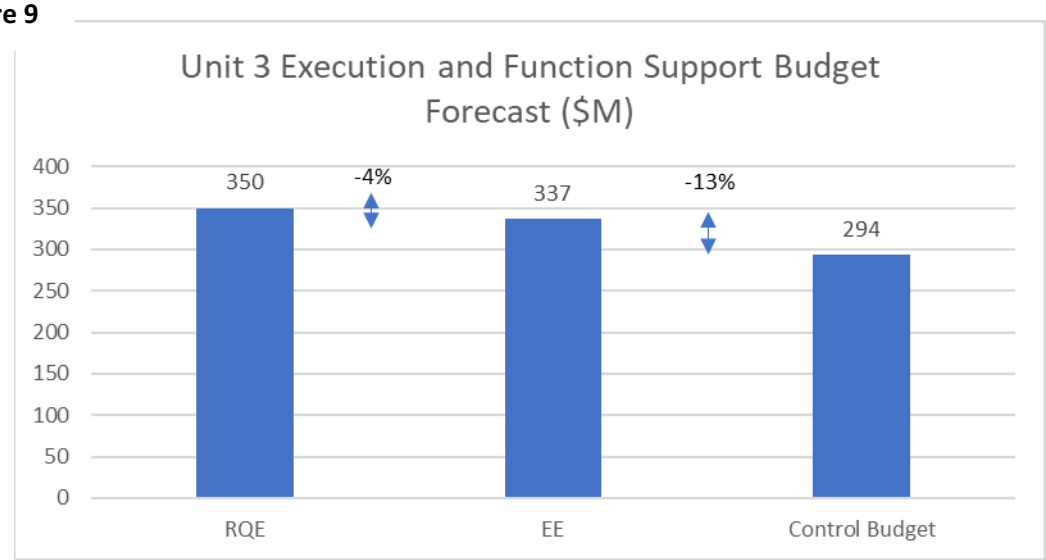
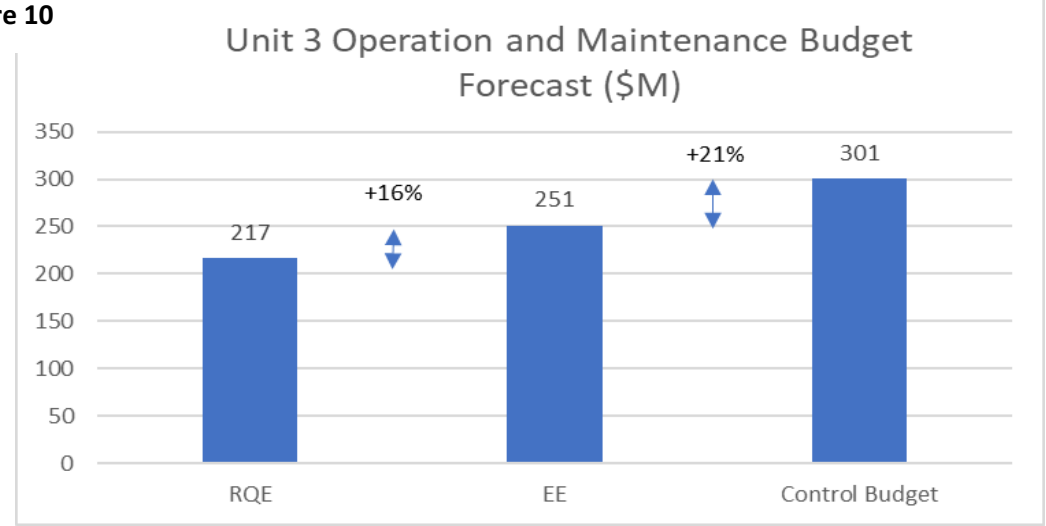



**Figure 10**




Major Cost Drivers from RQE to Unit 3 Control Budget:

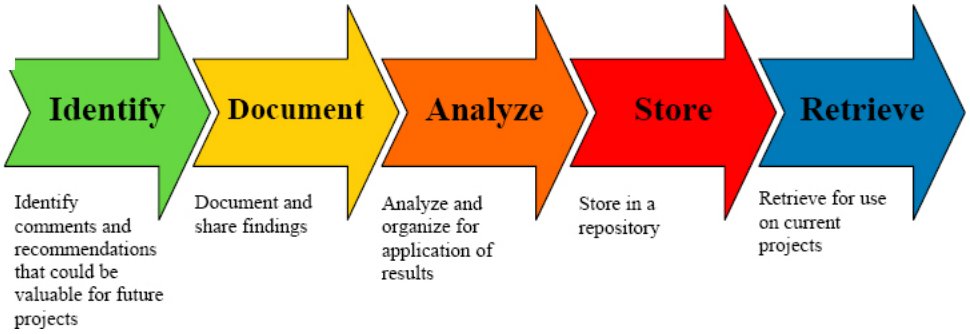
- Change to 24x5 shifts reduces monthly burn rate
- Additional cost due to schedule alignment for revised generation dates
- Maintenance: additional blues usage
- Radiation Protection: increased trades rates; increased support; additional planning, training, RWPB support

# IV. Industry Comparisons and Benchmarking

## A. Unit-over-Unit Improvements

The construction industry highly values the capturing and use of lessons learned from a project. In a presentation to a Project Management Institute (PMI) seminar, Sandra Rowe and Sharon Sikes provided a process for collecting and utilizing lessons learned:[7]

**Figure 11**




Throughout the course of the Unit 2 Project, the DR Team has followed a very similar sequence with extraction of the lessons learned from the project's performance.

From RQE forward, OPG has operated on the assumption that it should realize unit-over-unit improvement in cost and schedule based on leveraging lessons learned and OPEX from each successive refurbishment. The experience and lessons learned derive not only from Darlington, but also earlier refurbishments of CANDU units at Bruce, Wolsong, Point Lepreau and Embalse, each of which CanAtom's partners have supported. In addition, there are lessons from the Pickering Return to Service Project and other nuclear and non-nuclear projects where similar scopes of work were performed multiple times in series, under similar circumstances, and the result the second time through was dramatic improvement. Some examples from our team's background include:

- **Pickering A Return to Service**: OPG performed the Pickering A Return-to-Service (RTS) project beginning in the late 1990s and extending to 2005. The Pickering A units were placed in lay-up condition in 1997 and required extensive refurbishment and upgrading before they could be returned to service. The original program budget was $780M and three-to-four years' schedule for all four units. The initial phase, the Unit 4 RTS Project, was more than 300% over-budget and two years late. A detailed root cause assessment attributed these overruns to: (1) poor scope definition at the outset of the project; (2) poor planning of the work; (3) beginning construction before engineering and planning were sufficiently complete; (4) inadequate project controls that led to a misunderstanding of the project's progress; among other causes. Unit 4 was returned to service in the summer of 2003, and the decision to proceed to the next unit's (Unit 1) refurbishment was in doubt. After a lengthy re-planning process during which the OPG Project Team directly addressed each of the Unit 4 lessons learned, the Unit 1 team established a revised $1B cost estimate (including contingency) and 1-year schedule based on 100% completed design and substantially completed planning and assessing. Unit 1 finished on-time and on-budget despite encountering latent issues and other "known unknowns" that had been anticipated as part of the re-planning process. Overall, Unit 1 represented a $500M and 2-year improvement over Unit 4 and was recognized by Engineering News Record Magazine for revitalizing OPG's

[7] Rowe, S. F. & Sikes, S. (2006). Lessons learned: taking it to the next level. Paper presented at PMI® Global Congress 2006—North America, Seattle, WA. Newtown Square, PA: Project Management Institute.

nuclear program.[8] The Project Team was in advance planning stage of the Restart of Units 2 and 3 when these projects were cancelled due to an adverse assessment of unit conditions.

- **Calvert Cliffs 1 and 2 Steam Generator Replacement Project**: Constellation Energy replaced the steam generators in its twin reactors at the Calvert Cliffs Nuclear Generating Station in 2002-3. The Unit 1 project encountered significant welding issues and missed schedule by nearly 50 days. The Owner and contractor, SGT, engaged in a re-planning project based on a root cause analysis and lessons learned from Unit 1 and reexamining fundamental assumptions for execution. The result on Unit 2 was the project was completed in 66 days, 32 days ahead of schedule. The effort set a world record for quickest steam generator replacement and was completed in 58 fewer days than Unit 1. Moreover, Unit 2's SG replacement welding had zero rejectable indications with no weld repairs required. The most significant welds, done on the steam generator girths, covered 52 feet in circumference per steam generator. Overall, the girth welds improved from 47-days on Unit 1 to 18-days on Unit 2. Mayo A. Shattuck III, Chairman, President and CEO of Constellation Energy Group, stated, "Our crisp execution enabled us to complete this far ahead of schedule. This was much more than a routine refueling outage and major equipment replacement. It was truly an example of what can be achieved with high performance teamwork and meticulous planning." [9] Calvert Cliffs Vice President Peter Katz attributed the outage's success to the outage team's ability to work cohesively and to incorporate lessons learned from across the industry. "We built a strong team to focus specifically on the outage, and we spent months prior to the outage training, qualifying personnel and testing equipment and techniques," Katz said.

Similar to these examples, Darlington Unit 2 has served as the proving ground and laboratory for lessons learned that can be folded into immediate improvements on Units 3, 1, and 4.

## B. 24/5 Shift Pattern and Craft Overtime

Labour proficiency, sustained productivity and availability of craft workers are several key risks that were realized on Unit 2. The risk of having a relatively small pool of highly skilled nuclear workers presents a challenging problem for Units 3/1/4, which will each have a period of overlap and will run concurrent to Bruce Power's MCR Program.

While there are benefits to the 4 on/4 off shift utilized on Unit 2, it can require a heavy PMT burden to effectively manage the craft workers. The intent of the 4 on/4 off extends the project "day" to a full 24 hours, filling in the time each day a two shift, 10-hour day does not cover. However, Unit 2 lessons learned showed that the high numbers of craft workers with myriad qualifications and training made managing 4 on/4 off difficult for CanAtom. At the end of each work series, Unit 2 field management often temporarily suspended the 4 on/4 off shift for the two shift "safe sprint" to utilize the best of the skilled craft workers in a concentrated effort.

To mitigate these risks for the subsequent units, CanAtom and OPG are planning to use a 24/5 shift structure for approximately 53% of the duration of Unit 3's critical path. The immediate effect is to stretch the planned 930 working days to 1099 calendar days. In addition, the new shift pattern will require coordination at the field level as a number of work series, particularly in the early stages of the project, will continue on the 24/7, 4 shift schedule. In exchange, the benefits of the 24/5 schedule include:

- CanAtom will need fewer craft workers on Unit 3 than on Unit 2, which should result in increased productivity and lower overall cost;

[8] https://www.enr.com/articles/13339-ontario-utility-shakes-off-troubles-and-invigorates-nuclear-program?v=preview
[9] https://www.power-eng.com/2003/04/25/constellation-energy-group-completes-steam-generator-replacement-outage-at-calvert-cliffs-nuclear-power-plant/

- Craft workers can plan to work longer weeks from the onset of the project, instead of needing to work unscheduled overtime when the project fell behind, thus avoiding burnout;
- CanAtom and OPG will need fewer PMT to manage the work and be able to effectively spread its management personnel over multiple units.

Many in the industry who study the effects of overtime on craft productivity would support moving to the 24/5 shift pattern. "In a tight labour market, overtime has frequently become the planned schedule from the onset of the project," due, in part to, "a shortage of skilled craftspersons,… the premium pay associated with overtime has become a necessity to attract the required workforce."[10] This meshes with our experience, as the 50-hour week has become a typical schedule on projects in the United States, especially on projects that need to attract travelers.

Nonetheless, many in the industry also recognize that a 50-hour work week with 10-hours of overtime would eventually result in reduced productivity. Many of the labour studies on this issue relate to construction projects only slightly similar to the conditions in a nuclear construction environment. Much of the data analyzed in contractor associations (NECA, MCAA) relates to unplanned extended overtime, not a planned 50-hour week. Four studies performed in the 1970's to 1990's by heavy contractors and contractor trade associations conclude that a 50-hour work week results in a decline in productivity over a 12-14 week period. The range of productivity loss at approximately 5 weeks was 5% to 10%; over a 12-week period, productivity was impacted by a maximum of ~15%. The decline in productivity is much steeper for 60 and 70-hour weeks.

A more recent review by the MCAA concludes that unplanned 50-hour weeks result in productivity below 0.80 generally after seven weeks. (MCAA Bulletin No. OT1, revised, 2011) Moreover, the MCAA notes, "Experience indicates that a return to a normal 40-hour schedule tends to 'reset' the productivity of the crew, such that if the crew returns to an overtime schedule, the productivity loss would 'reset' to that of the first week of overtime." (Id)

These conclusions are significant for the DR Project. Because the majority of the work series in which the craft will be working 24/5 shift patterns are between 25 – 45 days, the workers on these shifts will get the relief described from the 50-hour work week before productivity loss occurs. Thus, CanAtom may be able to manage a large portion of Unit 3's labour in the "sweet spot" by balancing stretches of overtime fewer than 10-12 weeks and allow for the 40-hour/week reset for several weeks thereafter.

For the longer series (Calandria Tube installation, Fuel Channel Installation and Feeders), CanAtom is planning to employ a two-shift, 60-hour/week safe sprint at the end of these series. The impact of such planned overtime may not be as significant as the above studies of mostly unplanned overtime. One study looked at the impacts of long-term, extended overtime and found the impact of 50-hour week to be 5% to 10% over the long term. (Hanna, Taylor and Sullivan)

On the DR Project, labour availability, particularly in light of concurrent units, and capability, makes the 24/5 shift for Unit 3/1/4 a viable, if not preferable method to proceed. If CanAtom and OPG can effectively manage this shift pattern mindful of the trends cited above, CanAtom believes moving to the 24/5 shift will result in a $70M cost savings with manageable schedule impacts.

[10] Impact of Extended Overtime on Construction Labor Activity, Awad S. Hanna, P.E., M.ASCE, Craig Taylor and Kenneth T. Sullivan, Journal of Construction Engineering and Management, ASCE June 2005

## C. Estimate Classification

Prior to RQE, OPG adopted the guidance of AACE International to help characterize the quality and inputs to the DR Project's estimates. As we noted in our RQE Report, the AACEi has provided guidelines, not standards, for the construction industry to use as a communication device for "all the stakeholders involved with preparing, evaluating, and using project cost estimates. The various parties that use project cost estimates often misinterpret the quality and value of the information available to prepare cost estimates, the various methods employed during the estimating process, the accuracy level expected from estimates, and the level of risk associated with estimates."[11]

The AACEi Classification System was developed, "to help those involved with project estimates to avoid misinterpretation of the various classes of cost estimates and to avoid their misapplication and misrepresentation. Improving communications about estimate classifications reduces business costs and project cycle times by avoiding inappropriate business and financial decisions, actions, delays, or disputes caused by misunderstandings of cost estimates and what they are expected to represent."[12]

The AACEi authors of the Cost Classification System provide a series of objective criteria that can be used, often with modification for individual circumstances, for classifying estimates based on the methodology used and the maturity level of underlying information on which an estimate is based. AACEi identifies assignations from Class 5 (least mature) to Class 1 (most mature).

Based on the maturity of the inputs and overall quality level, Burns/Modus concludes that OPG's Unit 3 estimate is commensurate with a Class 2/1 estimate. The following comparison illustrates the effort applied by OPG and the vendors has aspects of both Class 1 and Class 2 estimates; we have provided a "√" to identify which characteristics are met by the Unit 3 estimate.

**Chart 6 Comparison of Estimate Class Characteristics – AACEi 18R-87[13]**

| Characteristic | Class 2 | | Class 1 | |
|---|---|---|---|---|
| Level of Definition | 30% to 70% of full project definition | | 50% to 100% of full project definition. | √ |
| Estimating Methods Used | Class 2 estimates always involve a high degree of deterministic estimating methods. Class 2 estimates are prepared in great detail, and often involve tens of thousands of unit cost line items. For those areas of the project still undefined, an assumed level of detail takeoff (forced detail) may be developed to use as line items in the estimate instead of relying on factoring methods. | √ | Class 1 estimates involve the highest degree of deterministic estimating methods and require a great amount of effort. Class 1 estimates are prepared in great detail, and thus are usually performed on only the most important or critical areas of the project. All items in the estimate are usually unit cost line items based on actual design quantities. | √ |

[11] AACE® International Recommended Practice No. 17R-97 COST ESTIMATE CLASSIFICATION SYSTEM TCM Framework: 7.3 – Cost Estimating and Budgeting
[12] ID
[13] AACE International Recommended Practice No. 18R-97, COST ESTIMATE CLASSIFICATION SYSTEM – AS APPLIED IN ENGINEERING, PROCUREMENT, AND CONSTRUCTION FOR THE PROCESS INDUSTRIES TCM Framework: 7.3 – Cost Estimating and Budgeting

| Chart 6 | Comparison of Estimate Class Characteristics – AACEi 18R-87[13] | | | |
|---|---|---|---|---|
| **Characteristic** | **Class 2** | | **Class 1** | |
| Expected Accuracy Range | Typical accuracy ranges for Class 2 estimates are -5% to -15% on the low side, and +5% to +20% on the high side, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Ranges could exceed those shown in unusual circumstances. | √ | Typical accuracy ranges for Class 1 estimates are -3% to -10% on the low side, and +3% to +15% on the high side, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Ranges could exceed those shown in unusual circumstances. | √ |
| Effort to Prepare | Typically, as little as 300 hours or less to perhaps more than 3,000 hours, depending on the project and the estimating methodology used. | | Class 1 estimates require the most effort to create, and as such are generally developed for only selected areas of the project, or for bidding purposes. A complete Class 1 estimate may involve as little as 600 hours or less, to perhaps more than 6,000 hours, depending on the project and the estimating methodology used. | √ |
| End Usage | Class 2 estimates are typically prepared as the detailed control baseline against which all actual costs and resources will now be monitored for variations to the budget and form a part of the change/variation control program. | | Class 1 estimates are typically prepared to form a current control estimate to be used as the final control baseline against which all actual costs and resources will now be monitored for variations to the budget and form a part of the change/variation control program. They may be used to evaluate bid checking, to support vendor/contractor negotiations, or for claim evaluations and dispute resolution. | √ |

Based on these criteria, the level of accuracy associated with a Class 2/1 estimate would support contingency in the range of 10%. Unit 3's 12% contingency against the ETC would appear to be appropriate given all of the considerations discussed herein. We provide some recommendations that could further improve the confidence level of the Unit 3 Control Budget and Schedule prior to Unit 3 breaker open.

## V. Recommendations and Risk Areas

Burns/Modus finds the process used in preparation of the Unit 3 Control Budget and Schedule consistent with a Class 2/1 estimate under the AACEi Classification guidance. Since the March DRC Meeting, the DR Team has addressed the open items then apparent, and the development of the schedule and cost estimates has proceeded in a constructive, progressive manner with significant challenge sessions occurring throughout. Issues we identified in our March 2019 Report with the quality of CanAtom's estimate were addressed and their Unit 3 estimate has been prepared on the basis of unitized production rates that were observed in Unit 2's performance. The lessons learned from Unit 2 should provide for significant improvements in performance for Units 3/1/4.

The major risks for Unit 3 appear at this time to be:

- The Turbine Generator work, including the controls change out and stator installation, that have not been done to date at Darlington and are more time-sensitive due to the unit overlaps;
- Any potential issues that may arise through the completion of Unit 2 that will impact Units 3/1/4;
- The initial unit overlap from Unit 1, which could challenge the planning of Unit 1 and the execution of Unit 3; and to a much lesser extent,
- The RFR Feeder Work, which as documented herein will need to evaluate and embed lessons from Unit 2 to mitigate a repeat of those issues;
- The ability to attract and retain qualified craft for the RFR work and the ability to train those resources to the level of proficiency required to perform the work at the expected ramp rates and productivity levels required to achieve the schedule.

The reduced risk that comes from repeating the work should provide confidence that Unit 3 can complete within the total RQE envelope, thus increasing the certainty of maintaining the total $12.8B RQE budget. The DR Team's work also sets a good course for continuous improvement of the budget and schedule for Units 1 and 4.

With that said, there is work remaining for the DR Team to accomplish for refining and honing the estimate and schedule for Unit 3's performance and progressive development for Units 1 and 4. The following are Burns/Modus's recommendations for OPG to consider related to Units 3/1/4:

- **Finalizing the Unit 3 Control Budget and Schedule**: The Unit 3 Control Budget and Schedule that is being presented to the BOD for approval is substantially complete, though can change if and when more is known about the remaining series that are currently in-flight on Unit 2. The DR Team's efforts to finalize the Unit 3 Control Budget and Schedule will continue until Unit 2 is completed and lessons learned can be extracted, evaluated, and transacted from the recently completed work (Lower Feeders), the remaining vault restoration and startup of Unit 2. In addition, there is work ahead for the team to complete the Unit 3 Execution Schedule and to ensure the Control Budget accurately reflects the final high-level adjustments to the RFR schedule and CanAtom needs to complete the Basis of Estimate documents for Unit 3. There is risk that the remaining work and analytical efforts could result in changes to the Unit 3 estimate. The DR Team believes this risk is bounded at this time by the Unit 3 Control Budget. In any event, all changes that occur after the BOD approval will be required to go through formal change control.

    - <u>Recommendation:</u> The DR Team should establish tracking metrics for the remaining work series to communicate any revisions to the Unit 3 budget and schedule; the team should also identify the milestones and schedule for completing the Unit 3 Execution Schedule, including all vertical slice and resource assessments and detailed schedule input needed for the Unit 3 baseline.

- **Feeder Work Requires Re-planning and Estimate and Schedule Updates to Build Confidence**: The Feeder Work resulted in the largest variances to the Unit 2 budget and represents the largest individual changes from U3EE to the Unit 3 Control Budget. The Feeder lessons learned examination has only just begun and until it is complete there is a risk that CanAtom's Unit 3 estimate could be impacted (reduced or increased). As with the other key series, a production trend emerged at the end of the Lower Feeder Installation that may be useful for establishing a forward-looking production rate. Once the lessons learned process is complete, CanAtom's Unit 3 Feeder plan, schedule and

estimate will require additional vetting to ensure consistency, accuracy and clearly identified changes from Unit 2.

- Recommendation: CanAtom should provide check estimates of select elements of the Feeder work. Such an estimate could provide additional comfort that the Unit 3 estimate is correct and properly bounding based on the risks of performance. CanAtom should also clearly identify any changes needed from RQE and detail the revised estimate for Units 3/1/4. Once the plan is complete, the Feeder program would benefit from a thorough, 360-degree readiness review that vets the Feeder team's ability to avoid and mitigate the issues that impacted Unit 2.

- **Lessons Learned Process Evolution**: As noted, Burns/Modus finds the current lessons learned process and the resulting information to be well developed and executed. With the unit overlaps and shortened planning periods, the lessons learned process will need to evolve for the results of the process to be timely for each successive unit. Moreover, the methodology for monetizing impacts from events for Units 1 and 4 needs to be standardized so that it can be completed more efficiently.

  - Recommendation: The lessons learned program going-forward should be evaluated to ensure timeliness, increase metrics and documentation for the future units. The DR Team should institute tracking metrics that identify the status of ongoing lessons learned and impacts. The process needs to be quickened and streamline for use on the overlapping units 1 and 4. The DR Team should establish a method for monetizing lessons learned directly linked to the estimate of the follow-on unit.

- **Project Controls Improvements**: The DR Team is already pursuing a combined project controls team with CanAtom. This plan revolves around combining collection points of data and producing a single set of project metrics from the OneTeam. As we have noted throughout Unit 2, the fidelity of the project controls systems has been achieved, though the methods used for forecasting and homing in on critical reporting formats need improvement.

  - Recommendation: This combined effort would benefit from a Unit 2 reporting lessons learned and assessment of effectiveness, followed by a strategic plan for improvements to cost and schedule reporting. The refined reporting methods would take advantage of the work of OPG's PMO. Once the work is better defined, the combined staff can be right-sized, and decisions can be made regarding systems, processes, etc. that can achieve economies of scale.

- **Estimating Unit 1 and 4**: The next units' estimating effort will be more urgent given the unit overlaps. This effort will rely on the forecasting and analysis of on-going Unit 3 work in real-time. In addition, there is an expectation for an ever-tightening range of outcomes, as the contingency for each unit appropriately lessens with performance on the 3rd and 4th unit. OPG will need [redacted] cooperation from CanAtom [redacted] to provide timely and accurate cost and schedule information needed for forecasting and estimating.

  - Recommendation: OPG should prepare and issue a standardized estimating template so that the estimates prepared by vendors are consistent with OPG controls and standards. Also, the OPG Estimating Group should perform early in the forecast review processes and perform

check estimates to validate vendor estimates. OPG should re-consider utilizing US COST (or a similar platform) for collection of cost data for Units 3, 1 & 4.

- **Training**: Given how important training will be for improving on Unit 2's performance, CanAtom should work shoulder-to-shoulder with OPG to refine the training program. CanAtom needs to set reasonable targets for training so that the effort is right-sized and not considered a panacea that will impose performance by itself.

    - Recommendation: CanAtom should establish a verifiable work plan with interim goals and tracking metrics to validate the effectiveness of the training. CanAtom should also grade the effectiveness of training based on field performance. There should also be a cost element applied to confirm CanAtom is providing value-for-money with its training program. Finally, the training program should be subjected to periodic independent monitoring.

- **Labour Management**: As noted, the plan for Unit 3 has been altered to recognize the risks with availability of craft labour. Moreover, the Unit 2 labour overrun and issues with productivity reflect a need for further analysis and changes. Much of what should mitigate these labour issues should come from lessons learned and improved CWPs and work instructions, and the 24/5 shift addresses the need for a smaller workforce. OPG has also taken the lead with local trades to establish programs to increase the population of qualified craft workers. However, there is a need for CanAtom to look deeper to retain the best craft and PMT for the long haul.

    - Recommendation: CanAtom should consider an incentive program that provides workers additional compensation for meeting schedule, budget, quality, safety and attendance goals. Such incentive programs are most effective when they are public goals, which create a level of professional competition and pride. In our experience, even small incentives can have a real impact on the craft. In addition, there should be some level of retention plan that ensures well-trained and experienced craft workers stay at Darlington through Unit 4.

- **Programmatic Approach to Units 3/1/4**: The DR Team is considering methods for applying a programmatic approach to the remaining units based on the repetition of performance of individual series across the remaining units. CanAtom has already broken its performance by Area Managers to begin this task. The team is looking for methods of retention of key workers who are managed for repeat performance of the same work series, which would eliminate learning curves and improve efficiency.

    - Recommendation: The DR Team is looking to establish a 3-unit execution strategy that is schedule focused to identify opportunities to roll-over personnel from one unit to the next with optimal time between overlaps. The DR Team should rationalize the PMT to the extent possible to spread their work across the three units. Along with this strategy change, the team should make appropriate decisions regarding potential bundling of work packages across the three units for repetitive performance. Also, there will be a need to change the method of reporting akin to a portfolio management program, where performance is gauged by unit and also by common work series. Finally, the DR Team should evaluate opportunities to rationalize the required roles and reduce OPG's PMT costs as a result of the change to a programmatic approach

**Appendix A – Sampling of Work Series Lessons Learned from Unit 2 v. Unit 3 Planning**

The following chart summarizes select key work series on the critical path that have been performed on Darlington Unit 2, reviewed for lessons learned and re-planned for Unit 3. The Unit 3 Plan columns show a comparison of CanAtom's assessed durations for each of these series on a 24/7 shift v. a 24/5 and summarize the basis for:

- Selecting the planned shift;
- Calculating the duration;
- Identifying from lessons learned how CanAtom is altering its work planning.

| Critical Path Work Series | Unit 2 Plan | Unit 2 Actual | Unit 3 Plan (24/7) | Unit 3 Plan (24/5) | Unit 2 Events | Unit 3 Plan Rationale |
|---|---|---|---|---|---|---|
| Defueling | 116 | 87 | **90** | N/A | Defueling exceeded the most optimistic duration | Unit 3 has assumed +3-day margin over best-ever performance on Unit 2; work will be on 24/7 shift |
| Vault Preparation; APT Install, Shield Plug Swap | 10 | 10.8 | 13.4 | **11.4** | Various series; Unit 2 went generally as planned | Shift pattern includes both 24/7 and 24/5 based on difficulty of tasks |
| Bulkhead; Containment Isolation; Prerequisite Work | 74 | 73 | 37.6 | **44 (24/6)** | Execution was impacted by welding issues, logistics and field management | Planned reduction in duration based on simplified bulkhead design from Unit 2; reduction in welding time; less complex pre-requisite work for Unit 3; Shift chosen is 2-shifts, 60 hr/week (24/6) due to nature of the work |
| Bulk Interferences and PDS Installation | 23.8 | 21.2 | 22 | **26.3** | Lost time with cable trays and rerouting | 24/5 shift due to length of series; productivity gains and reduced scope assumed as part of Unit 3 series |
| RTP Installation | 33 | 56 | 46.5 | **50.4 (24/6)** | One time events and issues from Unit 2 installation assessed; resulting in 15 day reduction to critical path; CanAtom's further analysis reduced to 9.5 days. | Work will be performed on 24/7 and 24/6 schedule due to nature of the work. |
| End Fitting Removal | 37 | 55.8 | 29.64 | **41.5** | 6-day late start; 20-day late finish; 10 documented incidents of One Time Events | Repairs to End Fitting tool to improve reliability; increase to base duration due to overall difficulty. 24/5 shift chosen due to longer series, benefit of not working weekends is catch up on flasking, and |

| Critical Path Work Series | Unit 2 Plan | Unit 2 Actual | Unit 3 Plan (24/7) | Unit 3 Plan (24/5) | Unit 2 Events | Unit 3 Plan Rationale |
|---|---|---|---|---|---|---|
| | | | | | | reducing number of trades needed to be trained for execution |
| Pressure Tube Removal/ Calandria Tube Removal | 34 + 30 | 40.6 | 25.8 | **36** | 16 issues identified resulting in 12 days of impacted performance | D3IP Innovation to perform CT and PT Removal together; 24/5 shift chosen based on PT Removal duration; net savings of 30 days on critical path |
| Tube Sheet Bore Cleaning and Inspection | 33 | 33 | 23 | **24.1** | Slow ramp-up; Productivity issues to be enhanced on future units with additional tooling. | Training improvements and tooling; 24/5 shift to increase productivity and reduce number of craft trained |
| Calandria Tube Installation | 102 | 116 | 85 | **90** | One Time Events caused 39 days of delay | Process and tool enhancements, improved training, proficiency and productivity will reduce duration; 24/5 shift chosen due to long duration, specialized training |
| Fuel Channel Installation | 125 | 161 | 116 | **123** | Problems with tool and material management, training caused 46 days of delay; issues with ramp-up to sustainable production level | CanAtom is addressing reasons for slow ramp-up; re-working training and logistics; tool and material availability. 24/5 shift pattern with improved ramp-up time |
| Lower Feeder Installation | 96 | 193 | 97 | **117.2** | Multiple One Time Events beginning with Upper Feeder Installation issues; logistics and set-up for welding resulted in down-time; weld failure rates spiked; field management and craft productivity | CanAtom to assign an Area Manager and reorganize entire Feeder campaign; utilize smaller, highly trained crews from Upper Feeder through Lower Feeder work. 24/5 shift chosen for smaller workforce, use of weekends for tool maintenance and logistics; duration and estimate for Lower Feeders includes last month of Feeder install will be run on a 24/6 schedule, once the crews get up to speed they will work Saturdays in a "safe sprint" |