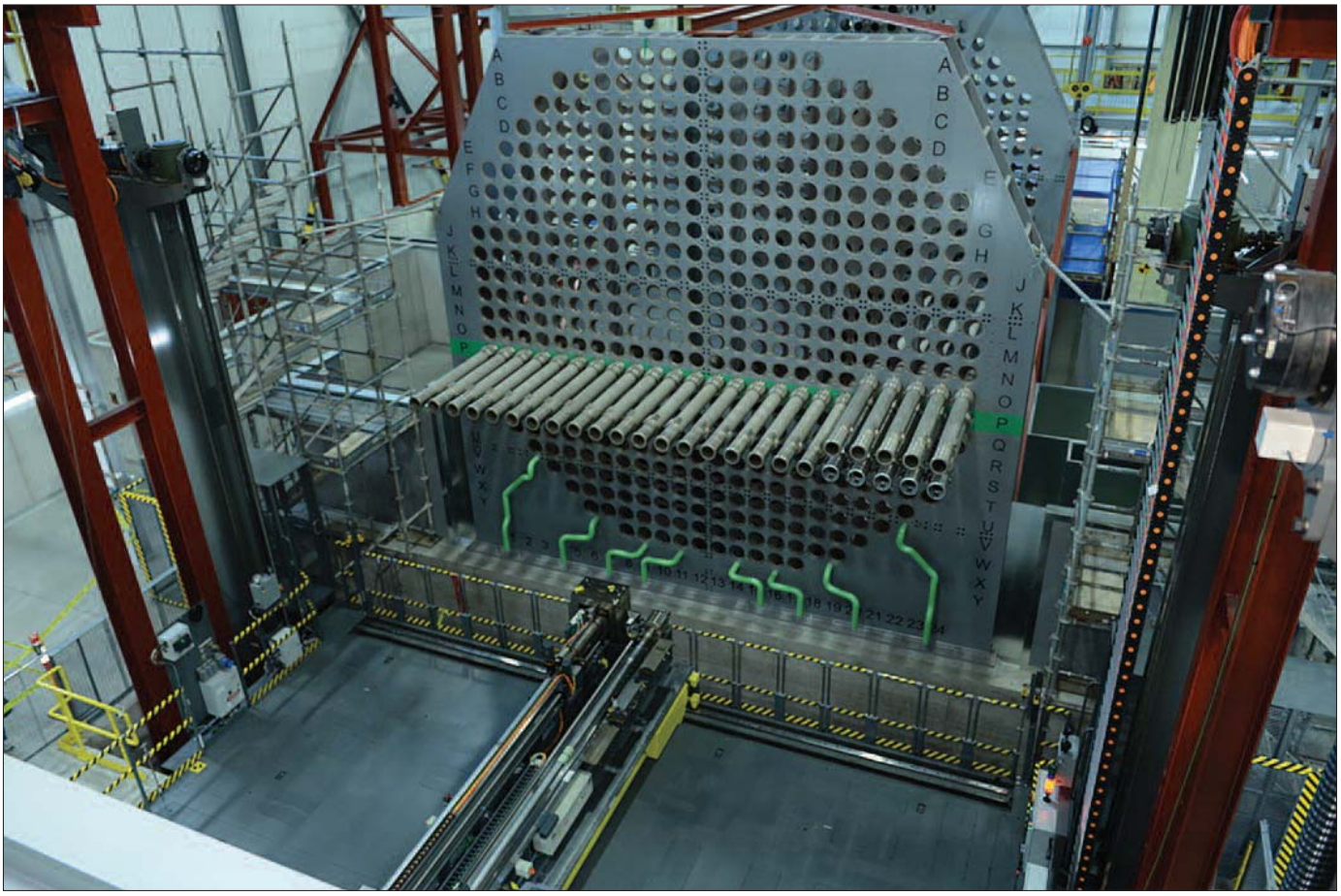


The reactor mock-up with the retubing tooling platform, heavy worktable, and cutting tools.

Darlington station to double its lifetime of service to Ontario

By Dick Kovan

Lessons learned from previous CANDU refurbishments provide the basis for Darlington's 10-year project plan.

The refurbishment of the Darlington nuclear generating station will ensure that the 3,512-MWe station remains the mainstay of Ontario Power Generation's (OPG) electricity system for another 30 years. The first of the station's four CANDU 6 reactors should start its refurbishment program next year. Based on the current schedule, the Darlington Refurbishment Project will be completed and all of the reactors will be in operation by 2025.

Darlington's reactors, each rated at 878 MWe, are the youngest and largest of OPG's nuclear fleet. The plant, which is located in Clarington, 70 km (about 44 miles) east of Toronto, has maintained strong operating performance since it began commercial operation in the early 1990s and currently produces 17–20 percent of Ontario's electricity.

In June 2006, OPG was directed by the Ontario government, the company's single shareholder, to carry out feasibility studies to consider the option of refurbishing the Darlington reactors in order to extend their service lives. Following the completion of preliminary assessments, OPG announced

The Darlington Energy Complex

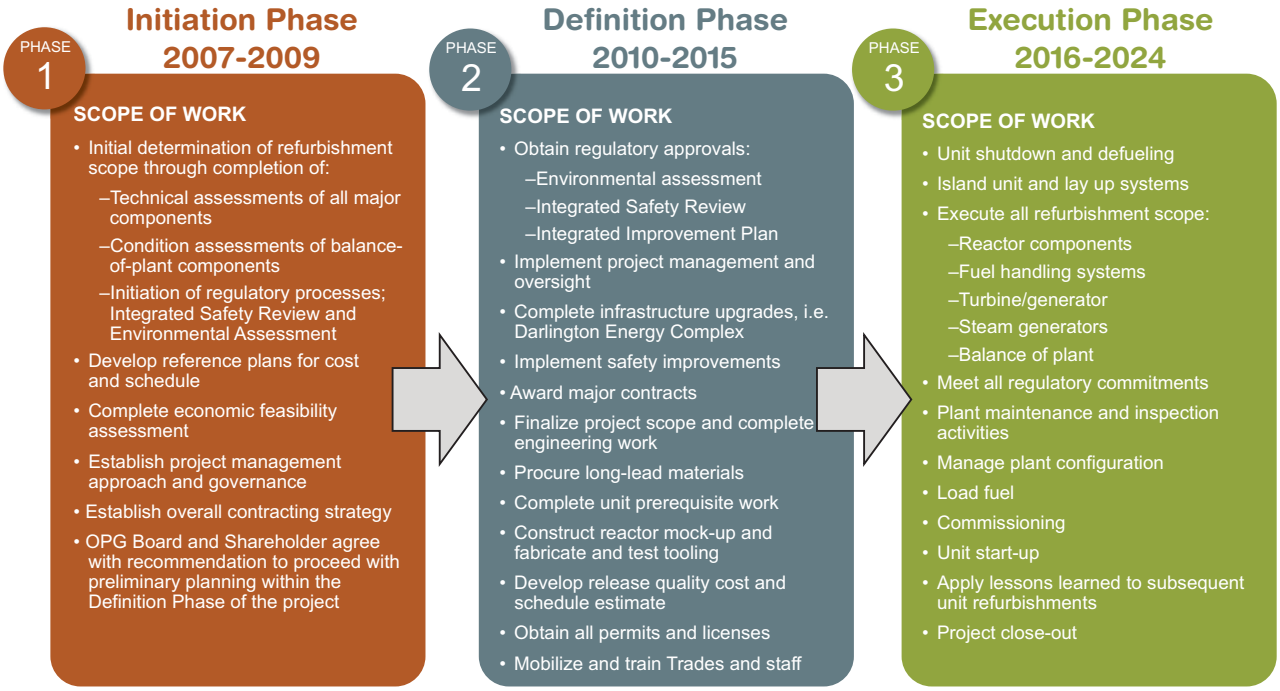


Fig. 1. The three phases of the Darlington Refurbishment Project and the work scopes to be carried out during each phase.

in February 2010 that it would go ahead with the refurbishment. This decision was later confirmed by the Ontario government in December 2013 when it released its Long-Term Energy Plan.

Planning a refurbishment

A mid-life refurbishment, which is undertaken when a reactor is nearing 30 years of service, is now a planned part of the life of a CANDU reactor, allowing it to operate for up to 60 years. A CANDU reactor vessel is a large, heavily shielded calandria with hundreds of tubes containing fuel channels. Being the largest CANDU 6 reactor design, the Darlington calandria contains 480 horizontal fuel channels with 6,240 fuel bundles encased in Zircaloy sheathing. Each reactor will be out of service for about three years for its refurbishment, which involves the replacement of fuel channels, feeder pipes, calandria tubes, and end fittings; the renovation of steam generators, turbine generators, and fuel handling equipment; and system improvements and plant upgrades to meet current regulatory requirements.

In late 2007, OPG commenced what was the first of a three-phase program for the refurbishment project. This Initiation Phase focused on assessing the condition of the plant, determining a preliminary scope of work to be carried out during the project, and performing an economic feasibility assessment. This first phase was followed by a Definition Phase, and then an Execution Phase, which are all outlined in Fig. 1.

The Initiation Phase was completed in 2009. Considering that Darlington is one of the top-performing CANDU stations in the world, it is not surprising that assessment results were promising and that OPG decided to move forward with the project.

Project definition

Once OPG announced that it would carry out a refurbishment program, the focus moved to the Definition Phase, which involves, in general, establishing project management, finishing the detailed design for the refurbishment, completing negotiations for vendor contracts, obtaining regulatory approvals, and locking down the refurbishment project's scope of work, budget, and schedule.

To manage the refurbishment, OPG chose to take on the roles of general contractor and project manager for all aspects of the Darlington project. This allows OPG to have direct oversight of the vendors and their work on the many tasks that make up the refurbishment project.

OPG established the Darlington Refurbishment Team (DR Team), made up of people who have extensive refurbishment experience, to plan and implement the project. According to OPG, this is the same model used for the highly successful refurbishment project at South Korea's Wolsong -1 CANDU 6 plant, which is being used as a reference for the Darlington project. Atomic Energy of Canada Limited (AECL), which developed the CANDU technology, was a major contractor for the retubing project at Wolsong. Since then, SNC-Lavalin purchased AECL's commercial operations, now known as Candu Energy. SNC-Lavalin, in partnership with Aecon Industrial, won the engineering, procurement, and construction (EPC) contract for the retubing work package for Darlington.

Besides establishing the project management, many projects and other activities to be carried out in the refurbishment are spelled out during the Definition Phase. This includes the major reactor work to be done during the Execution Phase, as well as the Prerequisite Projects that are to be completed during the Definition Phase in readiness for the Execution Phase.

There are now 18 Prerequisite Projects divided into two broad categories, Facilities and Infrastructure projects, which tend to involve actual construction work, such as the Darlington Energy Complex (see *NN*, Apr. 2013, p. 46), and Safety Improvement Opportunities and Other Projects.

Major work packages

While the complete Darlington Refurbishment Project includes many individual projects of various scales and size, the activities included in the Execution Phase are covered by five major work packages that are planned and managed by the DR Team and are carried out under EPC contracts. Also, the 18 Prerequisite Projects that must be completed and ready for service at the start of the refurbishment have been assembled into a work package that is carried out during the Definition Phase.

The major work packages are as follows:

■ *Retube and feeder replacement*—This work includes the removal and replacement of pressure tubes, calandria tubes, and feeders in each reactor. This is the largest work package, accounting for about 60 percent of the total, and is vital to the success of the refurbishment. According to the 2014 year-end report, tooling development was complete, tool proving and testing were under way, and tooling performance was exceeding expectations.

■ *Turbine generators*—This work consists of inspections of and repairs to the four turbine generator sets and the replacement of

Millwrights leveling a section of a full-scale reactor mock-up of a Darlington reactor inside OPG's new state-of-the-art training facility located in the Darlington Energy Complex.

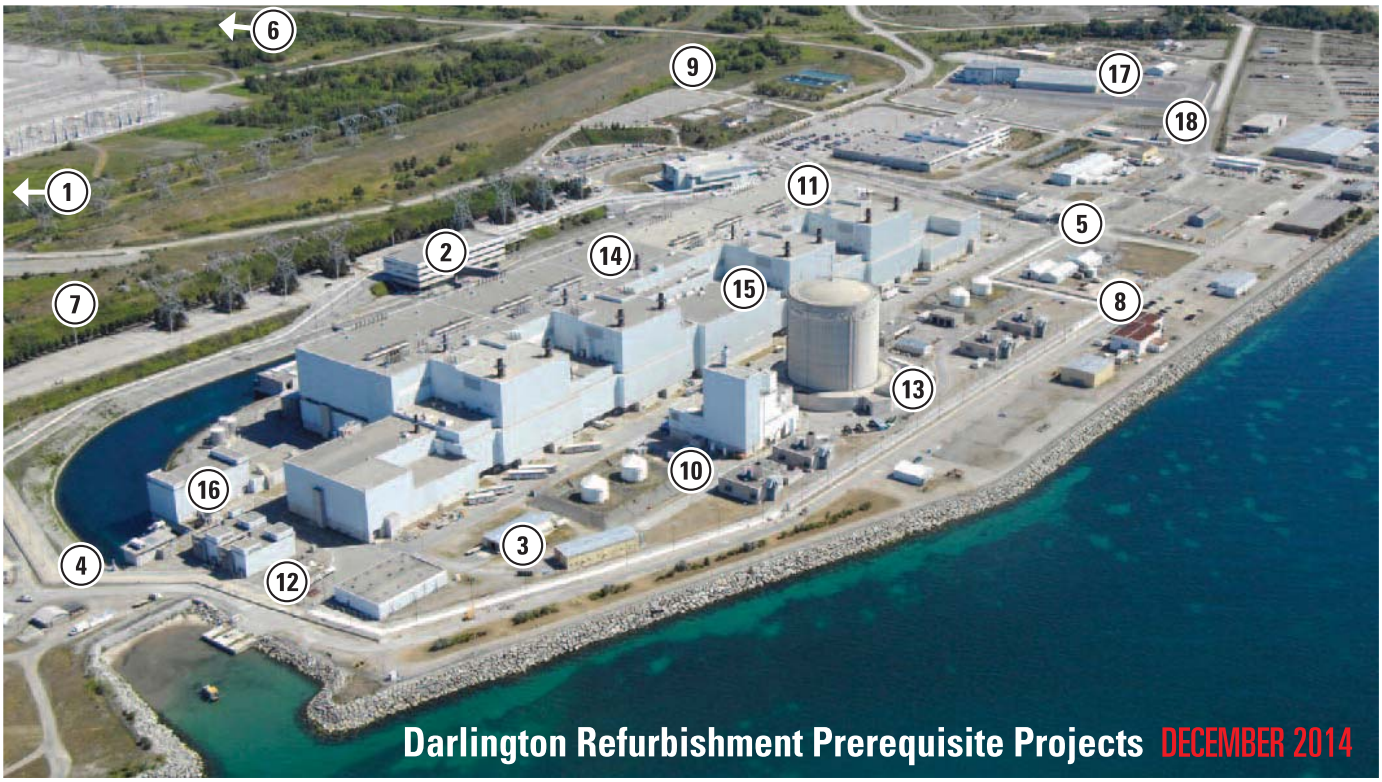
analog control systems with new digital control systems. Turbine generator work was on track, with detailed engineering to be completed early in 2015.

■ *Fuel handling*—This work involves the defueling of the reactor and refurbishment of the fuel handling equipment. Defueling detailed design was nearing completion, and the project team was to shift its focus to testing and commissioning. The awarding of contracts for the refurbishment project was delayed to simplify the engineering approach and was not expected to affect the overall schedule.

■ *Steam generators*—This work includes mechanical cleaning, water lancing, and inspection of and maintenance work on the generators. Detailed engineering was in progress, and the processes that will be used to execute steam generator cleaning were being established and qualified.

■ *Balance of plant*—This work consists of a number of smaller projects to replace or repair components on the reactor side of the unit (such as heavy water and cooling systems) and on the conventional side of the unit (such as electrical system, piping, and valve work). The balance-of-plant work program was slightly behind schedule due to contract award delays, but progress had been made in awarding contracts and detailed engineering was under way.

■ *Prerequisite Projects*—Eighteen prerequisite projects were under way to support the execution of the refurbishment and/or plant life extension. Of those projects, three were already completed and 13 were on schedule. The Auxiliary Heating System project will take longer to bring into service, and construction challenges with the Heavy Water Storage Facility (D_2O Storage) have increased the project's costs, delaying the facility's in-service date. The total cost is within the cost envelope established for this bundle of work.



Project	Project Description	Project	Project Description
	Facilities and Infrastructure Projects		**Safety Improvement Opportunities/Other**
1	Darlington Energy Complex (complete/in-service)	12	Additional (3rd) Emergency Power Generator
2	Operations Support Building Refurbishment	13	Containment Filtered Venting System
3	Retube and Feeder Replacement Island Support Annex	14	Power House Steam Venting System
4	Refurbishment Project Office	15	Shield Tank Overpressure Protection
5	Vehicle Screening Facility (complete/in-service)	16	Emergency Service Water Projects
6	Holt Road Interchange Improvements	17	Retube Waste Storage Building
7	Site Electrical Power Distribution	18	Used Fuel Dry Storage
8	Auxiliary Heating System		
9	Domestic Water and Sewer (complete/in-service)		
10	Heavy Water (D_2O) Storage and Drum Handling Facility		
11	Retube Waste Processing Building		

Fig. 2. The Prerequisite Projects, which must be completed prior to the start of the Execution Phase. Tasks 1, 5, and 9 are already finished.

Project prep and progress

OPG has made significant progress on much of the work to be carried out during the current Definition Phase, including the completion of plant inspections, which help in determining the full work scope of the project and detailed engineering. Major contracts have been awarded and the project's regulatory approval program continues to meet its milestones. The Darlington Energy Complex is now open, and construction of the training and tool testing facility is complete (see sidebar). To mark its readiness, OPG held an open house over three days in November, during which time several thousand people were able to enter an area with full-size reactor mock-ups to learn about the plant and the refurbishment project. Darlington plans to make this an annual event.

OPG said that it is on track to obtain all required regulatory approvals, as well as to have all project contracts awarded, tools tested, staff trained, and a detailed schedule and fully committed budget approved, well before the Execution Phase of the outage begins in 2016.

Regarding costs, OPG has noted that while its preliminary estimates indicated that refurbishment made sound economic sense, a project of the scale and scope of the Darlington refurbishment is a significant investment. Intense examination of the scope of work has led to a total cost estimate of about Can$10 billion in 2013 dollars (about $8 billion). While OPG said that it remains confident that the project cost will be less than this figure, it will continue to refine the numbers.

The status of the Prerequisite Projects that must be in place before the reactor refurbishment commences are shown in Fig. 2. According to the DR Team, the overall

program health is good, with the majority of ongoing projects and work progressing well, based on cost and schedule targets. Two of the Prerequisite Projects that had encountered serious problems are now getting back on track (these are discussed in the following section). OPG is confident that the refurbishment of the first reactor will begin in October 2016 as scheduled.

The project management model

According to OPG, its project management approach aims, among other things, to "minimize risk to OPG, to the Ontario government, and to the ratepayers of Ontario." This is mainly achieved, the company said, by building on lessons learned from other refurbishments and large-scale, complex projects.

For example, prior CANDU refurbishments undertaken by OPG and other operators have often suffered significant delays, cost overruns, or both. These do, at least, provide valuable lessons for the Darlington project. Possibly the most important lesson to take note of is the confirmation of the value of investing significant resources in nuclear project planning and preparation. This led OPG to start planning many years in advance of project execution, and to focus particular attention on determining the scope of work and completing detailed engineering.

Some other more specific priorities that have been set based on experience include performing in-depth plant condition assessments and inspections, establishing the facilities and infrastructure needed to support the work, securing all regulatory approvals well in advance, and building a schedule that is realistic and allows lessons learned to be applied in real time.

While these would be priorities that most project managers would strive for, Pierre Tremblay, president of the OPG subsidiary

Full-scale reactor mock-up ready for service

When the Darlington station's Reactor Mock-up and Training Area was being readied for the training of workers and testing of tools last November, Ontario Power Generation (OPG) took the opportunity to display this unique facility with a three-day open house. The many hundreds of members of the public who attended each day to learn about the Darlington Refurbishment Project were also able to visit the Darlington Nuclear Information Center, which is housed in the new Darlington Energy Complex.

Construction of this technologically advanced training center was completed in March 2014. The facility includes a full-scale replica of a Darlington reactor vault, as well as a number of smaller mock-ups identical to sections of the reactor. With the reactor mock-ups in place, the specialized tools needed to support refurbishment were brought in to the area.

For replicating an entire reactor, right down to the exact bend in every pipe, the latest in laser scanning technology was used to scan the inside of the Darlington -2 vault to produce an accurate model of the thousands of reactor components. OPG drawings were then overlaid with the laser-scanned model to confirm accuracy.

The reactor mock-up is built to accurately represent the size and space constraints within the Darlington reactor vaults, simulating what will be encountered during the actual work on the reactor. Not only the vault but every door, pipe, hallway, and overhead light has been replicated. According to Roy Brown, director of retubing and feeder replacements, "This will allow workers to familiarize themselves with every inch of the reactor vault. They will practice the work, perfect techniques, perform full dress rehearsals using actual tools before they begin working inside the station."

Workers will also train on floor mock-ups, which can be reconfigured to simulate a myriad of different training scenarios. "With these mock-ups," explained Allan Freeburn, the retubing and feeder replacement project manager, "We can recreate a potential roadblock and problem-solve it to mitigate any delays in the reactor vault on the site. Another benefit is the opportunity to test new strategies."

Visitors at the Darlington Energy Complex Open House.

The refurbishment requires many specially designed tools for the various jobs to be done, such as removing existing components and installing new ones, undertaking inspections and repairs, and returning the units to service. Over 450 unique tools are being designed for the Darlington project.

The reactor mock-ups and tools are also used to validate the tooling and procedures to ensure that the tools perform according to contract specifications. The testing of the tools and the workers' practice will also be important to determine the correct timing and precise sequence needed for executing each refurbishment activity and to help establish the critical path for the project.

In the summer of 2013, the complex itself became the first major construction project completed as part of the Darlington Refurbishment Project. The facility also serves as the headquarters for the Darlington Refurbishment Team and houses a 70,000-square-foot warehouse where parts, components, and tools will be stored. "A problem we ran into in past refurbishments," said OPG spokesperson Neal Kelly, "was getting the tools and various pieces of equipment into the plant, due to security and other reasons." All materials needed for the work will now be taken into the warehouse, where they will be screened and secured well before their use is required. They can then go straight into the station, avoiding delays, allowing OPG to better manage the huge equipment inventory, he said.—*D.K.*

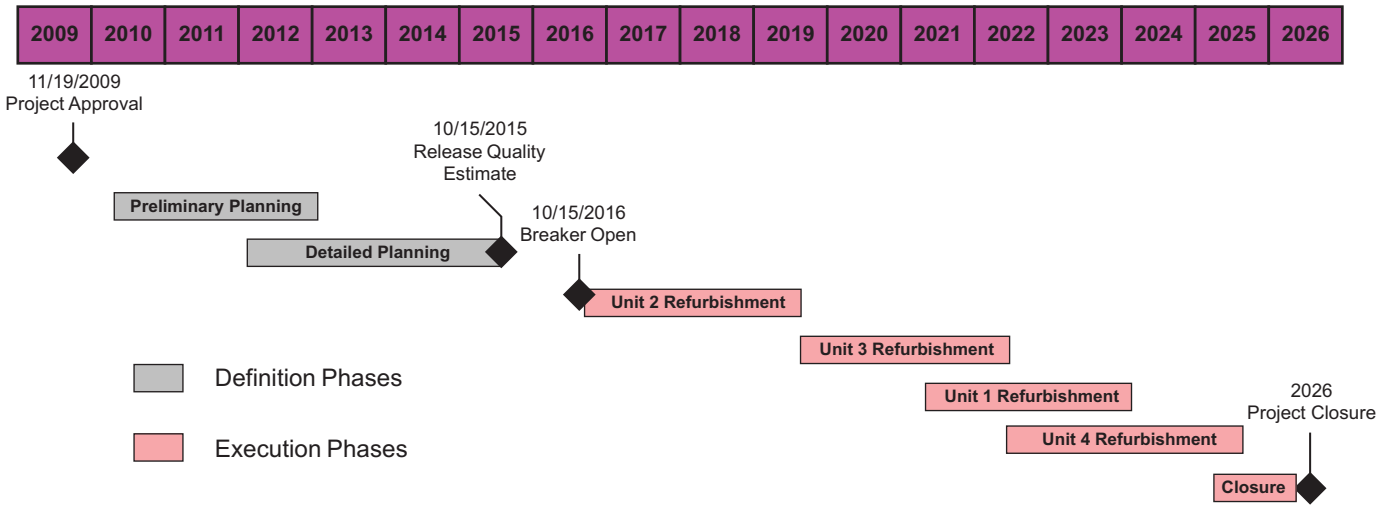


Fig. 3. Timeline showing the main milestones of the Darlington Refurbishment Project. Note that there is no overlap between the Unit 2 work (which occurs first) and the Unit 3 work, but overlap does occur with the work on Units 3 and 1, and Units 1 and 4.

Canadian Nuclear Partners, stressed their importance for managing a megaproject such as the Darlington Refurbishment. Tremblay noted many measures designed to control risks for this project, among them those that follow.

OPG introduced a phased approach to project management to maintain budgetary control. Under this process, board of directors approval is required to release the funds for each subsequent phase of the project. Approval will depend on the results of detailed reviews carried out at decision points to ensure that work has been completed satisfactorily prior to moving to the next phase. Should basic assumptions change, particularly regarding project economics, this approach provides opportunities to alter course. Tremblay stressed the importance of such funding "gates" to control risk. "We will not get a second chance to do a project of this scope and we simply have to get it right the first time," he said.

Another focus for preparing for the Darlington Refurbishment Project was setting up an appropriate organization able to manage a 10-year program featuring four reactor refurbishments. As having the right management team in place is crucial, it was also considered prudent to plan for changing management teams through the lengthy course of the project. The magnitude of this project also requires ensuring that a large pool of people with the right range of skills is available.

An interesting change in approach for the project that will mitigate risk was OPG's decision to change the schedule to ensure that the refurbishment work on the first unit is completed before work is started on the second. The initial plan called for the refurbishment of the second unit (actually the plant's Unit 3) to begin before the refurbishment of the first unit (Unit 2) was completed. By removing the overlap, the DR Team will be able to focus completely on the first unit and will allow for any lessons learned and improvements implemented in the first refurbishment to be incorporated into the work program for the subsequent units.

Another focus was to ensure that workers are fully prepared to carry out critical project tasks before they enter the plant. This led to the decision to construct the advanced training and tool testing center mentioned earlier, which includes a full-scale mock-up of the reactor. Among other benefits, this will help to ensure that workers and tools can access the places where maintenance tasks are to be carried out, and that the workers are totally ready to undertake their jobs when they walk into the plant.

An important lesson for the project came to light when problems arose in managing some of the early Prerequisite Projects—in particular, the D_2O Storage Facility and auxiliary heating steam system. While the DR Team is focused on the primary execution packages, the job of managing these other projects was given to OPG's existing Project & Modifications (P&M) group. It became apparent that the management processes used by P&M for the types of projects it successfully undertook for years were not suitable for the Darlington project.

After a number of problems arose, threatening the schedule, OPG asked its independent oversight agent, Burns & McDonnell Canada and Modus Strategic Solutions Canada (BMcD/Modus), to review the situation. It found that the early cost estimates provided by vendors performing the work were unrealistically low due to a limited understanding of the scope of the project and unfamiliarity with the requirements for undertaking projects on a nuclear site. It also noted a number of management issues, including that the P&M team had not instituted the appropriate level of project oversight.

OPG has since introduced new measures to ensure a common project management and controls approach in keeping with best practices across all departments. Actions taken included changes in the project team leadership to ensure the right level of management control, a more active "hands-on" approach to contractor management as practiced by the DR Team, and improved processes to ensure more accurate early cost estimates that reflect the full scope of the work to be done.

Next major milestone

In its reports to OPG, BMcD/Modus found in general that the DR Team is fully committed to taking action when problems occur, noting, in particular, "an aggressive approach to understanding and implementing timely course correction where areas for improvement were identified."

OPG's focus is now on the next major milestone, the submission of the full project cost and execution schedule, known as the Release Quality Estimate (RQE), to the OPG board later this year. In this regard, BMcD/Modus said that OPG has devoted significant effort to locking down the project's scope, particularly for activities that carry significant risk. It is also endeavoring to complete all detailed engineering by mid-year in order to produce a high-quality project cost estimate for the RQE.

BMcD/Modus stressed that the primary commercial risks to Ontario for this project stem from the potential for unplanned cost and schedule overruns, and considers that a high-quality RQE is a major element in reducing that risk. It noted that this has been demonstrated in many mid-life refurbishments and other nuclear projects where the basic input to developing the RQE, such as the project scope and detailed engineering, have not been fully completed when construction actually begins. OPG is working hard to avoid such a situation. NN