DARLINGTON REFURBISHMENT PROJECT
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OPG’s Darlington Nuclear Generating Station is one of Ontario’s most important assets. Since the early 1990s, it’s been producing about 20 per cent of the province’s electricity. That’s enough to power two million homes each day.

After years of reliable generation, this clean-power workhorse now requires a mid-life refurbishment.

Refurbishing Darlington will provide 30 more years of safe, reliable baseload power with virtually no greenhouse gas emissions, helping Canada meet its climate change targets. It will also allow OPG to continue to moderate electricity prices and maintain the positive economic benefits of continued operation.

The continued operation of the Darlington Station is expected to result in a $89.9 billion in economic benefits to Ontario. At its peak, refurbishment will create an average of 14,200 jobs per year, lifting employment by 555,013 person-years in Ontario over the life of the station. The ongoing operations of Darlington Station are expected to boost personal income in Ontario by an average of $1.6 billion per year from 2017 to 2055, or by a total of $61.4 billion.

With a completion timeline spanning 17 years — from 2010, when the project was approved all the way to 2026, when the station is expected to be finished – the Darlington refurbishment is a very big job that has to be done right.

OPG is well-positioned to deliver this project. We’ve already made sure Darlington is one of the world’s top performing nuclear stations. And we’ve put in years of detailed planning, built a state-of-the-art training facility, assembled the best team, and partnered with top companies from across Ontario.

Investing in Darlington Nuclear is an investment in Ontario. OPG is committed to completing its refurbishment safely, on time and on budget.

We hope you find this booklet informative. We will remain open and accountable to the people of Ontario who have entrusted us with this important and historic project.
Darlington: Investing in Ontario’s Future

Refurbishing the 4-unit Darlington Nuclear Generating Station is a significant investment in Ontario’s future and will be Canada’s largest clean-energy climate change initiative.

Ratepayers: The power from a refurbished Darlington will provide consumers with stable, predictable prices for the next 30 years. The price of power will be lower than other sources, and as a result, OPG will continue to moderate the price of electricity for the customers of Ontario.

Economy: The Darlington refurbishment project will create thousands of jobs and positive economic benefits across Ontario. According to the Conference Board of Canada this $12.8 billion project will:

- Boost Ontario’s Gross Domestic Product (GDP) by $14.9 billion;
- Increase jobs in Ontario by an average of 8,800 per year over the duration of the project;
- Raise Ontario’s household income by an average of $502 million per year (or by a total of $8.5 billion); and
- Increase combined federal, provincial, and municipal tax revenues by $5.4 billion.

It will also maintain the positive economic benefits that arise with 30 years of continued station operation. This is an investment in Ontario’s economy.

Environment: Refurbished nuclear units will avoid or displace about 300-360 million tonnes of CO₂ emissions from Ontario gas-fired generation. This represents another significant OPG action to combat climate change as we undertake Canada’s largest clean energy project.

And the benefits don’t stop when the project is done they continue on for the life of the station. The total reduction in GHG emissions from 2024 to 2055 following refurbishment is estimated to be 297 MT CO₂, with an average reduction of 9.6 MT CO₂ per year. This is equivalent to removing approximately 2,000,000 cars from Ontario’s roads each and every year.
Bruce Power and OPG have a long-standing relationship as operators of CANDU reactors, sharing best practices and information through a range of industry forums including the CANDU Owners Group (COG) and the World Association of Nuclear Operators (WANO). Both organizations have a history of operational performance excellence and are committed to the value of “Safety First.” They achieve this high standard through active collaboration, transparency and continuous improvement.

The Long-Term Energy Plan encourages Bruce Power and OPG to work together to share knowledge and leverage economies of scale. The value generated through this ongoing collaboration includes potential cost savings, schedule improvements, risk reduction, dose reduction and more.

It is not just Bruce Power and OPG that gain from these collaborative efforts – Ontarians benefit, too. By working together, the two operators can provide the province with a reliable and clean source of electricity while delivering the best value to Ontario customers, now and for decades to come.
Darlington Refurbishment is a mega-initiative that will generate $14.9 billion in economic benefits to Ontario and create 11,800 jobs per year, at its peak. It will also increase provincial household revenues by $8.5 billion and government revenues by $5.4 billion.

How? By partnering with hundreds of top companies across Ontario to help us successfully execute the project safely, with quality, on time and within budget.

Our plan is to successfully refurbish Darlington and, in doing so, set a high standard for mega-project execution. OPG, construction vendors and contractors are working as one to achieve a successful project outcome.

While the project is the largest clean energy initiative in Canada, it can be difficult sometimes to grasp the magnitude of its impact. To help everyone see the big picture, an online interactive map displaying the locations of our many vendor partners can be seen at: http://refurbpartners.com/.
The Darlington Energy Complex

The Training Facility

OPG constructed a world-class training facility featuring a full-scale reactor mock-up, warehouse space for equipment, and training classrooms, inside the Darlington Energy Complex, located in Clarington, Ontario. The training facility:

- Allows staff to practice their refurbishment work tasks, to perfect their techniques and perform full “dress rehearsals” using real tools and wearing full protective equipment long before they begin actual work inside the station; and
- Ensures all workers are thoroughly trained and tested in a safe, realistic and controlled environment with all the obstacles, constraints and potential challenges they may face in the station.

The Mock-up

The training facility offers multiple mock-up models including a replica of a Darlington reactor vault. It houses a full-scale, reconfigurable replica reactor suitable for tool performance testing and integration, as well as training purposes.

The Tooling

Tooling is the design and construction of unique machinery and tools. Darlington refurbishment requires specially designed tools for component removal and installations, and inspections and repairs. Work tasks will be practised in the training facility to determine the correct timing and precise sequence needed for each activity. High-quality training with the right tools in the right environment maximizes efficiency and minimizes costs. This type of up-front investment is key to OPG’s project management approach.
Phased Project Management

**Initiation Phase**
2007 - 2009

- Initial determination of refurbishment scope through completion of:
  - Technical assessments of all major components
  - Condition assessments of balance of plant components
  - Initiation of regulatory processes; Integrated Safety Review and Environmental Assessment
- Develop reference plans for cost and schedule
- Complete economic feasibility assessment
- Establish project management approach and governance
- Establish overall contracting strategy
- OPG Board and Shareholder agree with recommendation to proceed with preliminary planning within the Definition Phase of the project

**Definition Phase**
2010 - 2015

- Obtain regulatory approvals:
  - Environmental Assessment
  - Integrated Safety Review
  - Integrated Implementation Plan
- Implement project management and oversight
- Complete infrastructure upgrades, i.e. Darlington Energy Complex
- Implement safety improvements
- Award major contracts
- Finalize project scope and complete engineering work
- Procure long lead materials
- Complete unit prerequisite work
- Construct reactor mock-up and fabricate and test tooling
- Develop release quality cost and schedule estimate
- Obtain all permits and licences
- Mobilize and train Trades staff

**Execution Phase**
2016 - 2026

- Unit shutdown and defuelling
- Island unit and lay up systems
- Execute all refurbishment scope:
  - Reactor components
  - Fuel handling systems
  - Turbine / generator
  - Steam generators
  - Balance of plant
- Meet all regulatory commitments
- Plant maintenance and inspection activities
- Manage plant configuration
- Load fuel
- Commissioning
- Unit start-up
- Apply lessons learned to subsequent unit refurbishments
- Project close-out

We are using a phased management approach to Darlington’s refurbishment. The Initiation Phase was completed in 2009. The Definition Phase began in 2010 with detailed planning. In 2015, we finished the work required in the Definition Phase and obtained approvals to proceed to the Execution Phase, beginning with testing and training.

On Oct. 15, 2016, OPG will take the Unit 2 nuclear reactor offline to execute Darlington Refurbishment. This three-year (40-month) project will be the first of four such outages as we refurbish the plant’s four units over the next 10 years. During this period, OPG will remove, replace and repair critical components in each reactor.

We call this step “Breaker-Open,” because we will officially disconnect from Ontario’s power grid to start the work.
The Darlington Refurbishment Program management team brings a wealth of experience and knowledge to the Darlington Refurbishment Program (DRP). We’ve gathered a significant amount of industry information on the planning and execution of major construction projects. We’ve also drawn on the considerable expertise and project management successes from OPG’s Hydro-Thermal Operations. We’ve adopted some key strategies that help distinguish this project from other complex construction projects.

- We’ve built a full-scale mock-up of the reactor vault to assist in the training of personnel and the development and testing of tools and work plans. Numerous time trials with the tooling systems have helped us build a high confidence schedule. Training will ensure worker familiarity with tasks and tooling compatibility before actual work begins. The learning curve will happen at the training facility, not at the reactor face.

- We’ve completed comprehensive inspections and component condition assessments as well as the majority of the detailed engineering design work, a full year before execution.

- We’ve gained regulatory certainty by securing Canadian Nuclear Safety Commission approval of the Environmental Assessment and the Integrated Implementation Plan (IIP). The IIP lists the regulatory committed work and schedule required to support refurbishment and long-term safe operation of Darlington.

- We’ve completed significant infrastructure upgrades at the Darlington site, including new road works, parking lots, project offices, work annexes, and waste management facilities. Many upgrades are geared to improving worker productivity; that means safely getting people to the work site and ready to work, without interfering with the station operations.

- We’ve invested in a number of modifications at Darlington to further improve public safety.

- We’ve awarded the major contracts using a commercial strategy:

  - There is more than one Prime Contractor (PC). OPG has a separate contract with each PC. They are responsible for the completion of work under their particular contract.
  - OPG is the integrator between the prime contractors and is responsible for the entire project.
  - OPG and the contractors are aligned on common goals.
  - We’ve used pricing models that avoid significant risk premiums, and we’ve allocated risk to the entity best able to manage it.
  - OPG retains project management responsibility and design authority for the DRP.

- We developed the project cost estimate in accordance with OPG practices and the Association for the Advancement of Cost Engineering estimate classification model. All detailed engineering and work planning is complete and 90 per cent of the work is at Class 3 or better. We have high confidence in the overall project scope, cost and schedule estimates.

After years of planning, extensive inspections and benchmarking, 40 years of operational and project management experience, and a ground-breaking nuclear training and testing facility, we are confident we can deliver this project on time and on budget.
It will take close to 10 years to complete the refurbishment of all four Darlington reactor units. The duration for each outage is approximately three to three and a half years, though the duration is expected to reduce with subsequent outages.

The refurbishment outage sequence is Unit 2, 3, 1, 4. Unit 2 is to be complete before the start of Unit 3, to allow the implementation of lessons learned.

For purposes of managing the project, OPG will pursue the target schedule below. Prior to the start of each unit’s outage, OPG will develop detailed unit specific costs, schedules, risk, and other plans. Once the final schedule is base-lined for that unit, it will be used to measure project performance.

Funding will be released on a unit-by-unit basis. This provides opportunities to review project performance prior to proceeding to the next unit. This is also aligned to the principles outlined in the December 2013 Ministry of Energy’s Long Term Energy Plan (LTEP) that require us to incorporate off-ramps. It is imperative that we succeed on each unit to get the approval to proceed to the next unit.

Based on the current assumptions that each of the Darlington units will operate to 235,000 Effective Full Power Hours (EFPH), this schedule results in no idle time on operating units.
The **10 Steps** of Refurbishment

The Darlington Nuclear Generating Station meets about 20 per cent of Ontario's electricity needs. The station is approaching the mid-point of its operating life and Ontario Power Generation is overseeing a $12.8-billion refurbishment project.

To complete the project safely, each of the four CANDU reactors will be taken out of service for **about three years** beginning in 2016. The steps include:

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### STEP 1 SHUTDOWN THE REACTOR
- Refurbishment takes place when a reactor is not producing electricity.

### STEP 2 REMOVE FUEL & HEAVY WATER
- All **fuel bundles** are removed using remote-controlled machines.
- Once the fuel is removed, **heavy water** is drained from the system and transferred to appropriate storage.

### STEP 3 ISLAND THE UNIT
- After the reactor is defuelled, it is separated ("islanded") from the operating units with physical barriers. This helps employees perform work safely while reducing impact on the operating units.

### STEP 4 REMOVE FEEDER PIPES & TUBES
- One at a time, components will be removed: 960 **feeder pipes**, 960 **end fittings**, 480 **pressure tubes** and 480 **calandria tubes**.
- Material removed from the reactor will be safely stored in licensed waste facilities.

### STEP 5 REPLACE FEEDER PIPES & TUBES
- With the heavy water and tubes removed, the **calandria** is inspected before new components are installed.
- The new replacement parts are placed into the calandria in order: calandria tubes, pressure tubes, end fittings, feeder pipes.
- As each is added, it is rigorously inspected to ensure it complies with original CANDU requirements.

### STEP 6 OTHER MAJOR COMPONENTS
- In parallel to refurbishing the reactors, work is done to ensure all other components including **Turbine Generators**, **Steam Generators**, **Fuel Handling Machines** are ready for another 30 years of operation.

### STEP 7 PLACE NEW FUEL IN REACTOR
- The reactor is now ready to be loaded with **new fuel bundles**.

### STEP 8 RETURN HEAVY WATER TO REACTOR
- The reactor’s original heavy water, now purified, is pumped back into the calandria.
- The feeder pipes and fuel assemblies will also be filled with clean heavy water.

### STEP 9 RETURN REACTOR TO SERVICE
- Before a reactor can be returned to service, it must undergo regulatory tests to ensure all systems will operate as designed.

### STEP 10 RETURN REACTOR TO FULL POWER
- Successfully refurbished, the unit will be capable of producing safe and reliable electricity for 30 more years.
- Learnings from each unit’s refurbishment will be applied to remaining reactors.
Unit Shutdown and Layup

The Shutdown (SD), Layup (LU) bundle requires establishing specific conditions to shutdown the Darlington unit(s) and layup the unit’s systems to maintain a protected environment, until the systems are returned to service following refurbishment activities. Provision of those services to support field work execution includes:

- Upgrades (modifications) to breathing air and service air systems to support vault work and other field execution activities.

- Power supply/distribution requirements, alternative cooling water supply, and associated modifications to support Refurbishment work execution needs (those that are not already provided by the individual projects).

The SD/LU project includes the following items, the first three are described in detail:

1. Monitoring of Permanent Station System Components and Equipment
2. Steam Generator (SG) Primary Side Layup
3. SG Secondary Side and System Generator Emergency Cooling System (SGECS) Layup
4. Breathing Air Capacity Enhancement
5. Cranes Maintenance
6. Dry Air Provision to Nuclear Side Systems
7. Dry Air Provision to Conventional Side Systems
8. Low Pressure Service Water Alternate Cooling Supply
9. Moderator Flush
10. Monitoring of Temporary Equipment and Laid Up Systems
11. Service Air Capacity Enhancement
Unit Shutdown and Layup

Operational layup plans have been developed to support an outage that is longer than normal at Darlington Nuclear Generating Station. The project developed the plans to help visualize taking the existing plant from its current operating state to the desired laid up state, as per input from engineering, operations and supporting organizations. These plans were used as a reference to develop the detailed designs for each system to be laid-up. The resulting modifications will be implemented via separate work plans to place the station into the optimal laid up state for refurbishment and maintenance work.

Layup modifications and work plans are managed by the Shutdown/Layup Bundle Director, and will be supported by permit strategies, engineering modification, and ongoing maintenance support. Temporary modifications will be removed at the end of the refurbishment outages.

1. Monitoring of Permanent Station System Components and Equipment

To support refurbishment activities, the monitoring and maintenance of permanent station system components and equipment will be undertaken. Activities involve layup of station equipment and components as well as recurring preventative maintenance work such as rotating pumps, motors, fans, stroking valves, taking oil samples, corrosion protection and restoration prior to Return to Service etc. This will ensure that all permanent station system equipment/components are in their proper layup conditions throughout the duration of the refurbishment.

2. Steam Generator Primary Side Layup

After the Steam Generators are shutdown and drained, the Shutdown Layup project will be responsible for installing a dry air purge (via installed dry air skids) in the Steam Generator Primary Side circuit to ensure the assets are protected from the effects of corrosion over extended periods of long outages. To achieve this layup condition, the following tasks are included in the project:

- Install and remove primary side bungs
- Installation of temporary modified manway covers to accommodate injection of dry air through SG tubes
- Circulation of dry air to maintain Relative Humidity (RH) < 40%
- Incremental monitoring and surveillance of SG primary side dry air purge
- Removal of temporary manway covers and SG box-up prior to returning system to Operations

3. SG Secondary Side and System Generator Emergency Cooling System (SGECS) Layup

This project involves placing the Steam Generator Secondary Side (SG SS) and Steam Generator Emergency Cooling System (SGECS) in the appropriate lay-up states to support execution of the refurbishment project.

Chemically treated water will be pumped via wet recirculation skids through the SG SS as well as the second stage reheat drains and inter unit feedwater tie. In addition pressure monitoring devices will be installed at various locations across the system for monitoring of the flow. Lastly, a nitrogen blanket will be applied to the SGECS tank and at the top of the SGs (steam drum, above the water level), up to the main steam piping. To prevent the nitrogen from flowing into the secondary side steam circuits, flow stopping devices will be installed upstream of the boiler stop valves.
Defuelling is the first segment on critical path once the refurbishment breaker is open.

The purpose of the Defuelling Project is to safely remove all fuel from each reactor core in a cost effective manner in order to minimize outage duration. Flow Defuelling was selected as the preferred method. It relies on hydraulic drag of primary heat transfer coolant over fuel to “wash” fuel into the fuelling machine.

**The two major changes related to the project are:**

- Implementation of Universal Carriers (UC); and
- The equipment required to defuel an entire reactor.

The UC will be permanently installed on the station fuel handling systems and will allow a Darlington Fuelling Machine to fuel and defuel without having to change out the carriers.

The equipment required to defuel the reactor includes: the Dummy Fuel Bundle (DFB); the Flow Restricting Outlet Bundle (FROB); the Fuel Push Tool (FPT); a related software update; and modifications to the New Fuel Transfer Mechanism (NFTM) to accommodate the new UC and to facilitate loading of the DFB and FROB, and unloading of the fuel.
Defuelling

**Flow Restrictive Outlet Bundle (FROB)**
The function of the FROB is to mimic the flow resistance of a fuel string and prevent a large scale core bypass of coolant flow once a channel has been defuelled.

**Fuel Push Tool (FPT) / Dummy Bundle Push Tool**
The FPT works in conjunction with DFBs to safely remove fuel from channels where the coolant flow is too low to allow for flow defuelling of bundle pairs.

**Dummy Fuel Bundles (DFB)**
The function of the DFB is to mimic the mechanical characteristics of existing fuel bundles. In channels where there is limited flow, DFBs will be used in a process called “push defuelling.”

**Universal Carriers (UC)**
UCs allow for flexibility for one carrier to be used for either fuelling or defuelling the reactor units without the need to swap carriers. Darlington currently uses two sets of carriers and swaps between fuelling carriers for fuelling and outage defuel carriers for defuelling.
The Refurbishment Island (RI) Project will create a safe, precise work area separated from the operating plant through a system of physical barriers and controls. Once separated, the RI goal will be to maximize the ability of workers to perform work safely and efficiently on the unit that is being refurbished, while minimizing the impact on the operating units.

The Islanding Project can be broken down into the following principle elements:

- Establishing barriers and access control around the RI to keep refurbishment staff from entering operating unit areas and station workers from entering refurbishment work areas.
- Isolating the refurbishment unit reactor vault from station containment once the irradiated fuel has been removed from the core (commonly referred to as “installing the bulkhead”). This will allow both airlock doors to be opened to facilitate worker and material transfer into/out of the vault, which will significantly improve worker efficiency. Bulkhead installation is the single largest element of the Islanding Project.
- Establishing terminal points on station systems to allow them to be isolated from the operating units to the maximum extent possible. Where necessary modifications will be installed, either in planned outages that precede the refurbishment outage (preferred) or at the start of the refurbishment outage.

The Islanding Bundle includes the following:

1. Bulkhead and Containment Isolations
2. Barriers
3. Islanding Pre-Refurbishment Projects
4. Airlocks
5. Button Up Modifications
6. Low Pressure Service Water Booster Pump
7. System Islanding
Islanding

1. BULKHEAD AND CONTAINMENT ISOLATIONS

The vault of the outage unit will be isolated from containment through the installation of a bulkhead and other containment sealing provisions. This modification will enable:

- Safety of refurbishment unit workers
- Productivity and outage efficiencies
- Decrease in impediments to operating units (i.e. fueling)

2. CONSTRUCTION ISLAND BARRIERS

Islanding barriers will provide separation of the islanded unit from the operating units. These barriers will enable the construction island to be created and will separate the refurbishment staff from the operating unit staff. This will minimize the impact of refurbishment on the operating units.

Scope includes construction and personnel barriers, marked pathways and signage required to establish the construction island.

This work will include outside pathways.

3. ISLANDING PRE-REFURBISHMENT PROJECTS

- Negative Pressure Containment - This modification is required to maintain post-accident monitoring capability for containment pressure when Unit 2 is isolated from containment.

- Heavy Water (D₂O) Management Modifications - This work is required to ensure that the over-pressure protection is available at all times during station operation for the station D₂O transfer headers.

- Environmental Qualifications (EQ) of 5/6 CB4 - This modification will allow us to credit the standby generators as a source of power.

OTHER WORK IN THIS BUNDLE

4. AIRLOCKS (one-time procedural change, will support all units)

Modification is required to enable both sets of airlock doors and transfer chamber doors to be open at the same time.

Opening of airlocks and transfer doors will support free movement of materials and equipment, once containment bulkhead is installed.

5. BUTTON UP MODIFICATIONS (applies to all four units)

Modifications in the form of inhibiting the automatic button-up signal from the outage unit are required for work protection reasons, and work execution support.

6. LOW PRESSURE SERVICE WATER BOOSTER PUMP (one-time procedural change, will support all units)

This work will support Islanding the refurbishment units by adding operational margin to LPSW booster pump set points.

7. SYSTEM ISLANDING

This work will establish terminal points on station systems so they are isolated from the operating units.
A Darlington reactor has 480 calandria tubes which hold 480 pressure tubes (one inside the other), as well as 960 feeder pipes – all of which will be replaced.

Two automated tooling platforms (re-tube tooling platforms) are installed at each end of the reactor, travelling up and down the face of the reactor. Work tables are installed on the tooling platforms which travel back and forth across the face of the reactor and hold specialized tooling to enable component replacement.

This is the largest work package in the Darlington Refurbishment Project, representing the critical path schedule and the core of the program.

**The Re-tube and Feeder Replacement (RFR) Project includes full engineering, procurement and construction services for:**

- Fuel channel and feeder mock-ups in the Darlington Energy Complex (DEC) for tool testing and training;
- Development of tooling and systems to perform replacement and inspection tasks;
- Replacement of fuel channels, feeders and supporting hardware and associated parts;
- Internal inspection of calandria vessel; and
- Replacement or inspection of components.

**The Re-tube and Feeder Replacement Work Bundle includes:**

1. RFR Project Bundle - Major Re-tubing - Definition Phase
2. RFR - Re-tube Waste Processing Building (RWPB)
3. RFR Project Bundle - Major Re-tubing - Execution Phase
Re-tube and Feeder Replacement

1. RFR DEFINITION PHASE

MOCK-UP: The RFR team constructed a full scale fuel channel mock-up area with the following:
- Fuel channel arrays
- Feeder section with headers
- Fuelling machine bridge
- Airlock mock-up
- Additional mock-ups

TOOLING: This scope also includes the design, engineering, construction, completion and testing of the tooling (removal, install, inspection, contingency and other tooling as described in the tooling design requirements document) on the mock-ups.

Mods Engineering, Procurement, Execution Planning:
This scope includes the engineering of station mods, procurement of reactor components for Unit 2, and preparation of execution documentation such as construction work packages.

2. RE-TUBE WASTE PROCESSING BUILDING (RWPB)

The project includes the design, construction and commissioning of a Re-tube Waste Processing Building (RWPB). This building will house the volume reduction tooling system and process the intermediate-level refurbishment waste.

Used reactor components will also be delivered from the outage unit to the RWPB in appropriately shielded flasks.

3. EXECUTION PHASE

The Re-tube and Feeder Replacement is core scope that supports the primary reason for executing a refurbishment outage at Darlington.

The scope includes the re-tube of 480 pressure tubes and calandria tubes and the replacement of all feeder piping.

Major activities:
- New pressure tubes
- New calandria tubes
- New end fittings
- Fabrication and installation of new feeders

CONSTRUCTION OF THE MOCK-UP IS COMPLETE.

Part of the re-tube project includes a significant number of engineering changes to perform vault preparation, and also restoration of the vault after re-tube has been completed.

THIS SCOPE WILL BE EXECUTED DURING U2, U3, U1, U4 OUTAGES
Refurbishment Support Facilities (RSF) is a bundle of work required to support the refurbishment scope and staff in and around the station. It includes common areas such as shops and storage, washrooms, and offices for refurbishment workers.

The RSF bundle includes the following items (the first three are described in detail):

1. RSF Maintenance and Custodial
2. Shops and Work Areas
3. Contaminated Shops and Scaffold Storage
4. Decontamination Tool S107 Upgrades
5. Radiation Protection and Teledosimetry Facility
6. Washrooms
7. Work Control Area
Refurbishment Support Facilities

1. RSF MAINTENANCE AND CUSTODIAL
A maintenance contract is required for the upkeep of all RSF facilities throughout the duration of the refurbishment project. These facilities include: non-contaminated shops and assessing office trailer, washrooms, radiation protection teledosimetry trailer, work control area trailer, decontamination facility S107, and contaminated workshop/scaffold storage area.

2. SHOPS AND WORK AREAS
To facilitate refurbishment activities, a number of dedicated temporary shops, work areas and facilities are needed to improve workflow. These modifications will facilitate the organization, storage and staging of work by vendors participating in the refurbishment, as well as for OPG staff providing project direction.

The shops will be located on the refurbishment unit during the refurbishment and relocated after the unit has been refurbished. Once removed, the area is to be left in pre-refurbishment conditions.

3. CONTAMINATED SHOPS AND SCAFFOLD STORAGE
The contaminated machine shop, with the contaminated scaffold storage area in the Reactor Auxiliary Building, will facilitate work on contaminated components, tooling and materials. This project will construct a consolidated grouping of the machine shop with the scaffold storage area at the south end of the 87.7m elevation of the Reactor Auxiliary Building.

The areas will contain machines, equipment, radiation monitors, bins and storage areas, and various services with appropriate active ventilation. The areas will be enclosed with partitions to ensure radiation protection controls. The overflow areas will be designated for contaminated scaffold storage since additional space may be needed based on operating experience. These areas will be shared by multiple contractors and vendors.
Each Darlington reactor has a set of large, industrial turbines consisting of a high-pressure turbine (HP) and three low-pressure turbines (LP) located in the large turbine hall, which runs the entire length of the station (more than half a kilometer long).

The turbine generator sets, auxiliaries, and controls are highly specialized equipment designed and supplied as an integrated system for Darlington nuclear.

OPG’s station condition assessments and component inspections have shown that the turbine/generators can operate reliably for another 30 years after refurbishment and do not need to be replaced.

The project is utilizing two vendors to perform the work: GE-Power (formerly Alstom) as the Engineering Services and Equipment Supply (ESES) and SNC Lavalin/Aecon Joint Venture (JV).

The JV will provide the integration and field execution of the entire project scope, including equipment supplied from the ESES. This will include the engineering change control-related work, limited procurement, and field execution.
Turbine / Generator

Scope Differences: Turbine/Generator Unit-Over-Unit

Turbine Generator maintenance includes turbine blade inspections called Phased Array - a leading edge technology which allows for the inspection of complex geometries (as found in our turbine blade roots and rotor steeples) that cannot be seen with the human eye. The work scope can be broken down into the following elements:

1. TURBINE + AUXILIARIES
   - Complete disassembly, inspection, and reassembly of LP and HP turbines and auxiliaries.
   - Long Lead and Maintenance Spares for the assembly/disassembly of the steam turbines and auxiliaries.
   - Installation of erosion protection rings on blade carriers of LP-turbines to address erosion-corrosion.
   - Inspect and repair condenser struts, as required.

2. GENERATOR + AUXILIARIES
   - New Generator Midsection: A new generator midsection will be provided for U3. Old components (end shields, end covers, etc.) to be reused.
   - Stator rewind and Generator Spare: Stator rewind will occur on U3 stator to be installed on U4, and the U4 stator will be rewound and become a station spare.
   - Generator Auxiliaries: Replacement of stator cooling water, hydrogen cooling, and seal oil skids, and integration with turbine controls.

3. MOISTURE SEPARATOR REHEATER (MSR)
   - Inspect and repair moisture pre-separators.
   - Inspect / repair all internal components of the MSR vessel.
   - Inspect and refurbish / replace selected MSR motor operated valves, as required.

4. STEAM TURBINE/GENERATOR ELECTRONIC CONTROLS
   - The turbine control equipment will be composed of 14 new control panels to be installed in the Main Output Control and Protection Equipment (MOCPER) room. These panels include the turbine control and protection system, the Turbine Supervisory System (TSS) and human machine interface. The hydraulic controls will be upgraded with new servomotor controls and new Electric Hydraulic Controllers (EHC). A new two out of three trip block will enhance the reliability of the turbine control. The TSS system will require new field sensors and probes as it interfaces with the new two out of three trip block. The old mechanical over-speed system will be replaced by an electronic over-speed detection system.
   - The excitation control equipment will be composed of ten new control panel cubicles to be installed in the excitation room. This panel includes the main excitation control panels. The power rectifier, field breaker, de-excitation control cubicles and a human machine interface.
   - The scope includes modification to the Main Control Room (MCR). The alterations in the MCR include changes to the digital computer control software, push buttons, annunciation windows and alarms.
Each reactor unit at the Darlington has four steam generators (SG) measuring 22 meters in height and containing 4,663 U-shaped tubes which carry extremely hot and heavy water under high pressure pumped from the reactor.

While a kitchen kettle gently produces steam at 100 degrees Celsius, a Darlington SG creates high-pressure steam at 265 degrees Celsius and five megapascals (MPa).

OPG’s station condition assessments and component inspections have shown the SG’s can operate reliably for another 30 years after refurbishment, and do not need to be replaced.

The Steam Generator Project scope of work has been generated from the steam generators Life Cycle Management Plan (LCMP) and the Component Condition Assessment (CCA) program. These were undertaken to identify elements of the SG and other heat exchangers which require inspection, maintenance and/or modifications in order to support the extension of Darlington’s operating life.
1. STEAM GENERATORS (SG)

The SG project has been broken down into separate elements of work to be performed throughout refurbishment. These include:

- **Primary Side Cleaning** – mechanical cleaning of magnetite from the inner diameter of the SG tubes.

- **Secondary Side Cleaning (Waterlancing)** – cleaning of the outer diameter of tubes at the tubesheet with a combination of high pressure lancing and low pressure/annulus flushing with visual inspections of the tubesheet area.

- **Access Port Installation** – allows additional visual inspection locations of SG internals during and post refurbishment. The ports are also required to provide future ability to clean the upper support plates and preheater region through waterlancing or future chemical cleaning, access for foreign material retrieval, and remote inspection of U-bend region and upper supports.

- **Inspection and Repair** – is required per the SG LCMP. This work includes tube plugging.

- **Divider Plate Inspections, Boiler Open/Close, and Inspection Support** – primary side divider plate leakage measurements using the acoustic leakage inspection system will be undertaken during the refurbishment outages to compare measurements conducted in previous outages.

- **Bleed Cooler Inspection and Bundle Replacement** – In accordance with the CCA, bleed cooler tube wall thickness measurements will be taken. Based on the results, tube plugging may be required. Bleed cooler bundle replacement is contingent on the results of the initial inspection.

THIS SCOPE IS REQUIRED ON U2, U3, U1, U4
The Darlington fuel handling system loads approximately 20,000 fuel bundles each year. It must remain reliable.

The Fuel Handling Work Bundle is to improve fuel handling reliability through inspections and replacement of critical components during the refurbishment outage. The system is a trolley based system, to allow flexibility in fuelling.

The fuel handling system must also be reliable in order to meet schedule and performance commitments for refurbishment and other running units.

Following re-tube activities, the fuel handling equipment must be returned to the station in a condition suitable for operation to end of life.

**The Fuel Handling Bundle includes the following:**

1. Powertrack Refurbishment
2. Reactor Area Bridge and Carriage Refurbishment
3. Irradiated Fuel Bay Heat Exchanger Replacement
Fuel Handling

This is a non-critical path activity. However integration with the station refuelling program is fundamental for successful implementation of this project.

1. POWERTRACK

The fuel handling system at Darlington performs routine online fuelling operations using fuelling machines mounted on trolleys. The power track provides a flexible avenue for power, control and signal cables to be connected to the trolleys from the central service area. One of the major activities in the refurbishment program is to refurbish the three existing power tracks, to ensure the continued operation of the fuel handling system to the end of station life.

This will be done with the support of an external contractor, who will be responsible for the procurement and construction of the components for the power track. This is a like-for-like replacement; no modification scope is required. The scope of work requires the replacement of the following components:
- Power track chain
- Power track support rollers including shafts and wheels, end drums including shafts
- Power track power, control and cables.

2. REACTOR AREA BRIDGE AND CARRIAGE REFURBISHMENT

The Reactor Area Bridge assembly supports a fuelling machine carriage. Vertical motion provided by the bridge, along with horizontal motion provided by the carriage, positions the fuelling machine head at any channel so that refuelling can be accomplished. The Reactor Area Bridge assembly consists of a bridge beam supported between two elevators which travel up and down on two fixed columns. Two bridges are provided for each reactor and are located adjacent to and parallel with the reactor face.

Refurbishment scope will replace a number of major components on the Reactor Area Bridge and carriage. All replacement components are like-for-like, with no Design Modifications envisioned. Installation and removal of the Reactor Area Bridge and Carriage is a critical path activity and will be repeated on every Darlington unit, with the Reactor Area Bridge removal at the beginning of the refurbishment and the reinstallation towards the end.

3. IRRADIATED FUEL BAY HEAT EXCHANGER REPLACEMENT (COMPLETE)

The Darlington Irradiated Fuel Bay system is comprised of eight heat exchangers and the corresponding piping equipment; at every side of the station there is one irradiated fuel storage (main) and one irradiated fuel storage reception (small) bays for a total of four bays.

Existing equipment performance did not satisfy the design basis and could not meet anticipated needs of the DNGS Refurbishment project during core defuelling.

A decision was made to perform a like-for-like replacement of “plate packs” for all eight irradiated fuel bay heat exchangers prior to 2015, in order to restore cooling capacity and mitigate margin management issues.
The Balance of Plant (BoP) work includes work in nuclear systems and conventional systems.

This work package will perform work on more systems and has more equipment and components than any other bundle.

Balance of Plant contains modifications and a large number of non-modification scopes of work.

**The Balance of Plant Bundle includes the following items. The first four are described:**

1. Adjusters
2. Auxiliary Shutdown Cooling System Heat Sink
3. Valve Rehab
4. Valve Preventive Maintenance
5. Containment
6. Electrical Rehab and Preventive Maintenance
7. Emergency Heat Sink
8. Emergency Service Water Line 15
9. Fire Protection
10. Fission Chambers
11. Preventive Maintenance – Other
12. Primary Heat Transport and Auxiliaries
13. Regulating Flux Detectors
14. Service Water (Stopple Plug)
15. SHIM Operations
16. Unique Components
17. BoP Scope Definition Legacy Work
1. THE ADJUSTERS
The scope of this work is a like-for-like replacement of the 16 adjuster rod assemblies (i.e., rod, cables and pins to drive mechanism attachment components currently in core at Darlington.

Each Adjuster Absorber (AA) consists of a stainless steel flexible cable, flange, nuts and washers, support rod, cotter pins, tube and a steel or titanium center rod. The flexible cable that hangs an adjuster rod will be detached from the drive mechanism and used to hoist the element into the reactivity mechanism flask for transport to the Wet Cask Handling Bay (WCHB) located in the west fueling facility auxiliary area.

Associated with the adjuster assembly are upper and lower shield plugs. The upper shield plug can be removed as the AA is being transferred to the flask. The lower shield plug will need to remain with the AA as it is being transported to the WCHB (it cannot be easily separated from the assembly). In order to reuse the lower shield plug, it will need to be separated from the AA in the WCHB. New lower shield plugs will be installed in Unit 2 to allow activation decay time for those that have been removed. Recycled lower shield plugs will be installed in the remaining units.

2. AUXILIARY SHUTDOWN COOLING HEAT SINK
This modification consists of installing two new auxiliary Shutdown Cooling (SDC) pumps considered as backup pumps (forced flow capability), which will be used as heat sink during unit outages.

The new pumps are not required for cool down or for accident heat sink. The new Auxiliary Shutdown Cooling (ASDC) pumps and their support services (power, pump cooling, etc.) are independent, diverse (to the extent practicable), and physically separate from the existing SDC pumps.

3. VALVE REHABILITATION
The valve rehabilitation project strategies apply to 11 valve groups (328 valves total) within the primary heat transport, shutdown cooling, moderator, low pressure service water and compressed air systems. The scope will address known or anticipated deficiencies to the existing station valves (both nuclear and conventional), including inspections, overhaul, repack, and replacements.

Two of the valve groups (moderator main isolators and service water isolation valves) require replacement. Where the opportunity exists, a blended strategy will be used to perform replacement on the first refurbishment unit and overhauls.swaps on the remaining three units.

4. VALVES – PM/CM
Valve preventive maintenance and a portion of the corrective repair maintenance items have been included in the Balance of Plant bundle.

This scope work will be done in conjunction with the valve rehabilitation scope which includes over 650 individual work items in numerous systems throughout the plant.
Specialized Projects

The Specialized Projects Bundle includes:

1. Shutdown System Computers
2. Vault Coolers
Specialized Projects

1. SHUTDOWN SYSTEM COMPUTERS

Each CANDU unit has two special Shutdown Safety systems (SDS1 and SDS2) which monitor reactor conditions such as heat transport system pressure, reactor power and coolant flow.

The Darlington Shutdown System (SDS) computers are comprised of a network of 14 computers per reactor unit which are being upgraded to modern platforms with new software.

Work includes the following:
- Replace the obsolete SDS1 and SDS2 trip computers to improve reliability and plant safety.
- Replace the obsolete SDS1 and SDS2 display/test computers to improve reliability and plant safety.
- Provide sufficient spare parts and major components as required.
- Procure the hardware for all four units together to ensure consistent revisions of components.

2. VAULT COOLERS

The design function of the vault cooler assemblies is to remove heat from the reactor building during both normal and out-of-spec conditions.

The scope of the work for the Vault Cooler Refurbishment is:
- A like-for-like replacement of the vault cooler coils and fan motors to improve temperature/cooling performance in the fault.
Return To Service

The Return to Service work covers a range of activities to return the refurbished unit back to full operating power.
Return to Service

The Return to Service Program controls the processes, procedures, and organization that will be used to manage the restart. It includes activities from construction completion acceptance of work completed by OPG and the vendors, modification commissioning and system restart activities and testing to allow the unit to return to full power.

The return to service of each unit has been segmented into four phases with a further nine Restart Control Hold Points (RCHP). These hold points will ensure that all of the necessary prerequisites are complete and the appropriate approvals have been received prior to transitioning from one state to another. This ensures equipment, systems, operating procedures and trained staff are ready to proceed with the next step in the start-up process.

Restart phases include:

- Restart activities prior to fuel load;
- Fuel load and activities prior to the guaranteed shutdown state removal;
- Approach to critical and low power testing; and
- High power testing and power escalation to full power.
Darlington Life Extension and Continued Operations

The feasibility of Darlington reaching 2055 and beyond is dependent on fully executing the DRP and undertaking other life extension work at Darlington necessary to support continued operations.

This includes ongoing normal maintenance and outage work of the unit that is being refurbished as well as the implementation of Darlington’s capital investment portfolio and other site improvements. All of this work and the schedule for its implementation are described in the Darlington Integrated Implementation Plan (IIP) which has been approved by the CNSC.

Maintenance and Outage Work

The Refurbishment team will manage all routine, scheduled maintenance required on each unit during the refurbishment outage of that unit. It primarily includes preventive maintenance work orders, but also includes station backlog and corrective maintenance work. The scope includes all of the routine work the station would normally execute as per the station outage plan.

The routine outage work for Unit 2 is referred to as D1621. The cost of this work is not included in the DRP because it is normal station maintenance work. However during the Unit 2 refurbishment outage it will be managed by the Refurbishment team because it is a more effective way to integrate the outage work with the refurbishment work schedule.

Regardless of which organization is doing the work or how it is funded, during the refurbishment outage it is all co-ordinated through one single, integrated schedule managed by the Refurbishment organization.
The Human/Machine Interface

Automated Guided Vehicles

During the Darlington Refurbishment Project, OPG’s staff and trades people will be heavily focused on overseeing, implementing and monitoring an incredible number of moving parts. In fact, approximately 70 per cent of the project’s efforts involve transporting thousands of materials and tools into and out of the nuclear reactor vault.

In order to handle these often massive loads, OPG has acquired two automated guided vehicles (AGVs) which offer robotic handling to safely increase efficiency and accuracy.

The AGVs are programmed to follow sensors or magnetic strips stamped onto the station’s floors. They can turn on a dime, are accurate within millimetres and allow for agility in transportation that is critically important in confined spaces, such as a nuclear reactor vault.

Retube Tooling Platform

The Retube Tooling Platform (RTP) weighs 45,000 kg and is the single largest tool of the Retube and Feeder Replacement (RFR) tooling set. The RTP consists of four columns and an elevating work platform.

During refurbishment, workers will need to access each of the 480 fuel channels on the reactor face. This critical tool moves up and down the reactor face while the heavy work table moves side-to-side. Specialized tools are fastened to the table – the tools are designed to reach inside the fuel channels - to cut and remove them, inspect the components, and install new ones.

This table is real timesaver. In past outages, workers would have to get on and off the fuelling machine bridge platform to do this type of work. This RTP and heavy work table can safely traverse with workers – and tools – aboard.
Darlington Site Safety and Infrastructure Projects

A number of systems, facility and infrastructure projects are being implemented at Darlington to improve plant safety and to support plant continued operations and refurbishment. The locations are shown in the map on page page 36 and a brief description of each is provided below.

1. **Darlington Energy Complex (DEC):** The DEC houses a full reactor face training mock-up facility, warehouse space, a public information centre, and office space.

2. **Operations Support Building (OSB):** The OSB houses Operations support staff and has been refurbished to comply with current code requirements and to extend the life of this building to meet the business needs of a refurbished Darlington station through the station’s continued operation.

3. **Re-tube and Feeder Replacement Island Support Annex (RFRISA):** This building will provide final staging of the reactor components (pressure tubes, calandria tubes, end fittings and feeders) prior to installation and support Darlington online and outage maintenance activities.

4. **Refurbishment Project Office (RPO):** This new three story building located outside of the protected area at the west end of the plant will facilitate efficient entry and exit of the large amount of construction staff required for refurbishment and outage maintenance activities. This building will also house change rooms and showers facilities, security search equipment and offices.

5. **Vehicle Screening Facility:** To facilitate security searches of all incoming and outgoing vehicles, a new vehicle security screening facility, referred to as the “Sally Port”, has been installed.

6. **Holt Road Interchange Improvements:** Upgrades have been made by the Ministry of Transportation Ontario to the existing Highway 401/Holt Road interchange that provides the main entrance to the Darlington station. The interchange allows for improved traffic flows that will also accommodate the projected increased workforce and traffic growth, in part related to refurbishment activities.

7. **Site Electrical Power Distribution System Upgrades:** Various parts of the Darlington Site Electrical Distribution System are being upgraded with new transformers, switch gear and cabling to provide power to existing buildings and new buildings at the station.

8. **Auxiliary Heating Steam Facility:** The oil/electric-fired Boiler House for providing heating steam to the station was not capable of supporting long term operation. A new Auxiliary Heating Steam Facility will supply back-up heating steam to Darlington Station and will also support Station outages associated with Containment and Vacuum Building Outages.
Water and Sewer: To support the refurbishment and operation of Darlington NGS, the site water and sewer infrastructure has been upgraded. The project provides reliable domestic and fire water supply to the station and sewage water piping and lift stations now connect the Darlington site to the municipal systems.

Heavy Water Management Building (HWMB): The new Heavy Water Management Building provides sufficient heavy water storage capacity at the Darlington site and services for ongoing Tritium Removal Facility (TRF) and station operations.

Re-tube Waste Processing Building (RWPB): Adjacent to Unit 4 on the east side of the station, will house equipment for volume reduction of the removed reactor components. Removed reactor components will be transferred via an enclosed corridor between the unit and this building where machines will cut and crush the material for interim storage in Re-tube Waste Container (RWC) flasks. The RWCs will then be transferred from the RWPB for storage in the RWSB.

Third Emergency Power Generator (EPG3): A third EPG is being installed to complement the two existing EPGs to improve the availability and reliability of the Emergency Power System for delivery of power following a Design Basis Event.

Containment Filtered Venting System (CFVS): The purpose of the CFVS is to prevent containment system failure from over-pressurization following an unlikely event of a multi-unit severe accident.

Powerhouse Steam Venting System (PSVS): The PSVS is being modified to increase overall system availability and reliability through the installation of additional control units on each unit.

Shield Tank Overpressure Protection (STOP): Additional overpressure protection is being installed to prevent potential shield tank failure in the extremely unlikely event of total and sustained loss of heat sink to any unit.

Emergency Service Water (ESW): Permanent fire water pumps have been installed to augment the existing Emergency Service Water System (ESW) for supply to the Firewater system. Permanent piping from the ESW will also be installed to allow the new Firewater pumps to supply emergency make-up water to the Heat Transport System.

Re-tube Waste Storage Building (RWSB): The RWSB is for the interim storage of Re-tube Waste Containers (RWCs) containing removed reactor components.

Darlington Waste Management Facility Expansion (DWMF): The existing DWMF is being expanded to provide additional used fuel Dry Storage Container (DSC) storage capacity needed for long term operation of the Darlington station.
Darlington Site Layout

1. Darlington Energy Complex
2. Operations Support Building
3. Re-tube and Feeder Replacement Island Support Annex
4. Refurbishment Project Office
5. Vehicle Screening Facility
6. Holt Road Interchange Improvements
7. Site Electrical Power Distribution System Upgrades
8. Auxiliary Heating Steam Facility
9. Water and Sewer
10. Heavy Water Management Building
11. Re-tube Waste Processing Building
12. Third Emergency Power Generator
13. Containment Filtered Venting System
14. Powerhouse Steam Venting System
15. Shield Tank Overpressure Protection
16. Emergency Service Water
17. Re-tube Waste Storage Building
18. Darlington Waste Management Facility
DARLINGTON
REFURBISHMENT
PROJECT

October 2016