

UPDATE OF OPG'S DECOMMISSIONING COST ESTIMATES & LESSONS LEARNED

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Abstract

Canadian regulations require that planning for decommissioning take place throughout a licensed facility's lifetime. As such, decommissioning plans and associated financial guarantees are updated and are required to be submitted to the Canadian Nuclear Safety Commission (CNSC) to support licence conditions. The Financial Guarantee is supported by decommissioning funds that have been set aside for Ontario Power Generation's (OPG's) decommissioning liabilities. OPG has recently completed their decommissioning cost estimate update that is normally performed on a five year review cycle. OPG has adopted a nominal 30 year deferred decommissioning strategy for its' nuclear generating stations as its planned approach.

This paper provides an overview of the improvements made to OPG's 2015 decommissioning cost estimates from the previous update performed in 2010 and the approach used. The technical assumptions and plans used in 2010 have been revised to include a more refined waste management strategy, incorporate recent Pickering safe storage planning assumptions and other important updates. This paper provides insight into the process used to validate the estimate and assumptions, challenges experienced, lessons learned and opportunities for future improvements to the estimate.

1. Introduction

Upon the formation of OPG, a risk sharing agreement was entered into between OPG and the Province of Ontario / Ontario Financing Authority (OFA). This agreement, called the Ontario Nuclear Funds Agreement (ONFA) was effective April 1, 1999. The intent of ONFA is to:

- a) Ensure that funds are available to satisfy OPG's long-term liabilities associated with management of nuclear waste as well as decommissioning of all generating stations and associated facilities,
- b) Limit the financial exposure that OPG faces for costs related to used fuel management, and
- c) Support OPG requirements for a financial guarantee to the CNSC to satisfy station license requirements under the Nuclear Safety and Control Act (Canada).

In accordance with ONFA, OPG makes payments to segregated funds for decommissioning. Reference plans which include cost estimates along with funds contribution profiles were prepared upon the implementation of ONFA and are updated on five year cycles.

Based on the above, OPG is required to prepare updates to plans and associated cost estimates for the decommissioning of OPG owned Nuclear Generating Stations (NGS) and waste management facilities. The NGS include: Pickering, Darlington and Bruce A and B (currently under lease to Bruce Power). The waste management facilities include:

- a) Used fuel storage facilities located at each NGS
- b) Low and intermediate level waste (L&ILW) management facilities located at the Bruce site:
 - Western Waste Management Facility (WWMF)
 - Radioactive Waste Operations Site 1 (RWOS1)
 - Central Maintenance and Laundry Facility (CM&LF)
 - Spent Solvent Treatment Facility (SSTF)

1.1 OPG's Decommissioning Strategy

OPG's strategy at the end of commercial operations is to defuel, dewater and maintain the NGSs in a safe state for nominally 30 years followed by dismantlement, demolition, and site restoration. This option is commonly referred to as 'Safstor'. OPG will retain ownership of the site throughout the course of the decommissioning process and restore the site to a state suitable for other OPG uses. OPG has chosen a decommissioning strategy that incorporates the best safety for workers, public and environment as well as the best value for customers.

OPG's decommissioning strategy has historically been reviewed on a five year cycle. The previous review was completed in 2010. This paper is based on the review completed for the 2015 decommissioning cost estimate update.

The cost estimate is structured to include costs for each decommissioning stage as shown below:

- Stage 1 - Preparation for Safe Storage
- Stage 2 - Safe Storage
- Stage 3 - Preparation for Dismantling
- Stage 4 - Dismantling
- Stage 5 - Site Restoration

Figure 1 below shows the overview of the overall decommissioning strategy and timeline for Pickering NGS units.

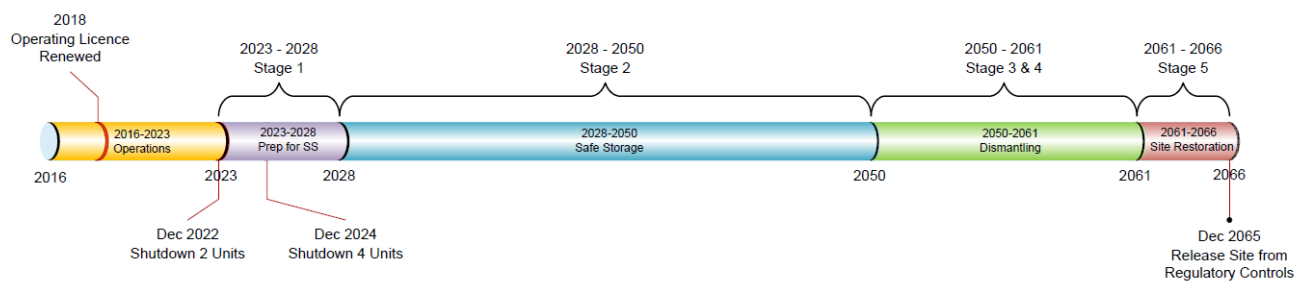


Figure 1 – Overall Decommissioning Timeline for Pickering NGS

1.2 Regulatory Requirements

There is an ongoing need to maintain credible, up-to-date plans and cost estimates for decommissioning of OPG's NGS and waste management facilities.

OPG is also obligated to meet the requirements of the Canadian Nuclear Safety and Control Act with regard to the operation and decommissioning of its nuclear generating stations. Under the Act, OPG must provide a financial guarantee known as the “CNSC Financial Guarantee” for the eventual decommissioning of its nuclear generating stations and facilities. Agreements are in place between the CNSC, OPG and the Province of Ontario for the purpose of the CNSC Financial Guarantee.

The CNSC Financial Guarantee prepared by OPG needs to meet the following requirements:

- CNSC Regulatory Guide G-206 “Financial Guarantees for the Decommissioning of Licensed Activities”
- CNSC Regulatory Guide G-219 “Decommissioning Planning for Licensed Facilities” and
- Canadian Standards Association (CSA) N294-09 “Decommissioning of facilities containing nuclear substances”.

CNSC Guide G-219 requires that Preliminary Decommissioning Plans (PDPs) be prepared in support of station licenses and financial guarantees. The PDPs submitted to the CNSC identify the overall approach to the decommissioning of the facilities including the planned decommissioning strategy.

To meet the requirements of the CNSC Financial Guarantee, OPG prepares cost estimates for decommissioning of OPG facilities including OPG owned and leased NGS and waste management facilities on a five year review cycle.

1.3 Stakeholder Needs

The needs of various stakeholders drive the continuous improvements and reviews of the decommissioning cost estimate. There are various stakeholders involved and their needs are described below:

- 1) OPG - To ensure that appropriate plans and associated liabilities are maintained and recognized in corporate plans and financial statements. Estimates are also used in maintaining segregated funds, rate setting with the Ontario Energy Board (OEB) and for interfacing on facility licensing with the CNSC.
- 2) Province of Ontario - The Province is the counterparty with OPG on decommissioning liabilities for OPG owned facilities. The Province confirms funding exists for the liabilities estimated and also supports the financial guarantee provided by OPG to the CNSC.
- 3) CNSC - The CNSC needs to be satisfied with plans for decommissioning. License renewals for OPG’s facilities require a financial guarantee to satisfy these liabilities. The submission to the CNSC includes PDPs for its facilities. In addition, annual reports are provided to the CNSC to communicate the status of the financial guarantee.
- 4) OEB - Ontario regulations require that OPG, through rate setting with the OEB, recover the revenue requirement impact of its’ nuclear decommissioning liability arising from the current approved plans.

- 5) Residents/Station Communities - Communities have a need to be satisfied that plans are in place for decommissioning of stations in their communities and funds are in place to implement the plans to prevent decommissioning liabilities from being incurred by future generations.

2. Approach to Perform Cost Estimate Updates

The cost estimate update process includes the six stages and is shown in Figure 2 below.

OPG employs leading experts to assure that best industry practices are used to prepare the cost estimates. For the latest update cycle, OPG prepared estimating requirements to procure the services of a vendor to perform OPG's cost estimate update. The selected vendor, TLG Services Inc., (referred to as Estimator) uses a propriety decommissioning cost model and their expertise in the decommissioning field to perform the update. The propriety cost model is based on industry decommissioning costs, lessons learned and specific unit cost factors.

During the early stages of cost estimate preparation, OPG compiles the data used as inputs within the estimate model. These inputs address the:

- Latest economic trends
- Changes in assumptions
- Plant data
- Technical advances in the performance of any field-related activities which would affect final decontamination and dismantling of a facility, and
- Work scope amendments including waste management costs and international experience in nuclear station decommissioning.

The Estimator receives the data from OPG and uses their proprietary cost model software and knowledge to estimate the costs. The results are provided to OPG in the format of a Work Breakdown Structure (WBS) with accompanying Work Element Definition Sheets (WEDS), cash flows and schedules compiled into a report format. OPG undergoes a review process of the updated cost estimate report to ensure assumptions and data have been incorporated correctly. The estimate review includes several working level reviews, challenge meetings and steering committee and executive level management reviews before acceptance of the estimate by OPG from the Estimator. Once accepted the estimates are packaged for submission to the Province and Regulator for final review and approval.

The level of definition, resulting accuracy and cost estimate class of the base decommissioning cost estimates are determined by the Estimator. Estimator judgment is used to determine allowance¹ at all levels of the WBS with input from OPG.

¹ A specific provision for unforeseeable elements of a cost element within the defined project scope, particularly important where previous experience relating estimates and actual costs has shown that unforeseeable events will increase costs and are likely to occur.

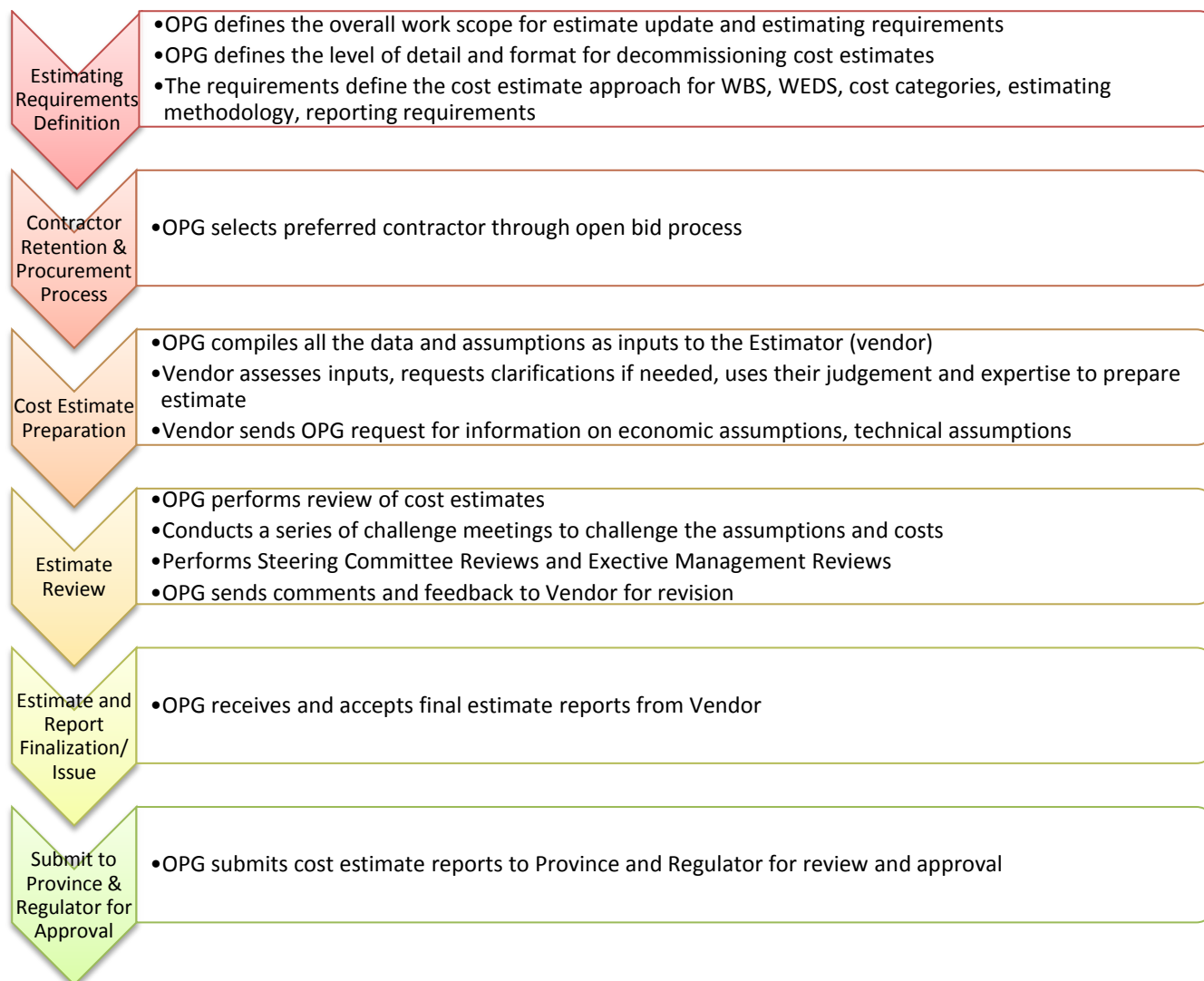


Figure 2 – Cost Estimate Update Process

3. Technical Assumptions in Cost Estimate

3.1 Assumption Process

One of the initiatives used to improve the update process was the development of an Assumptions of Record (AOR) document. Historically, decommissioning assumptions were distributed throughout various OPG documents with the basis for some of the assumptions not being readily available. As a result, the AOR document was created to identify and summarize the assumptions and associated basis and has become the main source of input to the estimate update. The purpose of the AOR document is to:

- Provide a systematic record of assumptions supporting current PDPs and associated cost estimates
- Act as the configuration basis over time for assumptions that have an impact on decommissioning Quality, Quantity, Timeliness, and Resources (QQTR)

- Act as a means to ensure consistent application of assumptions
- Act as an input to major business planning assumptions

Inclusion of the AOR for the current update has proved to be a significant improvement in managing the assumption basis and allowing for input into the estimate in a controlled manner. In addition, the AOR will ensure the cost estimates are consistent with the planning assumptions and information provided in OPG's PDP for all stations and facilities. Going forward the AOR will be used to control and facilitate any changes to the cost estimate assumptions and basis.

In addition to the AOR, OPG commissions a number of decommissioning related technical studies that are used to support and form part of the assumption basis. Some of these studies are described in the sections below.

Part of the assumptions process is to determine how to apply certain plant information received from other nuclear sites into the estimate. In some cases, OPG had to determine how to apply Pickering specific findings (e.g. planning of Pickering safe storage project) to other OPG NGSs and waste management facilities estimates. The information had to be extracted and a scalability method was used to apply the data on either a unit basis, a 4-unit station basis or on a megawatt size basis. This was done to ensure consistent information across all of OPG's nuclear fleet cost estimates.

3.2 Plans and Assumptions for Preparation for Safe Storage

3.2.1 Plans for Preparation for Safe Storage

In advance of the end of commercial operations at the Pickering NGS (tentatively 2 units slated for 2022 and the remaining 4 units slated for 2024), planning has been initiated for the Pickering Safe Storage Project.

The project will prepare and plan for the Stabilization Phase (first 3 years after shut-down) and the Safe Storage Phase (approximately 30 years). The goal of the project will be to minimize residual hazards on site by defueling reactors, dewatering systems containing tritiated heavy water, and placing systems no longer required to support the operation of the station into an Inactive Safe State. All systems no longer required will be removed from service, de-energized, drained of gas and/or fluids, and permanently isolated from operational systems. Structures, Systems and/or Components (SSCs) required to support the station will be modified, reconfigured, and/or reconstructed, as required, in order to meet the needs of the station over the Safe Storage period.

Safe storage preparation for Pickering units by OPG and subsequent safe storage period activities to date have resulted in planning and scoping data being obtained for use in the decommissioning planning and cost estimate updates. The applicable data was provided to the Estimator to be used in the preparation of the cost estimates for the decommissioning of the remaining Pickering units and application to Darlington and Bruce stations.

3.2.2 Preparation for Safe Storage Assumptions

A collaborative process between OPG Nuclear Decommissioning personnel, OPG Pickering safe storage project team and the Estimator was established for the current update. The safe storage costs

and assumption were challenged at a detailed level by all parties to arrive at a common and reasonable cost consensus.

Some of the assumptions updated in this round of estimate update include:

- Defueling strategy
- Energy consumption – heating and electrical
- Plant reconfiguration for safe storage (i.e. plant modifications)

In support of the advancement of the Safe Storage defueling strategy, the previous defueling assessment and cost estimate was evaluated to confirm that the underlying assumptions were both valid and consistent with the most up to date planning assumptions for the project. The results of the evaluation indicated that a number of gaps exist between the previous assessment and current defueling procedures/operations. Furthermore, current defueling operations take considerably longer than past estimates which were based on ideal conditions. The defueling strategy was reviewed and challenged by various experienced personnel in order to come up with the most realistic yet efficient process and cost.

The previous decommissioning cost estimate used a “cold and dark” heating strategy during the safe storage period. This strategy is a feasible option in the U.S. industry and OPG’s previous estimate was based on this experience. However, the strategy was reviewed and it was determined that a change was required from “cold and dark” to “warm and dim”. The driver for this change was the requirement to maintain the light water systems such as fire water and drainage, as well as heavy water storage tanks on site, radioactive liquid waste storage and legacy spent resin tanks. These requirements came to light as part of the project planning and scoping phase. As a result of this new information and requirements, OPG reviewed and validated the assumptions associated with energy costs. Energy costs are comprised of electrical consumption and building heating costs. The electrical consumption was estimated by incorporating OPEX from a similar sized 8 unit powerhouse at OPG’s Nanticoke Generating Station (coal fired plant) and Pickering Units 2 and 3 while including a judgement associated with higher nuclear requirements.

Another assumption that improved the cost estimate details was the inclusion of plant modifications that are required to re-configure the plant for long term safe storage. Previous estimates included a small allowance for this purpose. As the project is in the scoping phase, the plant modifications identified are in the areas of electrical supply and distribution, fire protection, environmental monitoring, building HVAC, other utilities, monitoring, and minor modifications.

Advances in the three scoping areas described above resulted in significant improvements over the previous cost estimates since they are based on the latest planning assumptions. Through the assumption review and validation process as new information becomes available, OPG will update the estimates accordingly.

3.3 Plans and Assumptions for Decommissioning Waste Management

3.3.1 Plans for Decommissioning Waste Management

At the time of decommissioning, OPG will produce three types of waste: low, intermediate and high level (used fuel) waste. OPG’s current plans for the management of these waste types are as follows:

- a) Low and Intermediate Level Waste (L&ILW) - At this time, OPG plans to place L&ILW generated during decommissioning in the proposed L&ILW DGR located in Kincardine. If expansion of the facility is required to accommodate additional waste volumes, OPG will obtain the appropriate regulatory approval for this work.
- b) High Level Waste (Used Fuel) - After commercial operations end, the units will be placed in the safe storage state. The first step to prepare the station for safe storage is to remove the fuel from the reactors and transfer to the wet bays on site. The fuel cools in the bays (during the safe storage period) and after an appropriate cooling period, will then be moved from the fuel bay into dry storage containers (DSCs) for interim storage on-site. The containers will continue to be stored onsite until a permanent disposal facility is available in the future. Under the Nuclear Waste Management Organization's (NWMO's) Adaptive Phased Management (APM) program, the long term disposal facility for used-fuel is currently expected to be in-service prior to the start of Pickering dismantling. For OPG, the management of the used fuel program is addressed under a separate used fuel fund.

3.3.2 Waste Management Assumptions

Some of the assumptions updated in this round include a review of the waste packaging available and waste generated, volumes and characteristics.

Packaging of Waste

The 2015 decommissioning cost estimates were improved by reviewing various packaging options available for the different waste types. For the management of Low Level Waste (LLW), OPG reviewed the suitability of various containers for packaging this type of waste. The most optimal container was chosen based on the efficient packaging density and costs. OPG commissioned a study to investigate commercially available container system technology options and propose an improved planning assumption for packaging, transport and disposal of decommissioning ILW. This study included the use of an integrated waste management strategy.

Waste Generated, Volumes and Characteristics

Specific areas of waste generated were also reviewed. The previous decommissioning cost estimate included costs for decontamination of the Primary Heat Transport (PHT) system. In 2012, OPG commissioned a study to assess the benefits of decontamination. The specific objectives of the study were to: 1) determine the best timing and options available for decontamination, 2) recommend the most suitable PHT system decontamination process and 3) assess the need for decontamination, considering deferred dismantling periods of 10, 20 or 30 years. Based on this study, decontamination has no benefit if dismantling is deferred beyond about 20 years. Therefore, updates were made to remove the PHT decontamination at the time of shutdown since OPG employs a 30 year safe storage strategy.

In 2014, OPG commissioned a study to develop a comprehensive radionuclide inventory estimates for decommissioning waste associated with all three of OPG's stations. The estimates were required to reflect their specific operating timelines. Radionuclide inventories associated with components subject

to neutron activation (fuel channels, calandria vessel, end-shield, reactivity control and safety shutdown systems and bioshield) were estimated from available data, both measured as well as predicted. In the case of out-of-core components, which are not subject to neutron flux (steam generators and feeder/header pipes represent the two largest surface area components), projections were based on available characterization data for radioactive surface deposits found on the internals of these components. The radionuclide inventory estimate would be used for waste disposal safety assessments. The study also provides a rational basis for dismantling and segmentation decision-making so that the packaged volumes of the overall waste, particularly that of ILW, can be minimized.

The overall decommissioning waste volumes were closely reviewed. Further preliminary studies were performed to include an estimate for contaminated reactor vault concrete and soil contamination.

3.4 Other Assumptions

Many other assumptions were updated during the most recent review including:

- a) Costs for retrieval, packaging and disposal of hazardous materials (i.e. asbestos, PCBs, lead, mercury, and other hazardous materials) which cannot reasonably be removed during station operations (i.e. are affixed to the station systems, structures, and components) were included in the current update. A previous assumption was that station operations would remove hazardous materials prior to end of commercial operations. These costs are now accounted for during the preparation for dismantling phase.
- b) Costs associated with long term management for heavy water were included in this round of update. Over the past few years, the value of heavy water has changed from an asset to a liability. Even though a strategy has not been chosen for the disposal of heavy water a reasonable cost allowance was allocated.
- c) During the estimate update process, a change related to insurance occurred. This was a result of updates to the Nuclear Liability Act. To accommodate this change, OPG re-worked and updated the insurance model inputs.

4. Estimate Validation

OPG strives to continuously monitor and incorporate industry best practices and has a high degree of confidence that the current plans are appropriate and sufficient based on the following:

- 1) Benchmarking of OPG's cost estimates against the international community of cost estimates for nuclear plants planning, undergoing, or completed decommissioning projects.
- 2) Independent third party reviews of OPG's cost estimates and plans are compared against estimating methodologies from the nuclear decommissioning industry.
- 3) Continuous review of international best practices in decommissioning nuclear power plants to improve and increase confidence of the plans.
- 4) Employing leading experts to assure OPG's approach and practices are of the highest quality.
- 5) Internal and external audit reviews to assess OPG's nuclear liability cost estimate processes.
- 6) Ensuring the decommissioning plans and estimates are in compliance with current CSA N294 standard and CNSC G-219 and G-206 guidelines.

5. Challenges and Lessons Learned

Many challenges were faced during the 2015 cost estimate update and several lessons were learned. Some examples are described below:

- 1) Reviewing OPEX/industry experience is vital to validate assumptions. As described in Section 3.2.2, OPG reconsidered its cold and dark strategy during the safe storage period in light of new information and requirements. As such, energy requirements for heating and electrical consumption had to be updated to reflect current information. The lesson learned was to review OPEX/industry experience, validate assumptions and continuously update the estimate with new information.
- 2) An important aspect of the cost estimate update process is managing internal stakeholder interfaces. Input is received from the various stakeholders early in the update process. There are many groups within OPG that are involved and participate in the update process such as:
 - Station Operations – provide input on changes to station plant inventory, hazardous material inventory and security.
 - Projects - the Pickering safe storage project group provide input into the preparation for safe storage phase.
 - Finance – provide input into financial assumptions including insurance and property taxes.
 - Regulatory Affairs – provide input into CNSC fees and environmental assessments.
 - Other Waste Management program owners - provide input into containers and timing of waste storage facilities in-service.

The lesson learned was to engage all cost estimate stakeholders early and upfront in the update process. The roles and responsibilities of all internal stakeholders are identified and documented in a Terms of Reference.

- 3) An on-going challenge to updating the cost estimates is keeping pace with a constantly changing business environment. The update process is complex and starts about 18 months in advance of the submission date to the Province. The update includes a 6 month review and challenge process from OPG's senior management. As such, some inputs change during the update process and have to be reworked. Some examples include changes to Pickering end of life dates, Darlington and Bruce refurbishment decisions and new shutdown dates. These changes caused changes in the associated waste forecasts. This required re-work to accommodate the new waste volume projections from new end of life dates. The lesson learned is to build extra contingency time into the schedule to accommodate late changes that arise late in the update process.
- 4) A constant challenge in the update process is keeping track of the changes being made to the estimates as they evolve and through the review process updates. The estimates experience much scrutiny from Stakeholders in the areas of what's changed, why it's changed, have costs increased or decreased and details of any scope changes. As such, having a variance analysis that shows the changes from the previous estimate is highly critical and very important.

- 5) A challenge that arose during this update was to appropriately identify the sequence of work planning activities that are inputs into the estimate. OPG wanted a better understanding of waste management characteristics while having an integrated waste management strategy. Studies were required to achieve this increased understanding of decommissioning waste. As such, conducting these studies in the right sequence is critical. Some of these studies were performed in parallel and were dependent on certain information that was not available until the other study was complete. For example, OPG was performing a radionuclide characterization study at the same time as a reactor dismantlement waste packaging study. OPG had to facilitate communication between the two vendors in order to bridge any gaps from the data from the radionuclide characterization study into the waste packaging study while completing it in the short duration of the estimate update. The lesson learned was to start these studies early on, in the correct sequence and have them completed prior to the cost estimate update process so they can be provided to the Estimator as an input at the start of the update.

Ideally, it would be best to have all inputs ready early in the update process and provide to the Estimator. However, since OPG had contracted studies running in parallel with the estimate update some of the information was going to be made available later in the cost estimate update process. As such, another lesson learned is to allocate time into the schedule for a second round of assumptions review during the middle of the update process.

6. Identifying Opportunities for Future Improvement

An important aspect of updating the cost estimate is to recognize opportunities for future improvements to the estimate. Continuous information gathering and planning details will further progress the cost estimates. Some potential areas to perform further studies that could reduce decommissioning planning uncertainty going forward are:

- Detailed waste characterization
- Calandria segmentation for a CANDU reactor
- Optimization of waste handling and packaging
- Volume reduction, waste minimization and consideration to further segregation of waste
- Dismantlement planning

7. Conclusions

OPG has submitted draft cost estimates to the Province for review with approvals expected by the end of this year. The cost breakdown by decommissioning stages for 2015 is shown in Figure 3 below.

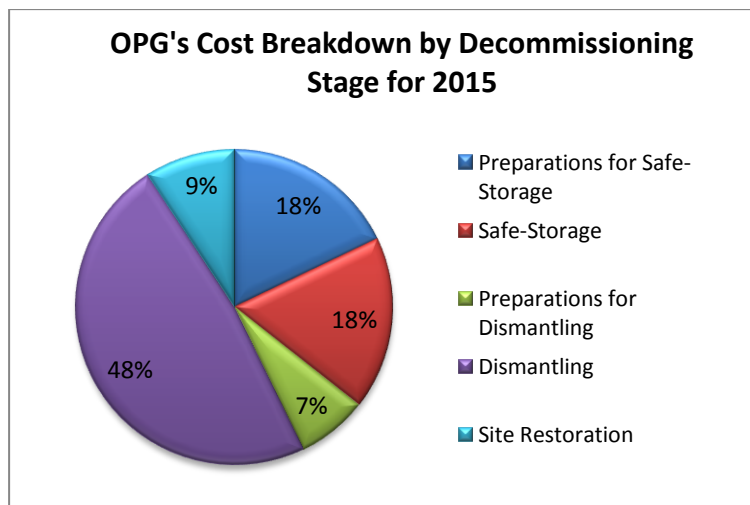


Figure 3 – OPG's Cost Breakdown by Decommissioning Stage

There are many complexities involved in updating the cost estimates related to decommissioning of nuclear power plants. The estimates are required to be based on key assumptions. It is important to have the correct up-to-date assumptions to reflect the realistic costs during decommissioning so that the decommissioning fund is appropriately funded.

OPG will continuously update their decommissioning strategies, plans and costs as required to incorporate lessons learned, address updates to regulatory requirements, and industry best practices. These updates will add clarity and accuracy to the decommissioning of OPG nuclear facilities. The cost estimates will continue to evolve and develop as the decommissioning project progresses and as more information becomes available with time. OPG plans to perform additional studies to further enhance the estimates and continue to validate assumptions.

8. Acknowledgement

We would like to acknowledge the contribution made by John Kennard and Geoffrey Griffiths in support of this work.

9. References

- [1] Canadian Nuclear Safety Commission, "Financial Guarantees for the Decommissioning of Licensed Activities", CNSC Regulatory Guide G-206, June 2000
- [2] Canadian Standards Association, "Decommissioning of facilities containing nuclear substances", CSA Standard N294-09, July 2009
- [3] Canadian Nuclear Safety Commission, "Decommissioning Planning for Licensed Activities", CNSC Regulatory Guidance G-219, June 2000