ONTARIO POWER GENERATION

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March 5, 2018

CD# P-CORR-00531-05310

**MR. M. A. LEBLANC**
Commission Secretary

Canadian Nuclear Safety Commission
280 Slater Street
Ottawa, Ontario
K1P 5S9

Dear Mr. Leblanc:

**Pickering NGS – Notice of Participation at**
**CNSC Public Hearing 2018-H6 and Written Submission –**
**Application for the Renewal of Power Reactor Operating Licence**

The purpose of this letter is to notify the CNSC that OPG will appear at Public Hearing 2018-H6 and to provide the associated written submission. This notification and submission are made pursuant to *CNSC Rules of Procedure*, Section 18(1) (a) and (b).

OPG will appear before the Commission on April 4, 2018 in Ottawa, for Public Hearing 2018-H6 Part 1, regarding the renewal of Pickering's Power Reactor Operating Licence (PROL) 48.04/2018 (Reference 1).

In support of the Part 1 hearing, attached is written submission CMD 18-H6.1. The Commission Member Document summarizes and updates information supporting Pickering's licence renewal application (Reference 2).

OPG is requesting a 10 year renewal of the Pickering Operating Licence. The current licence expires in August 2018, and the renewed licence that is being requested will cover continued commercial operation to the end of 2024 and transition to a safe storage state by 2028.

Pickering's licence renewal application and supporting references can be found on OPG's website and have been available to the public since September 2017. For the Commission's convenience, enclosed are a copy of the licence renewal application (Reference 2) and supplementary information to the application which was provided in response to CNSC staff requests for further information (Reference 3).

If you have any questions, please contact Dr. Jack Vecchiarelli, Manager, Pickering Relicencing, at (905) 839-6746, extension 5444.

Randy B. Lockwood
Senior Vice President
Pickering Nuclear

cc: CNSC Site Office – Pickering
CNSC Pickering Regulatory Program Division (copy to each staff)

References:

1. CNSC Letter, L. Levert to R. Lockwood, "Application for Renewal of Pickering Nuclear Generating Station Power Reactor Operating Licence (PROL 40.03/2018)", August 29, 2017, e-Doc 5309896 CD# P-CORR-00531-05130.

2. OPG Letter, R. Lockwood to M. Leblanc, "Application for Renewal of Pickering Nuclear Generating Station Power Reactor Operating Licence", August 28, 2017, CD# P-CORR-00531-05055.

3. OPG Letter, R. Lockwood to M. Leblanc, "Supplementary Information to the Application for Renewal of the Pickering Nuclear generating Station Power Reactor Operating Licence", December 11, 2017, CD# P-CORR-00531-05223.

Attachments:

1. "OPG Written Submission in Support of the Renewal of Pickering's Power Reactor Operating Licence, CMD 18-H6.1".

Enclosures:

1. OPG Letter, R. Lockwood to M. Leblanc, "Application for Renewal of Pickering Nuclear Generating Station Power Reactor Operating Licence", August 28, 2017, CD# P-CORR-00531-05055.

2. OPG Letter, R. Lockwood to M. Leblanc, "Supplementary Information to the Application for Renewal of the Pickering Nuclear generating Station Power Reactor Operating Licence", December 11, 2017, CD# P-CORR-00531-05223.

# OPG
# Written Submission

in support of the renewal of Pickering's
POWER REACTOR OPERATING LICENCE

Securing Ontario's Clean Power Future

ONTARIO POWER GENERATION

CMD 18-H6.1 PART 1 HEARING April 4, 2018

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# Executive Summary

OPG is applying to the Canadian Nuclear Safety Commission (CNSC) for a 10-year renewal of its Power Reactor Operating Licence for the Pickering Nuclear Generating Station (NGS). The current licence expires in August, 2018, and the requested licence renewal would cover continued commercial operation through to the end of 2024, and transition to a safe storage state by 2028.

This Commission Member Document (CMD) summarizes the evidence that demonstrates the Pickering NGS meets all the legal requirements of the Nuclear Safety and Control Act and the associated Regulations, and that OPG is qualified to carry on the licensed activities and makes adequate provisions to protect the health, safety and security of persons and the environment, and maintain national security and measures required to implement international obligations.

OPG is proud of the strong performance and many significant achievements of the Pickering NGS during the current licence term. This track record is a testament to the diligence and passion for excellence that all personnel are committed to, each and every day, in support of the safe and reliable operation of the station. Pickering's longevity has afforded OPG with an abundance of valuable operating experience such that staff are intimately familiar with the plant's operational characteristics. The plant is not the same as it was when it first started to operate – it is better; the design and operation of Pickering NGS has significantly improved over the years, and the plant performance is getting even better. In fact, Pickering NGS heads towards the next licence renewal period with some performance measures that are the best ever in plant history. Following  are some highlights of what has been accomplished at the Pickering NGS. These are just a few examples that demonstrate why the Commission and the public can be confident in the continued safe operation of Pickering NGS.

During the current licence term, Pickering NGS has continued to demonstrate strong conventional safety performance that is in the industry's top quartile. For instance, in 2014, Pickering reached 11 million hours without a single lost-time accident; and, in 2017, Pickering had its best-ever All Injury Rate with a remarkable value of 0.06. In November 2016, OPG received the Canadian Electricity Association's President's Gold Award of Excellence for Employee Safety in recognition of the company-wide All Injury Rate and Accident Severity Rate performance for 2013, 2014 and 2015. Furthermore, in each of 2015 and 2016, the station received the CNSC integrated plant rating of Fully Satisfactory (the highest rating from the regulator) based on the CNSC's evaluation of the 14 Safety and Control Areas.

Station reliability has improved significantly due to investments and improvements made over the licensing period. As a result, two of Pickering's units have had record operational runs - Unit 5 at 632 days and Unit 1 at 622 days. This can only happen because the plant is being maintained well. Combined with its best forced loss rate performance in site history (average of 4% over 2015 to 2017), Pickering NGS is continuing to achieve improved and more reliable operation, which in turn improves nuclear safety at the station.

Comprehensive safety analyses, both deterministic and probabilistic, confirm that the Pickering NGS design is robust and very safe. These analyses are within all safety analysis criteria and limits as well as below OPG's probabilistic safety assessment safety goals (severe core damage frequency and large release frequency for individual reactors). Moreover, in collaboration with industry, a first-of-a-kind whole-site risk assessment was performed to support that the overall risk of the entire Pickering site is low; this pilot work is at the forefront of international progress on probabilistic safety assessment.

As safe as Pickering NGS has been, nuclear safety has been enhanced over the current licence term with a number of significant safety improvements that OPG implemented, including physical plant improvements to safety systems, substantial investments to put in place emergency mitigating equipment (EME) Phase 1 and 2, and procedure improvements. The EME was utilized during a recent large scale emergency exercise, Exercise Unified Control (December 2017), which demonstrated the robustness of both on-site and off-site emergency preparedness measures.

Furthermore, an extensive Periodic Safety Review (PSR) was conducted in concert with the licence renewal application, and it has concluded that Pickering NGS has in place effective programs and processes for continued safe operation through 2024. Through OPG's Integrated Aging Management Program, appropriate maintenance, testing and monitoring are ongoing at Pickering NGS, with particular attention to major components such as fuel channels, assuring that the plant is fit-for-service and safe throughout the continued operating period. In addition, OPG is pursuing a number of plant modifications identified via the PSR process to further enhance the safety of the plant. Pickering NGS is safer today than it has ever been, and with the PSR modifications, Pickering NGS will be even safer during the next licence term.

OPG is particularly mindful of its social licence and the need to ensure protection of the public and the environment. OPG has an extremely strong track record in this area. OPG continues to demonstrate that the radiological releases into air and water from Pickering reactor operations are at levels that are far below regulatory limits and hence are protective of public health and the environment. The environmental monitoring program regularly samples water, air, and soil to ensure that both radiological and non- radiological emissions remain at safe levels. OPG posts the environmental monitoring results on its external website so that local communities and interested members of the public can verify the plant's safety. As a major achievement, Pickering NGS was recently issued a fish authorization by Fisheries and Oceans Canada, in recognition of the protective measures which OPG has undertaken for aquatic life and the participation in biodiversity and wildlife habitat programs. OPG will continue to show environmental stewardship in biodiversity and wildlife habitat programs. Pickering's performance will continue to improve, with the station priorities focusing on safety, reliability and human performance.

OPG also maintains strong relationships with local communities and with Indigenous groups. OPG recognizes that members of the public, stakeholder groups, and local communities have a legitimate interest in the operations of the Pickering NGS; the way in which it is operated and managed; and the means by which OPG keeps the risks to human health and safety, and to the environment, at a low level. OPG therefore shares information on facility operations and performance with members of the public, to enable interested individuals to monitor the safety of the plant and OPG's management record. OPG also works to develop positive relationships with local communities, including those in the vicinity of the Pickering facility and Indigenous communities, as well as with stakeholder groups that have a longstanding interest in the safety of nuclear power.

The transitioning of the station from commercial operation, at the end of 2024, to a safe storage state is being carefully planned. OPG has proven its ability to undertake such a transition with the successful safe storage of Units 2 and 3. Well-established procedures exist for the associated activities of reactor defueling and dewatering, as Pickering NGS utilizes these procedures during unit outages.

In its Licence Application submitted to the CNSC, Pickering made a set of six major commitments related to the continued safe and reliable operation of the plant through the requested licence term. These are:

- Nuclear safety will be assured such that plant personnel, the public and the environment are protected;
- Systems, structures and components at the plant are fit to continue commercial operation to the end of 2024, and inspection programs will ensure fitness for service during the next licence period;
- Staff are qualified and competent to operate the plant, and this will be maintained through the next licence period, including sufficient staffing numbers;
- Impacts of plant operation to the public, workers, and the environment will continue to be of low risk and adequately mitigated, while continuing to provide the various societal and environmental benefits of plant operation;

- Transparency and appropriate public and Indigenous engagement will continue; and
- OPG will continue to invest in Pickering to support the above objectives, including to improve equipment reliability, to assure fitness for service until the end of commercial operations, and to further enhance nuclear safety.

This CMD contains and references the information necessary for the Commission to make its decision associated with the licence renewal application. Following the Introduction, Section 2 explains the evidence that OPG is qualified to operate Pickering NGS with adequate attention to protection of the public, workers, and the environment, through management systems and programs that ensure that safety is the overriding priority in all activities at the station. This evidence is presented in terms of OPG's six commitments for safe and reliable operations through the licence term, listed above.

Section 3 consists of a brief description of each of the CNSC's Safety and Control Areas (SCAs), highlights strengths and noteworthy achievements in these areas, and updates information contained in the Licence Application to reflect 2017 results. Section 4 reviews some additional regulatory matters including the Cobalt-60 program and the Nuclear Liability Act.

Finally, further technical details on the Pickering Periodic Safety Review (PSR2), assurance of fuel channel fitness for service, and Pickering whole-site risk assessment are provided in three Addenda to the CMD.

# 1. Introduction

Ontario Power Generation (OPG) is applying to the Canadian Nuclear Safety Commission (CNSC) for a ten-year licence renewal to operate the Pickering Nuclear Generating Station (NGS), including continued commercial operation to 2024 and post-shutdown activities leading to a safe storage state. OPG is confident that Pickering NGS will remain fit for service and that Pickering Nuclear staff are qualified to continue to operate the plant with adequate provision for human health and safety as well as environmental, security and international obligation considerations over the next licence term.

OPG is pleased to present the evidence in support of its Licence Application in this Commission Member Document (CMD). The CMD summarizes and explains the science-based case for the relicensing of Pickering NGS. It reviews the various physical, operational, and programmatic provisions that together assure the safe operation of the station throughout the entire licence renewal period, while meeting or exceeding the applicable regulatory requirements, codes, and standards as well as respecting social concerns and expectations for safety and transparency. As such, this CMD contains and references the information necessary for the Commission to make its decisions associated with the licence renewal application.

## 1.1 The Pickering Nuclear Generating Station

The Pickering NGS is located on the north shore of Lake Ontario in the City of Pickering in Ontario. The station generates approximately 14% of the electricity needs of the province of Ontario, at low operating costs and with virtually no greenhouse gas (GHG) emissions. Under the Long Term Energy Plan of the Province of Ontario, the continued commercial operation of the Pickering NGS will ensure that Ontario has a reliable source of GHG-free baseload electricity to carry it through the refurbishment of the Darlington NGS and the initial Bruce NGS units.

As shown in the site map below, Pickering NGS has eight CANDU nuclear reactors that are arranged on two sides of the station, with separate control rooms on each side of the station. Six of these units, Units 1 and 4 and Units 5 -8, are operating and generating electricity. Another two (Units 2 and 3) are no longer operating and have been in the safe storage state since 2010. The operating reactor buildings are connected to a common vacuum building, a major component of the Pickering NGS safety systems.

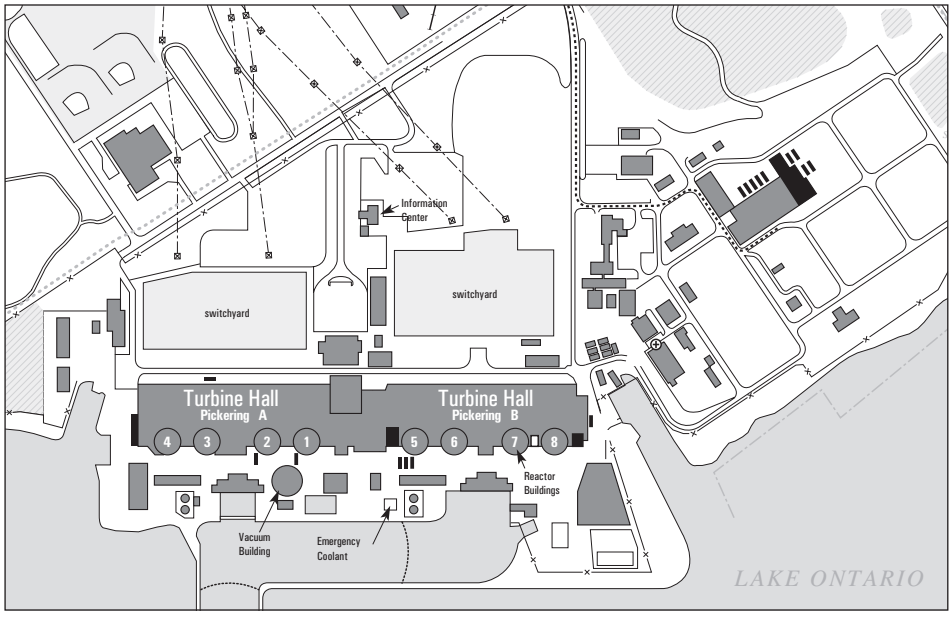



**Figure 1** - Site map illustrates the main structures of the Pickering nuclear station

## 1.2 The Licence Renewal Application and Associated Requests

The current Pickering Power Reactor Operating Licence expires on August 31, 2018.
As requested by the Province of Ontario in January 2016, OPG is pursuing the extension of Pickering NGS operations past 2020 to 2024 subject to the regulatory approval process.
The requested ten-year licence renewal would encompass commercial operation to the end of 2024 as well as the operation of transitioning the reactors to a safe storage state by 2028.

A ten-year licence term is desirable and appropriate, for the following reasons:

- It would allow OPG to expedite the post-shutdown activities and ensure an efficient and smooth transition to safe storage;
- It would provide regulatory certainty for OPG's shareholder, the Province of Ontario, and rate payers;
- It is consistent with the ten-year time frame that is normally associated with a Periodic Safety Review in Canada (as this CMD discusses in more detail later, the Pickering NGS licence renewal request is supported by a comprehensive Periodic Safety Review, which is an internationally recognized process that is systematically performed in concert with licence renewals);
- It does not impact the effectiveness of the compliance program established by CNSC staff or the authority of the Commission to suspend, revoke or replace the licence, including establishing new licence conditions; and
- It does not preclude reviews and ongoing public scrutiny of plant performance before the Commission.

With the end of commercial operation on December 31, 2024, all units will be shut down, and the fuel and heavy water will be removed from the reactors to begin the safe storage phase, in preparation for eventual decommissioning. The continued commercial operation of approximately six years will be achieved with additional safety enhancements to further reduce the already low risk of plant operation, and with ongoing inspection, maintenance and investments to assure fitness for service. The timeline for the activities planned for the licence term is shown in Figure 2 below.

OPG submitted a full Pickering Nuclear Generating Station Power Reactor Operating Licence Application to the CNSC in August, 2017 (Reference 1) and is requesting a ten-year licence renewal from September 1, 2018 to August 31, 2028. OPG has also submitted supplementary Licence Application information to the CNSC in December, 2017 (Reference 2), in response to CNSC staff requests for further information on some parts of the Licence Application. These documents demonstrate that Pickering will continue to be operated safely through the requested licence renewal term, providing detailed evidence that OPG is qualified to carry out the licensed activities and make adequate provisions to protect the health, safety and security of persons, and the environment and maintain national security and international obligations. The Licence Application and supplementary information to the Application are available to the public on OPG's website, **www.opg.com**.

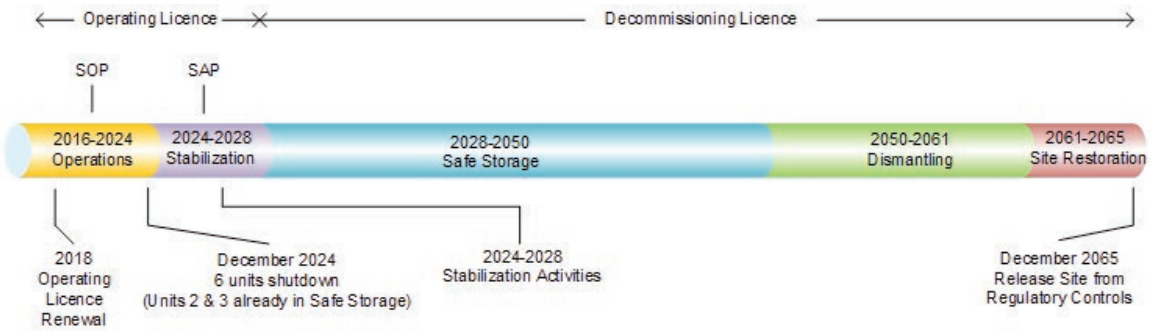



**Figure 2** - Pickering long-term plan showing the Sustainable Operations Plan (SOP) and the Stabilization Activity Plan (SAP) within an extended timeframe

Associated with the Licence Application is a request for the Commission to approve the operation of the fuel channels in Pickering Units 5-8 beyond their current limit of 247,000 Effective Full Power Hours (EFPH) to 295,000 EFPH for the lead unit.

> EFPH is a measure of the age of the fuel channels. It captures only those times when the fuel is undergoing fission, i.e., the nuclear chain reaction process which changes the characteristics of the fuel channel.

This extended operational period corresponds approximately to the intended end of commercial operation (December 31, 2024).

The activities that OPG is requesting be licensed under the new licence term are noted in Appendix A of the Licence Application.

OPG is also requesting that the list of activities authorized under the renewed licence include the import and export of nuclear substances consisting primarily of contaminated laundry (See Reference 2). These activities were the subject of a previous licence amendment, which was approved in October, 2017.

## 1.3 Key Considerations for Licence Renewal

The use of nuclear energy and substances is regulated under the Nuclear Safety and Control Act (NSCA) to ensure the safe operation of nuclear power plants, through preventing unreasonable risk to workers, the public and the environment. The systems, structures and components, as well as the managed systems, are in place at Pickering NGS to ensure that safety is the focus and overriding priority of all operations at the plant. OPG is committed to safe and reliable operation of the Pickering NGS and continues to meet or exceed all of the legal requirements of the Nuclear Safety and Control Act and the associated regulations.

OPG Nuclear and Pickering staff recognize that they are accountable to manage the facilities in a way that ensures that Ontarians benefit from the electricity the plant produces, at minimal risk to public health and safety and to the environment.

OPG takes seriously its responsibility to protect against the risks that are associated with nuclear power, including risks to workers from routine plant operations, risks to the environment from leaks or other emissions, and risks to the public from an accident. OPG is proud of the excellent safety record of its nuclear power reactors, including Pickering, and continues to work hard every day to maintain and improve that record.

The rest of this Section summarizes the key factors that ensure the safe and reliable operation of Pickering NGS, and outlines important considerations related to the scope of the Pickering NGS licence renewal request. More detailed and additional supporting discussions are provided in Section 2 as well as the addenda to this CMD.

### 1.3.1 Performance Highlights from the Current Licence Term

During the current licence term, Pickering NGS has continued to demonstrate strong safety performance with a conventional safety performance rating that is in the industry's top quartile. In 2014, Pickering reached 11 million hours without a lost-time accident, and achieved its best-ever All Injury Rate of 0.06 in 2017. In November 2016, OPG received the Canadian Electricity Association's President's Gold Award of Excellence for Employee Safety in recognition of the company-wide All Injury Rate and Accident Severity Rate performance for 2013, 2014 and 2015.

Pickering has received a CNSC integrated plant rating of Fully Satisfactory (the highest rating possible) in 2015 and 2016, through CNSC's evaluation of the 14 Safety and Control Areas. Probabilistic safety assessments have demonstrated that the risk of operating Pickering reactors is low, and below safety goals with respect to severe core damage frequency and large release frequency. In addition, OPG completed a first-of-a-kind whole-site risk assessment of Pickering with the overall conclusion that the risk of the whole Pickering site is low.

In the last three years, using the "As Low As Reasonably Achievable (ALARA)" principles, the Pickering collective radiation exposure (the aggregate doses received by all workers) has been reduced despite an increase in the amount of radiological work being performed.

Operational reliability has improved significantly as a result of investments and improvements made over the licensing period, with Pickering's Units 5 and 1 having record operational runs at 632 days and 622 days, respectively, and with Unit 4 on the way to its longest operational run. Combined with its best forced loss rate performance in site history (average of 4% in last three years), Pickering NGS is continuing to achieve improved and more reliable operation. This demonstrates that the station is well maintained.

Human performance over the licensing period has also improved as a result of initiatives implemented under the human performance strategic plan (e.g., focus on fundamentals, proficiency, and the use of error reduction tools) and the ability of the Station Leadership Team to recognize weaknesses and address them.

Pickering leadership recognizes the need to strive for continual improvement and engagement of the work force. Pickering's mission is improved performance year after year, so that the station's best day of operation is its last day of operation. Pickering's vision for 2018 is to "work with a passion for excellence founded on safety and quality". Station priorities are focused on supporting Pickering's performance goals to continue to improve safety, reliability and human performance.

Pickering's leadership team has actively promoted and enabled innovation in safety and reliability during the current licensing period and will continue to do so in the future. OPG is confident that many more applications will be developed in the next few years. Improved station performance will be driven by these innovations, which include:

- The use of a robot to complete repair work, avoiding worker radiation exposure; and avoiding a forced outage;
- A Wireless Battery Monitoring System which provides on-demand information through a smart phone application, taking the place of existing battery-related preventive maintenance tasks.
- A technology lab has been established, making available innovative tools including 3-D printers and scanners, water jet cutters, virtual reality and augmented reality technology. The results include hardware improvements, such as 3-D printed parts for use in trouble-shooting, and models of parts for use in design drawings and to support more effective design improvements in the plant, and thus enhance safety. New computer programs have been developed to locate and discharge suspect fuel bundles more quickly and efficiently. This provides a radiation dose benefit to staff. In the area of radiation protection of staff, collective radiation exposure has been reduced through innovative shielding and the use of an industry-first gamma spectrometry camera that allows real-time data collection and thus early awareness of changing radiation fields and their source.

OPG's environment program continues to demonstrate that the radiological releases into air and water from Pickering reactor operations are at levels that are far below regulatory limits, and hence are protective of public health and the environment. The environmental monitoring program regularly samples water, air, and soil to ensure that both radiological and non-radiological emissions remain at safe levels. OPG posts the environmental monitoring results on its website so that local communities and interested members of the public can verify the plant's safety.

OPG has successfully operated a fish diversion system at Pickering Nuclear since October 2009 to protect aquatic species. In recognition of this system and OPG's habitat improvement projects that are underway, Fisheries and Oceans Canada recently issued a fish authorization for Pickering NGS in January, 2018 (Reference 3). This is a major achievement that speaks to OPG's responsibilities to protect the environment.

Furthermore, Pickering Nuclear has updated its Environmental Risk Assessment (ERA) which confirmed that human and ecological risks due to exposure to contaminants and physical stressors associated with Pickering NGS and its activities are low.

This supports the overall conclusion that the Pickering site operates in a manner that is protective of the environment and the public. The ERA is being updated to incorporate review comments from CNSC staff. The updated Pickering ERA will be posted on OPG's external website.

Regarding emergency preparedness, OPG distributed potassium iodide pills to the entire population in the primary zone (10 km radius) around Pickering NGS. OPG is partnering in the Durham Regional NextGen public safety radio system and has installed new radio system infrastructure at the site. This allows seamless integration and interoperable communications with City of Pickering Fire Service responders using their own radios in the powerhouse. Most recently, OPG (Pickering) completed Exercise Unified Control to further assess the emergency preparedness of OPG, as well as emergency response agencies at the local, municipal, provincial and federal levels. The exercise successfully demonstrated a number of new initiatives including a new dose assessment software, web access to plant emergency information, and the new radio system.

Pickering maintains healthy, open relationships and partnerships with stakeholders, including government, media, business leaders, educational institutions, interest groups, and community organizations. OPG also meets regularly with Indigenous communities to provide details of nuclear operations and reports, and discuss interests and concerns over current and future operations of the Pickering NGS.

In summary, Pickering NGS has a strong track record of safe and reliable operation over the current licence term, demonstrating the abilities and qualifications of OPG to carry on the licensed activities and make adequate provisions to protect the public, workers, and the environment.

### 1.3.2 Nuclear Safety Improvements

Thanks to its CANDU design, the accident mitigation capability of Pickering NGS has always been robust. Nevertheless, OPG has continuously looked for ways to enhance nuclear safety, including implementing improvements to the physical plant.

For example, an integrated safety review for Pickering Units 5-8 was completed in 2009 for continued operation of the station (Reference 4); as part of this review OPG committed to carry out safety enhancements and reliability improvements, and has completed them all.

More recently, following the events that occurred at the Fukushima Daiichi nuclear plant in 2011, OPG engaged with the international nuclear community and undertook comprehensive studies to consider the lessons learned from that accident. While these studies confirmed the robustness of the Pickering NGS design for the types of hazards that are characteristic of the site vicinity, they also led to important risk insights and to the implementation of further safety measures at Pickering NGS. Additionally, in 2014 OPG committed to a risk improvement plan that encompassed a combination of physical improvements, changes to operating procedures, and improvements to analysis methodology for Pickering, focusing on Pickering Units 1 and 4. Pickering has provided an annual update to the CNSC on the risk improvement plan, and significant risk reductions have been shown (Reference 5).

Some of the more notable enhancements to the Pickering NGS to improve nuclear safety include the following items:

- Improvements to safety significant equipment (e.g., Units 1, 4 standby generator protective relay upgrades and reliability improvements, and stack monitor replacements);
- Emergency mitigating equipment (Phase 1) consisting of portable pumps and generators for responding to an extended loss of all AC power;
- Emergency mitigating equipment (Phase 2) including the provision of large electrical generators to provide power to restore key equipment such as the Emergency Filtered Air Discharge System (EFADS) for containment filtered venting, containment air cooling units, and hydrogen igniters following a total loss of AC power;
- Establishment of Severe Accident Management Guidelines to support the response to a severe accident;

- Supply of emergency makeup water to refill the emergency coolant injection storage tank, for gravity feed into the Pickering NGS units' heat transport systems;
- Passive autocatalytic recombiners for enhanced post-accident hydrogen mitigation in containment;
- Installation of removable flood barriers (at the Pickering Units 1 and 4 Standby Generator Fuel Forwarding Building), to provide additional protection following an external flood; and
- On-line refueling of the auxiliary power system, to maintain its capability to continuously provide power in an accident; and
- Procedural updates to enhance containment venting capability through the EFADS in situations without electrical power.

In summary, while safety analyses demonstrate that the Pickering NGS design is safe, robust and that accident risk is very low, Pickering has strengthened its accident mitigation capability by continuing to incorporate nuclear safety improvements and the lessons learned from the Fukushima event. Upgraded equipment and procedures are in place, and have been incorporated into periodic drills and exercises for emergency response.

Moreover, additional nuclear safety enhancements, which will further reduce the already low risk of Pickering NGS, are planned for implementation as part of the Periodic Safety Review process (PSR, described further below). The additional physical plant enhancements include:

- Piping modifications on Pickering NGS Units 1 and 4 to provide make-up water to Units 1 and 4 calandria vessels, heat transport systems and steam generators to ensure continuous post-accident fuel cooling and protection of containment; and
- Changes to the existing firewater system to allow the firewater from Pickering NGS Units 1 and 4 diesel driven firewater pumps to supply Pickering NGS Units 5-8 through station interconnection to provide an independent source of water supply.

Pickering NGS has always been safe. With the currently implemented nuclear safety improvements (EME, etc.), Pickering NGS is better prepared to deal with emergency events thereby further reducing the risk to the public. With the planned PSR modifications, the Pickering NGS will be even safer.

### 1.3.3 Extended Commercial Operation

*Periodic Safety Review*

In support of plans to extend commercial operation of Pickering NGS to the end of 2024, OPG has conducted a Periodic Safety Review (PSR). A PSR is an internationally recognized process that is defined by the International Atomic Energy Agency and regulated in Canada by the CNSC. Periodic Safety Reviews are typically performed in concert with, and in support of, the licence renewal of a nuclear power plant; the PSR is highlighted here as a major element in support of Pickering NGS relicensing.

The objective of Pickering's PSR, referred to as PSR2 as it builds on previous assessments, was to confirm that the design, operation, structures, systems, and components (SSCs) support continued operation to 2024. The PSR2 is thus a forward-looking assessment, which focuses on changes to requirements since the last applicable assessment. The PSR2 also recommends reasonable and practicable safety enhancements to further reduce the already low risk of the plant.

In the PSR2 for Pickering, fifteen safety factors and two complementary reviews have been conducted, covering all factors that are important to the continued safe operation of the plant. It concluded that there are no fundamental safety issues and that OPG has in place effective programs and processes for continued safe operation of the Pickering NGS through to the end of 2024. The results have been summarized in Safety Factor Reports that have been submitted to the CNSC. The safety factor reviews also identify enhancements to OPG programs based on new CNSC Regulatory Documents and Canadian Standards Association (CSA) standards.

The enhancements identified in these safety factor reviews have been consolidated with proposed resolutions that were then prioritized and ranked based on safety significance.

The results have been addressed, reviewed by CNSC staff, and documented in the latest Global Assessment Report (GAR) that was submitted to the CNSC in February, 2018 (Reference 12). The GAR concludes that the current Pickering NGS design, operation, processes and management system will ensure continued safe operation of Units 1 and 4 and 5-8, both in the short term, and for operation to 2024. The GAR also recommends reasonable and practical resolutions that further enhance nuclear safety.

As the final step in the PSR process, the actions that support the resolutions in the global assessment, with target completion dates, are documented in an Integrated Implementation Plan (IIP) (Reference 13). The Pickering NGS IIP actions include the PSR2-related plant modifications, mentioned above, to further improve nuclear safety. The IIP also includes administrative, change control, and reporting requirements to ensure that the IIP actions are well managed at Pickering NGS. The Pickering PSR2 IIP was submitted to CNSC staff, for review and acceptance, on November 30, 2017 (Reference 13). CNSC review comments on this IIP have been received. The comments have been addressed by OPG, and the revised IIP was submitted to the CNSC in March 2018 (Reference 14). The revised IIP was subsequently accepted by the CNSC (Reference 15) and is being posted on **www.opg.com**.

The IIP represents OPG's commitment to continued improvement for safe and reliable operation of Pickering NGS.

In summary, the Pickering PSR2 has acknowledged and credited many actions that were already in progress to enhance safety and reliability. The PSR2 review found that managed systems and programs are strong, and confirms that there are no safety issues that would preclude continued safe operation of Pickering NGS through 2024. Additional initiatives under existing programs have been identified that will ensure safety and reliability are maintained and enhanced throughout the extended operations period to the end of 2024, and the actions within the IIP will further enhance nuclear safety. Addendum A to this CMD provides a more detailed description of the PSR2 process, results, and actions planned for Pickering NGS. Key PSR2 documents have been posted on OPG's external website.

### *Fitness for Service*

The plant components at Pickering NGS are subject to gradual changes in condition as they age. For both safe and reliable operation of the plant, it is important to ensure that key components can continue to fulfill their intended functions and remain fit for service throughout the extended operating period. This is particularly true for the fuel channels, which contain the fuel bundles and ensure fuel cooling.

OPG has in place well established Fitness for Service (FFS) programs for major components that will ensure fitness for service is demonstrated until the end of commercial operation. OPG is confident that these programs demonstrate the continued fitness for service of major components and systems, structures and components important to safety. The life cycle management plans (LCMP) for the major components document the strategies and actions planned to facilitate demonstration of fitness for service of the components throughout the planned operating period.

### *Fuel Channels*

OPG has assessed the operation of the fuel channels on all units and the assessment has shown there is a sufficient margin of safety on fuel channel fitness for service limits to assure safe operation beyond the current operating limit of 247,000 Effective Full Power Hours (EFPH), for the lead reactor unit. Fuel channel fitness for service was also assessed as part of the Pickering NGS PSR2, and associated IIP actions have been identified for implementation. Specifically, OPG assures the fitness for service of all units to the new target service life of December 2024 on the basis of sound technical reviews, the established programmatic controls within OPG for managing fuel channel aging, and the availability of mitigating measures where required. In terms of EFPH, fitness for service of the Pickering fuel channels is assured up to 295,000 EFPH for the lead unit, corresponding approximately to the end of 2024.

The condition of the fuel channel components is regularly monitored via inspection programs, consistent with the life cycle management approach used for all major components, ensuring that the fuel channel component conditions remain within the licensing basis and fitness-for-service criteria of the applicable standards (CSA N285.4 and N285.8). OPG has robust processes in place for responding to inspection or surveillance results should they not satisfy the prescribed acceptance criteria, and to address relevant operational experience that could impact fuel channel fitness for service, plant safety or operability. Should inspection results identify that a component cannot be demonstrated to be fit for service, that component will not be placed back in service.

Addendum B to this CMD provides more technical details on OPG's management of the aging mechanisms relevant to the Pickering fuel channels, as well as the ongoing and planned research and development (R&D) that provides the science-based evidence in support of the assurance of fuel channel fitness for service through 2024. In collaboration with the Canadian nuclear industry, OPG will continue to discuss fuel channel-related issues with CNSC staff to ensure regulatory expectations are met.

In summary, OPG is confident that the Pickering fuel channels will remain fit for service for continued commercial operation up to 295,000 EFPH for the lead Pickering unit, corresponding approximately to the intended end of commercial operation on December 31, 2024. The associated PSR2 action plan for the fuel channels as documented in the IIP will ensure the required actions are taken for continued fitness for service through to the end of 2024.

### 1.3.4 End of Commercial Operation (ECO)

With the end of commercial operation (ECO) part way through the requested licence term for Pickering NGS, OPG understands the need for various activities to be carefully planned in order to support not only the post-shutdown phase, but also the transition in the years before the plant is shut down; see Figure 3 below. These considerations are discussed in the Sustainable Operations Plan (SOP) and the Stabilization Activity Plan (SAP).

*Sustainable Operations*

OPG will continue to ensure safe, reliable operation of Pickering to the end of commercial operation. While processes will remain in place to ensure Pickering NGS is operated and maintained using sound nuclear safety practices, it is recognized that new challenges might be faced due to the transition from an operating station to the End of Commercial Operation. The SOP is pro-actively developed to address these challenges in advance of ECO.

The SOP is based on all of the 14 Safety and Control Areas (SCAs) as defined by the CNSC. OPG recognizes that safe operation is based on the maintenance of both a healthy safety culture and the programs associated with each of the 14 SCAs. The SOP documents actions and defines stand-alone supplemental measures to existing programs (arrangements, activities or actions) which will be implemented.

The SOP will be submitted to the CNSC five years before the permanent shutdown of the first unit at the Pickering NGS. A progress update will then be provided annually, in December of each year.

In 2016, OPG submitted a SOP to the CNSC based on an assumed end of commercial operations date of 2020. There are currently standalone supplemental measures in three SCAs with plans in development. These are in the areas of Organizational Change, Human Performance, and Maintenance and Reliability.

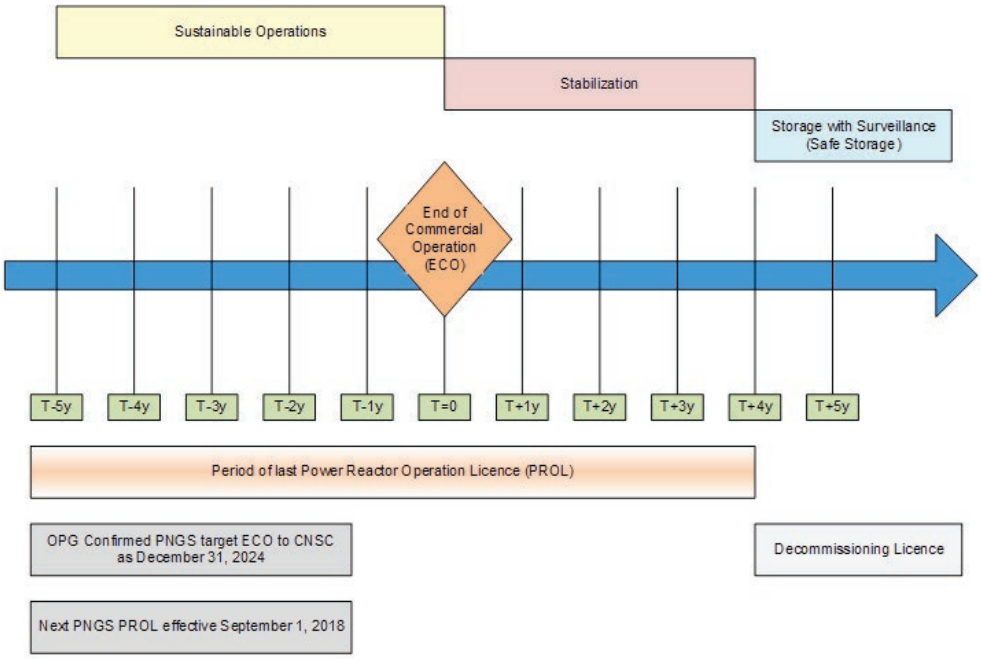



**Figure 3** - Pickering ECO Life Cycle Overview

For Organizational Change, OPG will develop a plan to ensure that capable, competent staff remains at Pickering NGS through the transition to ECO, safe storage and decommissioning. This plan will include a change management plan which will look at the impacts of the Pickering shut-down on both Pickering operations and on the broader Nuclear and OPG organizations and staff. It will cover activities related to leadership alignment, engagement of staff, internal and external communications, training and development, assessing and managing impact on people, business policies, processes and practices, and business readiness. Oversight will be provided to monitor performance of the transition to the new organization and ensure continued safe operations.

The Human Performance Initiative involves maintaining continuous monitoring and improvement of human performance to minimize the likelihood of nuclear safety events throughout the transition to ECO. This will be achieved by systematically identifying and addressing situations that are likely to lead to errors, reducing organization vulnerability and by challenging the integrity of defenses. Initiatives within the program also include communications, field presence and surveillance to promote human performance improvement, as well as utilizing benchmarking of similar plants and internal operating experience to maintain or improve human performance while in transition to ECO.

The Maintenance and Reliability Strategy involves determining the maintenance plans and activities to be performed prior to and after the shutdown of the units. In order to ensure safe and reliable operation of each unit at Pickering, existing programs and procedures will be used for equipment maintenance and reliability strategies during the transition to ECO. Procedures and processes will ensure that all of the maintenance necessary to ensure safe and reliable operation up to the shutdown of each unit is identified, as well as the maintenance necessary to sustain the systems that will be relied upon during the stabilization and safe storage phases.

The SOP will point to existing programs and the results of these programs to demonstrate fitness for service while approaching the End of Commercial Operation. The SOP will include specific supplemental FFS actions to augment existing programs where it is determined that programmatic changes or stand-alone actions within existing programs are required to resolve unique challenges while approaching ECO. Any supplementary actions which are not covered under these three areas will be addressed in the SOP in order to support safe and reliable operation of Pickering.

In summary, nuclear safety will be assured through to the end of commercial operation and staffing levels and competency will be appropriately maintained, while maintaining reliable plant operation and protecting the public, workers and the environment. OPG understands the special considerations that need to be addressed as Pickering NGS approaches the end of commercial operation and is confident that the transition will be carried out safely and effectively.

### *Stabilization Activity*

Preparation for Safe Storage includes the period leading up to the end of commercial operations as planning activities are carried out, as well as the execution of stabilization activities which will safely transition the Pickering NGS from its current electricity generating state to its Safe Storage State (SSS). The SAP documents OPG's planning efforts for the stabilization of the station and the SSS.

Stabilization involves defueling the reactors of spent fuel, dewatering systems containing heavy water, and removing from service the systems that are no longer required to support commercial operation of the station. Although the station will no longer generate power, an operational footprint will be required to continue to support operational and regulatory requirements, such as the storage and removal of fuel from the irradiated fuel bays, storage of heavy water, and ongoing monitoring and security activities.

The stabilization of the station from its current electricity generating state to its SSS will follow a phased approach, where the phases will be characterized by milestones in hazard reduction.

The operational need for structures, systems and components (SSCs) at each phase will be determined by a thorough and systematic review process, considering both regulatory and system requirements across all 14 CNSC Safety and Control Areas.

The SSCs not required for the operation of the station in the SSS will be placed in a passive safe state. Fitness for service of the required SSCs will continue to be managed during the post-shutdown phase (e.g,. for the irradiated fuel bays).

OPG operating experience, particularly from Darlington Refurbishment and Pickering Units 2 and 3 safe storage, as well as benchmarking of local and international industry experience has been integral to informing preparations for safe storage and will continue to do so as planning efforts progress.

OPG will continue to provide periodic updates to the CNSC with regards to the preparations for the execution of the stabilization of the Pickering station. More information on the planning for stabilization of the station and the SSS can be found in the Stabilization Activity Plan (Reference 6). Information on the safe storage phase can be found in the Preliminary Decommissioning Plan (Reference 7).

To ensure the protection of human health and the environment, OPG undertook a Predictive Effects Assessment (PEA) to evaluate the potential for adverse effects to human health and the environment from the activities associated with transitioning the station from operation to a safe storage state. The PEA encompasses both the stabilization phase and the safe storage phase (that is, it looks beyond the requested licence term). The PEA report was submitted to the CNSC staff (Reference 8) and has been posted on OPG's external website.

Overall, the change from power generation to the stabilization and safe storage phases will result in reductions in emissions from the Pickering NGS. No interactions are predicted to pose an unacceptable risk to humans or the environment during the stabilization and safe storage activities. Therefore, no new mitigation is required, based on the conclusions of the PEA that there are no predicted potential adverse effects from the stabilization and safe storage activities.

During both the stabilization and safe storage phases, OPG's environmental programs will be maintained, and will be updated as needed.

Emission control measures and discharge limits are specified within specific permits. These permits and mitigation measures provided in the station design will remain in place until it can be demonstrated, in discussion with the regulator as applicable, that they are no longer required.

In summary, with the successful safe storage of Units 2 and 3, OPG has demonstrated its ability to carefully plan and carry out stabilization activities at the Pickering NGS. Given this proven experience and detailed planning, OPG is confident that it will effectively and safely perform the necessary stabilization activities to systematically place the remaining Pickering units in a safe storage state as planned in the requested licence term. Furthermore, this will be performed in an environmentally responsible manner with further reductions to the already low emissions and with adequate protection of the public, workers and the environment, and in compliance with all applicable regulatory requirements.

## 1.4 Format and Organization of this CMD

In presenting evidence in support of the licence renewal request, and as recommended by the CNSC guideline on CMD writing, this CMD has been prepared to address the interests and concerns of a wide range of audiences. Accordingly, it presents the main points of evidence for continued safe and reliable operation through the requested licence period at a relatively high level, and provides more detailed technical information on certain key topics in a set of addenda.

The CMD presents the information supporting the licence renewal request in two parts. The first, in Section 2, summarizes the evidence in terms of six key commitments that underpin the case for relicensing of Pickering NGS:

- Nuclear safety will be assured such that plant personnel, the public and the environment are protected;
- Systems, structures and components at the plant are fit to continue commercial operation to the end of 2024, and inspection programs will ensure fitness for service during the next licence period;
- Staff are qualified and competent to operate the plant, and this will be maintained through the next licence period, including sufficient staffing numbers;
- Impacts of plant operation to the public, workers, and the environment will continue to be of low risk and adequately mitigated, while continuing to provide the various societal and environment benefits of plant operation;
- Transparency and appropriate public and Indigenous engagement will continue;
- OPG will continue to invest in Pickering to support the above objectives, including to improve equipment reliability, assure fitness for service until the end of commercial operations, and to further enhance nuclear safety.

The second part, in Section 3, consists of a brief description of each of the CNSC's Safety and Control Areas (SCAs), highlights strengths and noteworthy achievements in these areas, and updates information contained in the Licence Application to reflect 2017 results.

Section 4 contains discussions on specific issues of interest including the Cobalt-60 Program, financial guarantee, Nuclear Liability insurance and cost recovery.

Finally, Addenda A through C provide more details and technical information on the Periodic Safety Review, Fuel Channel Fitness for Service, and Whole-Site Risk Assessment.

# 2. The Case for Continued Safe Operation of the Pickering NGS

As noted previously, in submitting its application for a power reactor operating licence renewal for the Pickering NGS to the CNSC in August, 2017, OPG presented a set of six commitments on Pickering NGS performance through the requested new licence term. These commitments encapsulate the main areas of responsibility that OPG bears to the public and to the CNSC; they acknowledge public concerns and expectations; and they reflect the necessary compliance with regulatory requirements related to safety and reliability of the plant.

The requirement that each commitment entails, and the evidence that OPG is meeting it and will continue to meet it through the requested licence term, are explained in the Sections that follow. Each Section includes a description of the ways that OPG meets the commitment, supported by technical background information where this is helpful for an understanding of the concepts and terms used. The information includes some important evidence from the Licence Application that demonstrates that OPG has met, and in many cases gone beyond, regulatory requirements related to each Safety and Control Area (SCA), and that it is qualified and prepared to continue to do so through the next licence period.

## 2.1 Plant Safety Provisions Assure the Protection of the Public and the Environment

Nuclear safety is the primary and driving consideration for activities carried out by all personnel working at the Pickering NGS. The Nuclear President and Chief Nuclear Officer is accountable to the CEO and the Board of Directors for establishing a management system that fosters the priority of nuclear safety through the entire organization. Guiding principles established by the Nuclear Safety Policy state that:

- Nuclear safety shall be the overriding priority in all activities performed in support of OPG nuclear facilities;
- Nuclear safety shall have clear priority over schedule, cost and production
- Everyone must demonstrate respect for nuclear safety and conduct themselves in a manner that is consistent with the traits of a healthy nuclear safety culture (this is described in Section 2.3, below).

These principles are continually reinforced at Pickering NGS and are internalized by all personnel (employees and contractors) who support the operation of the plant.

The functions and activities described in this Section relate primarily to the Physical Design SCA and Safety Analysis SCA, described in more depth in Sections 2.4 and 2.5 of the Licence Application, respectively; information on emergency preparedness relates to the Emergency Management and Fire protection SCA, which is discussed in Section 2.10 of the Licence Application, and the Security SCA, which is addressed in Section 2.12 of the Licence Application.

### 2.1.1 Defence in Depth

Nuclear reactors contain a large amount of radioactive material that is contained within the fuel, and that constitutes a unique hazard and a source of heat. For this reason, a deep respect for the reactor core is at the heart of safe reactor operation, not only when the reactors are operating at full power but also when they are shut down (as there is no “off switch” for the heat generation). Accidents can happen - and they have happened, as witnessed by the Three Mile Island, Chernobyl, and Fukushima events, and from which many important lessons have been learned and incorporated in nuclear plants worldwide to improve nuclear safety, including at OPG’s nuclear stations. The Pickering NGS maintains a high degree of safety, and the risk of a nuclear accident is very low.

Essentially, the safety of the Pickering NGS is based on the Control, Cool, Contain principle, or “3 C’s”:

- **C**ontrol the reactor power
- **C**ool the fuel
- **C**ontain the radioactivity

This principle applies at all times under all normal and any abnormal conditions; whether the reactor is at power or shut down; whether the fuel is inside or outside of the reactors (as used fuel is removed from the reactor cores and stored in irradiated fuel bays for a number of years before eventually being transferred to dry storage facilities). The Control, Cool, Contain principle is a universally accepted cornerstone of the nuclear safety philosophy, which is rigorously met at Pickering NGS through the fundamental concept of Defence in Depth.

### What is Defence in Depth?

Defence in depth is the provision of multiple and redundant "barriers" to protect the public, workers and the environment from the radiological hazards of nuclear power plant operation. Conceptually, these barriers include engineered structures and equipment (and multiple backups), and they also include people-based barriers such as administrative processes and procedures as well as training; such provisions are all elements of a defence in depth approach to assure nuclear safety.

The defence in depth philosophy involves multiple, overlapping barriers so that no single initiating event or failure at the plant would directly impact on human health and the environment; many barriers are in place to prevent that from occurring. Each barrier is treated as though it is the last or only one, and no barrier is allowed to degrade on the assumption that other barriers are present for protection.

As such, the defence in depth approach requires high quality in the activities of design, procurement, construction, operation and maintenance. The approach also recognizes that barriers may not be perfect and that occasionally, people can make mistakes or equipment may fail.

However, that is part of the underlying basis for the defence in depth philosophy – it compensates for such scenarios, should they occur, by ensuring that redundant barriers are in place to prevent or mitigate accidents. The defence in depth approach is applied extensively at Pickering NGS, and for each of the 3 C's.

There are five physical barriers in place at Pickering NGS to restrict radioactivity from reaching the public. These barriers include:

- The fuel itself (ceramic pellets) within which most of the radioactivity is trapped;
- The fuel sheaths within which the fuel pellets are enclosed;
- The heat transport system, which is composed of the fuel channels, piping, and vessels through which the reactor coolant circulates to cool the fuel and contain any radioactive gases that may escape from the fuel sheaths;
- The containment system, designed to house the reactors and contain any potential releases of radioactivity from the heat transport system; and
- The exclusion zone that surrounds the facility and provides distance to the public from any potential releases.

These barriers are an integral part of five levels of defence in depth for the overall design and operation of the Pickering NGS. This is an international principle of nuclear reactor safety that encompasses reactor design, components and equipment, and operation.

#### *Five Levels of Defence in Depth for Pickering NGS*

The first level of defence is to be able to maintain normal operating conditions and prevent any failure in structures, systems or components (SSCs). This is achieved through use of conservative design, adherence to high standards and following best industry practices in the design and analysis of the plant, and by the use of high-quality materials and equipment. Furthermore, to ensure that SSCs are available and reliable to carry out their intended design functions, they are tested, inspected and maintained on a regular basis.

Should the first level fail, the second level of defence in depth is in place to detect any deviations from normal operation. Although the deviations may still be within the "safe operating envelope" (where safety analysis has shown that plant operation is still safe), the control and safety systems are conservatively designed to

intervene and return the reactor to the more restrictive, normal operating state so that a deviation does not escalate to an accident condition. These systems continuously monitor operating conditions (such as reactor coolant pressures, temperatures, and flows, and reactor power), and in the event of abnormal conditions, they function to return the reactor to normal operating conditions or safely shut down the reactor if necessary. These detection and control functions are carried out by systems made up of a number of independent, redundant, and diverse instruments and equipment in and around the reactors to ensure the full ranges of normal operating conditions are adequately monitored and controlled.

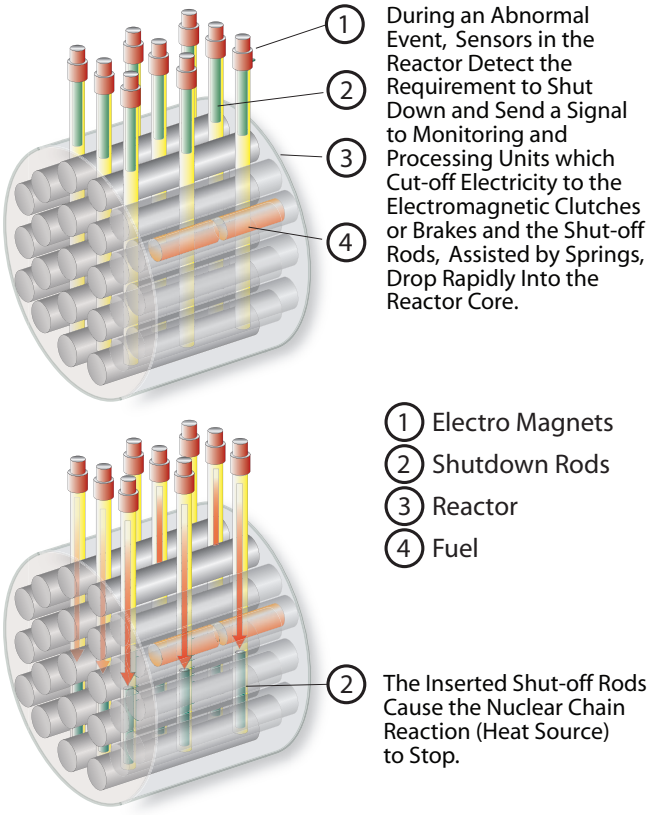



**Figure 4** - Example of Pickering defence in depth level 3

Should both the first and second levels fail, and an accident occurs, then the third level is in place to activate systems specifically designed to mitigate a design basis accident (DBA); this is an event that engages special safety systems, and to which the reactor is designed to respond (described in the text box "What are Design Basis Accidents?", page 23). For example, if there were a large rupture in the piping of the heat transport system (HTS) at one of the Pickering reactors that led to a loss of coolant accident (LOCA), one of the two shutdown systems (SDS) would rapidly shut down the reactor and the emergency coolant injection system (ECIS) would automatically start up and inject cooling water into the HTS. These actions would ensure that the fuel inside the reactor core is adequately cooled and that any release of radioactivity outside of the reactor core is limited.

Safety systems, such as the SDS, ECIS, standby power and other water supplies, that are designed to mitigate DBAs, have built-in redundancy for reliability and allow for maintenance of the systems. There is more than one way to carry out any safety function (e.g., supply water or electrical power, or control reactor power) and the associated safety systems are designed to be independent of each other (Group 1 and Group 2 systems), with equipment that is physically separated and spaced in different locations around the plant (so that a single hazard, such as a fire, is unlikely to impact all the equipment needed for a safety function). Furthermore, the plant design typically uses diverse means of carrying out the same safety function so as to avoid a common deficiency; for instance, either shutoff rods or liquid "poison" injection can be used to rapidly shut down the reactors in Pickering B. In addition, there are "fail-safe" features, meaning that if a component in a system fails, it fails in such a way that does not interfere with the safety functions of the rest of the system.

The fourth level of defence is the containment system which is intended to limit any releases of radioactivity to the environment during an accident. The containment system includes the reactor buildings and the vacuum building to which the reactor buildings are connected. If any radioactive gases and steam were released into a reactor building, they would be drawn into the vacuum building where the steam would be condensed (thereby reducing pressure in the reactor building) and the radioactivity would be contained with no large releases to the environment.

It should be noted that the containment system at Pickering NGS is very robust and is not limited to mitigating DBAs. In the very unlikely scenario that the third level of defence in depth fails and the event progresses to a beyond design basis accident (BDBA) (i.e., an extremely unlikely event for which the station has not been specifically designed; see "What are Design Basis Accidents" page 23) – the containment system offers substantial capability to continue to limit off-site releases.

With respect to BDBA management, the Phase 1 emergency mitigating equipment (EME) at Pickering NGS (portable pumps and electrical generators installed as a result of post-Fukushima reviews) serves as an additional set of barriers to further strengthen defence in depth. There are two types of strategies for their use as part of the fourth level of defence:

- (Level 4A) via Emergency Mitigating Equipment Guidelines that focus on fuel cooling, if the design basis equipment is unable to achieve that, and on preventing the event from progressing to a severe accident; and
- (Level 4B) via Severe Accident Management Guidelines, which focus on both the protection of containment and fuel cooling if an event has progressed to a severe accident, and on stopping the progress of the severe accident.

The Phase 2 EME serves to restore power with a focus on further protecting containment and minimizing radioactive releases to the public. Specifically, Phase 2 EME provides emergency back-up power to important containment equipment, namely, boiler room air conditioning units to assist with post-accident pressure suppression; hydrogen ignitors to limit post-accident hydrogen concentrations to safe levels in containment;  and the emergency filtered air discharge system (EFADS). These provisions serve to protect containment integrity and allow the use of the existing EFADS for controlled filtered post-accident venting of containment.

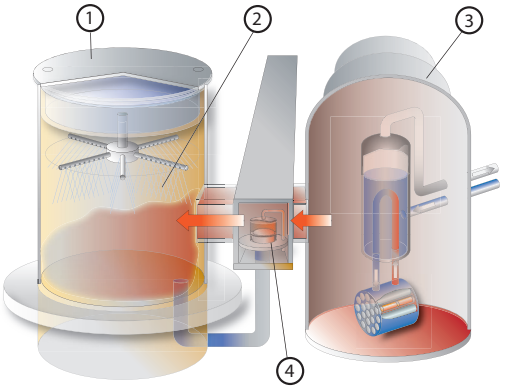



**Figure 5 -** Pickering containment system defence-in-depth level 4

Finally, in the highly unlikely event that all of the first four levels of defence in depth are breached, the fifth level of defence in depth provides both on-site responses and off-site protective measures that are associated with emergency preparedness (EP) provisions to mitigate the potential radiological effects of releases. This includes the possible sheltering and temporary evacuation of the local population, and the use of potassium iodide pills. The significant OPG efforts in support and strengthening of EP in the vicinity of Pickering NGS are discussed further in Section 2.1.4.

As a summary of the above plant provisions and defence in depth concepts, Figure 6 below depicts the various levels of defence in depth and the general type of equipment and documentation involved in responding to event progression. For Pickering NGS, multiple barriers to event progression, and multiple means to supply cooling water and electrical power, are in place to ensure adequate protection of the public and the environment, including for severe accident events.

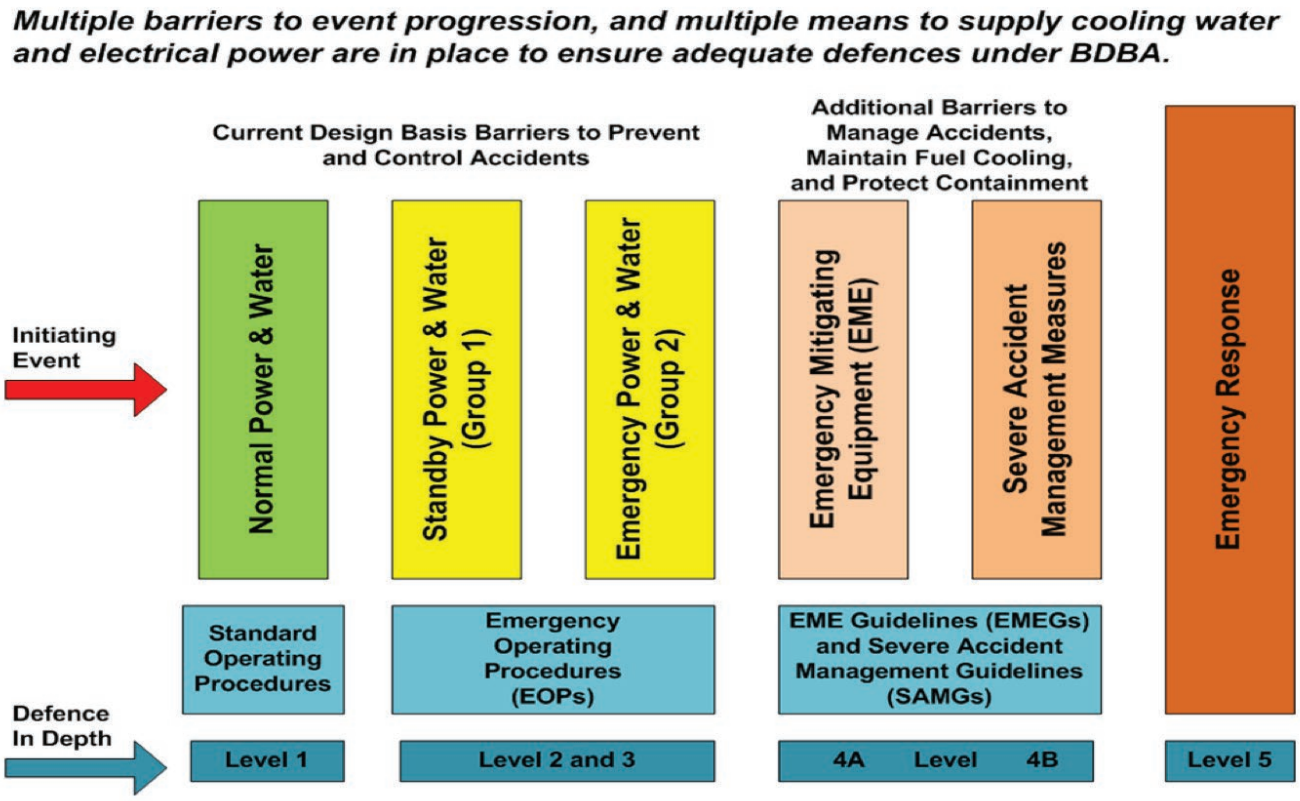



**Figure 6 -** Five levels of defence in depth with associated plant and administrative barriers.

### What are "Design Basis Accidents", "Beyond DBAs", and "Severe Accidents"?

Design Basis Accident (DBA): Accident conditions and/or event sequences against which a nuclear power plant is designed and for which the damage to the fuel and the release of radioactive material are known and kept within authorized limits. DBAs are low frequency events.

Beyond Design Basis Accident (BDBA): Accident conditions and/or event sequences which are very low frequency events (and hence are not part of the design basis) and which are potentially more severe than Design Basis Accidents. A BDBA may or may not involve significant degradation of the reactor core.

Severe Accident (SA): A subset of BDBA where there is potential for a large release of radioactive materials (i.e. in excess of regulatory limits) due to the following:

- Significant fuel and/or reactor core degradation has occurred,
- Radioactive materials have been released into the containment system, and
- Containment failure has occurred or could occur.

As a result of the Fukushima accident, beyond design basis accidents and severe accidents have been assessed for Pickering NGS. While these events remain extremely unlikely to occur, prevention and mitigation measures such as additional equipment and procedures have been implemented as a precautionary measure.

## 2.1.2 Nuclear Safety Analysis

OPG's safety analysis programs play a key role in supporting the plant safety provisions and the overall safety of the plant, as provided through the functions of controlling reactor power, cooling the fuel, and containing or limiting any releases from the plant. The basic types of safety analysis are deterministic and probabilistic. These serve different purposes but are complementary.

*Deterministic Safety Analysis (DSA)*

Deterministic safety analysis has been extensively used from the inception of the Pickering NGS design, and is a key tool for supporting the adequacy of the plant safety provisions. It is also integral to supporting the defence in depth approach (through to Level 5). DSA uses validated scientific models and conservative assumptions to analyze the response of the reactor and other plant systems to hypothetical abnormal or accident conditions, and assesses the potential consequences.

The applications of DSA include:

- Helping to demonstrate the effectiveness of the plant safety provisions used to mitigate design basis events;
- Showing that DBA licensing requirements are met (i.e., public dose limits);
- Helping to define the acceptable range and limits of plant operating conditions (safe operating envelope);
- Assisting in the design or modification of DBA equipment; and
- Providing information about accident consequences for use in probabilistic safety assessment (PSA).

The Pickering NGS DSA is governed by OPG's Reactor Safety Program and is periodically updated and submitted to CNSC staff. For Pickering NGS, the DSA demonstrates that adequate safety margins are in place for design basis events.

Of particular note, as the aging of the heat transport system may have an impact on safety margins, additional focus has been given to this aspect in the DSA. Deterministic safety analyses have been completed for several future aged condition accident scenarios for all Pickering units. The effects of aging of the Pickering reactors are managed effectively and OPG will ensure that safety analysis margins are maintained through to the end of commercial operation.

### *Probabilistic Safety Assessment (PSA)*

PSA has long been an important tool for assessing and managing nuclear power plant risk, and it is another key tool used to support the adequacy of the plant safety provisions. It too is integral to supporting the defence in depth approach (up to Level 5).

PSA answers three questions:

- What can go wrong?
- How likely is it?
- What are the consequences?

This is accomplished through detailed modelling of a reactor and the various supporting plant systems, and by conducting a systematic assessment of the possibility and consequences of incidents initiated by system failures or other events. In so doing, PSAs realistically simulate accident scenarios and potential system performance, and enable the identification of vulnerabilities in the plant so that nuclear safety can be enhanced through plant design modifications or changes to operating procedures, thereby further reducing the likelihood of an accident and its potential outcome.

PSAs are conducted separately for internal and external types of hazards, in particular for internal events, internal fires, internal floods, seismic hazards, and high wind hazards. Many other hazards are also examined and addressed as part of the PSA hazard screening process (in the process, some hazards – meteorites, for example – are deemed to be of such low likelihood that they were screened out, and not developed into PSA models).

Furthermore, the PSAs consider both 100% full-power operating conditions as well as outage conditions, in which a reactor is shut down with some equipment taken out of service.

Following are some examples of the valuable and practical uses of PSA:

- To identify safety improvements in the station design and operation;
- To understand the effects of different plant configurations and test the effects of alternate safety measures;
- To support operational decisions, for example, to assess the consequences of taking equipment out of service for maintenance, during normal operation or planned maintenance outages (this assessment determines if modifications to scheduled activities are required to reduce the risk levels of the activities);
- To provide insights into the important contributors to risk, i.e., the main initiating events that contribute to risk, and into the relative risk benefits of the different systems and components that are used to mitigate accidents (both these types of insights serve to help raise awareness and prioritization of safety-significant activities at the station); and
- To provide information about the likelihood of hypothetical events for use in the DSA (as such information is considered in determining the methodology and analysis rules to use for the different events analyzed by DSA).

The Pickering NGS PSAs are governed by OPG's Risk and Reliability Program and are updated periodically and submitted to CNSC staff. In addition, OPG's PSA methodology is subject to CNSC acceptance.

Of particular interest, the PSAs provide quantitative estimates of risk in the form of calculated risk metrics for each hazard type, for comparison to OPG's PSA safety goals. OPG's PSA safety goals are used as targets to help ensure that the overarching objectives around protection of the public and the environment are met.

This is achieved by limiting the likelihood of certain undesired consequences, namely, severe core damage and large off-site releases. As such, the OPG PSA safety goals are expressed in terms of a frequency with which severe core damage or a large release might occur for an individual reactor unit. That is, the safety goals are applied on a per-unit, per-year basis. To help manage risk, the safety goals are set at very low values:

- Severe core damage frequency (SCDF) should be less than 1 in 10,000 per reactor, per year;
- Large release frequency (LRF) should be less than 1 in 100,000 per reactor, per year.

These safety goals are aligned with international norms and CNSC safety goal definitions.

### What do SCDF and LRF mean?

The SCDF value represents the probability of a severe core damage accident occurring in the next year – with the goal being less than 1 in 10,000.

It is a "measure" of the plant's severe accident prevention capabilities (i.e., roughly associated with the effectiveness of Level 4A of defence in depth, Figure 6).

Similarly, the LRF value represents the probability of a large-release accident occurring in the next year – with the goal being less than 1 in 100,000. Note: The probability of a radiological health effect on the public from a large-release accident is even lower still.

LRF is a "measure" of the plant's severe accident mitigation capabilities (roughly associated with the effectiveness of Level 4B of defence in depth, per Figure 6).

### *Whole-Site Risk Assessment*

As discussed above, DSA and PSA are complementary analytical tools used to support the adequacy of plant safety provisions and to help demonstrate that plant risk is low.

These methods tend to focus on individual reactor units, while also taking into account possible interactions and effects associated with other reactors on the site. For instance, the current PSAs, and safety goals, are based on individual reactor units.

An action was placed on OPG to characterize and evaluate the overall risk of an entire nuclear power plant site, including the multiple reactor units at a station ("multi-unit" risk), other sources of radioactivity on the site (such as irradiated fuel bays), internal and external hazards, and reactor operating modes other than full power and outage states. This is referred to as "whole-site" risk. It should be noted that there is no international consensus yet on whole-site risk assessment methodology.

Arising from the 2013 relicensing of the Pickering NGS, the Commission requested that a whole-site PSA methodology be developed to estimate the Pickering whole-site risk. OPG has since led the development of a whole-site risk assessment in concert with owners and operators of other CANDU reactors. A comprehensive and first-of-a-kind, pilot study was conducted for the Pickering whole-site risk assessment. The work was submitted to CNSC staff in December 2017, and OPG presented a summary to the Commission on December 14, 2017.

Site risk has always been considered and managed at Pickering; nonetheless the pilot study enabled OPG to revisit the topic from a fundamental and holistic perspective, and to better characterize whole-site risk. The salient points from the work on Pickering whole-site risk assessment are noted below, and more details on this assessment can be found in Addendum C.

- The overall evaluation of whole-site risk involves the consideration of both qualitative and quantitative information that informs the judgement of risk. This includes many factors within a broad perspective that encompasses various programmatic, deterministic, and defense in depth considerations, as well as PSA.
- The traditional OPG PSAs have always been "multi-unit" PSAs in that they explicitly account for multi-unit interactions, even though the PSA results are expressed on a per-unit basis.

- Whole-site PSA is an important tool that supports whole-site risk assessment. The Pickering whole-site PSA has identified some additional risk insights, particularly around the understanding of the relative contributions of purely single vs. multi-unit risks and of the relative risk of different hazards from a site perspective.
- As part of the whole-site PSA approach, the per-unit based PSA results have been carefully combined to more fully quantify PSA risk metrics for each hazard and across all units on site (the "per-site" LRF results are shown in Table 1).
- The risks associated with other on-site sources of radioactivity, such as the irradiated fuel bays, as well other (lower power) modes of reactor operation, have also been systematically assessed.

It is important to note that whole-site risk should not be characterized by a single number, and the simple addition of risk estimates across all hazards is not technically appropriate.

Nonetheless, the calculation is straightforward and has been performed for Pickering NGS: the total per-site LRF is 0.82 x $10^{-5}$/yr, as shown in Table 1. This is a very impressive result as it is better than the current LRF safety goal of 1 x $10^{-5}$/yr – which is defined on a per-unit basis (i.e., the target for which individual reactor units are assessed against, for each hazard) and was not intended for site- based results that encompass all reactor units and all hazards.

The overall conclusion from the pilot study is that the Pickering whole-site risk is very low.

### 2.1.3 Safety Enhancements

As discussed in Section 1, OPG has continuously looked for ways to enhance the plant safety provisions at Pickering. These efforts have incorporated (a) enhancements that are identified as part of OPG's ongoing programmatic activities, including (b) lessons learned from incidents and operating experience elsewhere, as well as (c) other initiatives.

For instance, with respect to item (a) above, the Risk and Reliability Program requires that a risk improvement plan be developed and implemented to decrease the per-unit SCDF and/or LRF to the extent practicable if the calculated per-unit SCDF or LRF values are below the per-unit PSA safety goals but above the more stringent per-unit Administrative Safety Goals that are also in place at OPG (these are a factor of 10 lower than the PSA safety goals). As mentioned in Section 1, such a plan exists for Pickering NGS, with a focus on the Pickering Units 1 and 4.

| Hazard | Large Release Frequency (x $10^{-5}$ per year) |
|---|---|
| | per site |
| Internal Events | 0.18 |
| Internal Floods | 0.07 |
| High Wind | 0.31 |
| Internal Fires | 0.17 |
| Seismic | 0.09 |
| Total | 0.82 |

**Table 1** – Pickering NGS LRF summary. Numbers show expected frequency per 100,000 years of an accident caused by each hazard

With respect to operational experience (item (b)), the substantial enhancements implemented at Pickering NGS in response to the Fukushima accident are a prime example. These enhancements, such as Phase 1 EME, are also captured as part of the Pickering risk improvement plan.

Other initiatives (item (c)) include the additional plant modifications being pursued via the IIP actions associated with the recent Periodic Safety Review (PSR2).

To further drive improvements, OPG has set more challenging expectations through the per-unit Administrative Safety Goals. With the post-Fukushima improvements, Pickering NGS Units 5-8 already met the Administrative Safety Goals on a per-unit basis for all hazards. While the Pickering NGS Units 1 and 4 large release frequency values are already better than the per-unit PSA safety goal, OPG is endeavoring to further reduce the Pickering NGS Units 1 and 4 risk such that the more challenging Administrative Safety Goal is also met for all hazards on a per-unit basis. Section 1 highlighted a number of the key improvements to enhance the plant safety provisions at Pickering and enable the risk reduction.

Figure 7 illustrates the very significant progress and ambitious efforts to drive down the already low Pickering 1, 4 estimated per-unit risk, from the pre-Fukushima to post-Fukushima plant safety provisions, and to the post-IIP improvements. The pre-Fukushima results are representative of the station prior to the installation of modifications to address lessons learned from the Fukushima event. The post-Fukushima results are representative of the station upgrades and risk modelling improvements associated with OPG's follow-up to the Fukushima event. The post IIP estimate results are representative of the station after the PSR committed fire water supply to the Pickering 1, 4 steam generators, heat transport system and moderator are installed.

The risks associated with the operation of Pickering NGS are lower today than in the past and with the implementation of the PSR2 enhancements will be even lower.

As confirmed by the Pickering PSR2, there are no safety issues that would preclude continued safe operation of Pickering NGS through 2024.

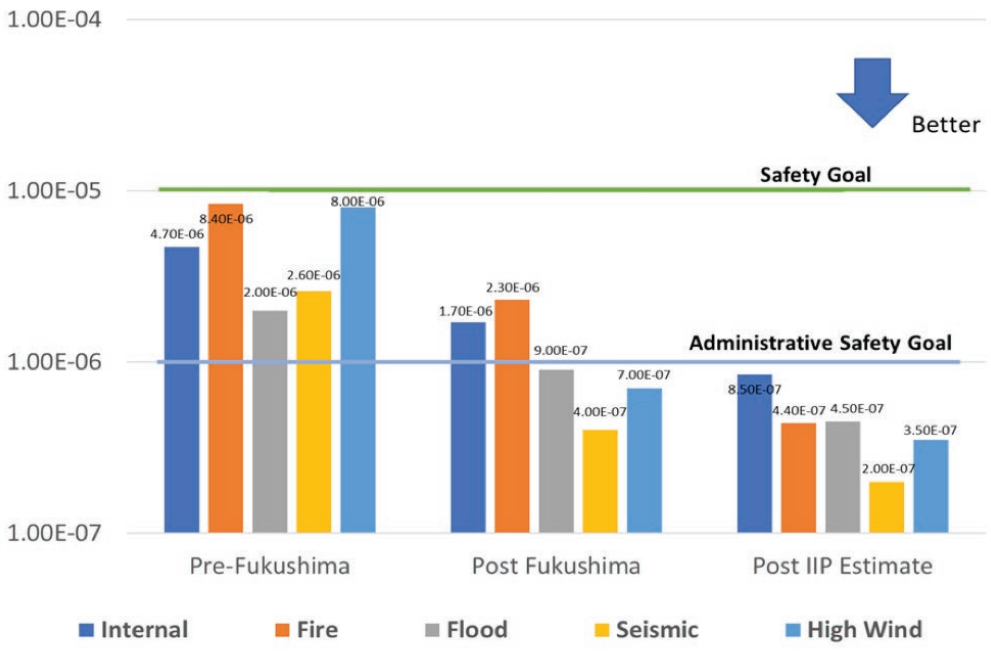



**Figure 7 -** Pickering NGS Units 1 and 4 reduction in estimated per-unit LRF

### *Beyond Design Basis Accident (BDBA) Containment Protection*

From an integrated public risk perspective, OPG concludes that the most effective means of protecting containment and minimizing large releases resulting from a BDBA is to prevent an accident from progressing to the point of challenging containment.

OPG has in place comprehensive probabilistic safety assessments (PSAs) for Pickering NGS 1, 4 and Pickering NGS 5-8 that demonstrate that the likelihood and public risk from a serious accident remains very low. Nonetheless, OPG continues to invest to further enhance safety at its nuclear facilities, as demonstrated by OPG's post-Fukushima actions that are intended to prevent an accident progressing to a severe accident following a BDBA. Specific safety enhancements include:

- Completion of hydrogen passive autocatalytic recombiners (PARs) installations in all Pickering units;
- Provisions for Phase-1 emergency mitigation equipment (EME) to provide emergency make-up water and power for ensuring continuous fuel cooling and monitoring. (See Figures 8 and 9);
- Completion of Severe Accident Management Guidelines (SAMGs) to provide plant staff with guidance on prevention and mitigation of accident progression to a severe accident;
- Completion of Phase-2 EME provisions that provide emergency back-up power to important containment equipment (boiler room air conditioning units and hydrogen ignitors on all units to protect containment integrity allowing the use of the existing emergency air filtered discharge system (EFADS) for controlled filtered post-accident venting of containment).

The purpose of a containment filtered venting system is to reduce large radiological releases following a BDBA by providing a provision for controlled filtered containment venting. At Pickering NGS this capability is achieved through use of the existing EFADS.

As committed in the PSR2 IIP, modifications are scheduled for implementation that are intended to further enhance safety by providing additional barriers that prevent BDBA progression to a severe accident, specifically;

- Provisions for emergency make-up of water to the calandria vessel, heat transport system and steam generators on Units 1, 4 to provide post-accident fuel cooling, thereby limiting radiological and environmental conditions within containment.

The modifications that are currently being implemented and committed in the IIP will minimize the likelihood of a large release by providing additional barriers to prevent accident progression, thereby protecting containment.

The design of the Pickering containment system minimizes post-accident radiological releases by its thick concrete structure that is maintained at negative pressure through use of the vacuum building and in the longer term, the EFADS.

The Pickering EFADS is comprised of multistage filters, a demister stage to remove most of the radionuclide-bearing water aerosols, high efficiency particle absorption (HEPA) filters to remove micron and submicron aerosols, and a charcoal filter to remove volatile radionuclides like iodine.

Although originally designed for design basis accidents, the Pickering EFADS can be also be used following a BDBA. There are two options for using EFADS post-BDBA. For the first option, operator procedures are currently in place for manually opening inlet valves to EFADS in the absence of electrical power. The second option allows EME-Phase 2 to restore power to the EFADS. Both options will allow controlled filtered venting of containment in the extremely unlikely event of a multi-unit BDBA.

### 2.1.4 Emergency Preparedness

As the fifth and final level of defence in depth, emergency preparedness provides a highly robust means of contending with any accident scenario and protecting the public. Pickering NGS has effective emergency response and fire protection programs that ensure a rapid and effective response to fire and conventional emergencies, as well as nuclear emergencies.

These programs consist of plans and full preparedness capabilities and activities, including frequent drills and exercises. These plans are integrated with plans and training with local municipalities, the Region and the Province of Ontario.

*Fire Protection and Conventional Emergency Preparedness and Response*

The OPG Fire Protection Program includes measures and activities to prevent fires, and to detect and suppress any fires that may occur at the Pickering plant. The Pickering Fire Protection Section includes specially trained staff and standardized emergency response procedures, equipment and training. Continued training for Emergency Response Maintainers (ERMs) is required, and team and individual performance is documented and evaluated yearly. Training has been enhanced through the use of field training simulators at the Wesleyville Fire and Rescue Academy, which is owned and operated by OPG.

Fire protection capability at OPG is integrated with City of Pickering fire services through a Memorandum of Understanding that defines the mutual responsibilities of each party and provides additional OPG resources for training of emergency response staff, and for dealing with major incidents. Pickering Fire Services and Pickering Nuclear Fire Protection staff participate in joint Incident Command Training, and in joint live fire training at Wesleyville each year, strengthening the working relationship and capabilities of both sides.

*Nuclear Emergency Preparedness Program*

The OPG Nuclear Emergency Preparedness Program ensures that OPG has adequate provisions for the nuclear preparedness and response capability to mitigate the effects of releases of radioactive material during postulated accidents. The program describes the structures, roles and processes that would be necessary to implement an effective OPG response to a nuclear emergency. It also provides a framework for interaction with external authorities and describes OPG's commitments under the Ontario Provincial Nuclear Emergency Response Plan (PNERP). OPG has completed many program enhancements, which ensure the program conforms with regulatory requirements including CNSC Regulatory Document 2.10.1.

An effective response to a nuclear emergency requires the use of some specific equipment. To ensure that necessary equipment is available to respond to a nuclear emergency, the Equipment Important to Emergency Response (EITER) program has been implemented. This program involves the identification of equipment that is required in a nuclear emergency response, as well as back-up equipment. EITER requirements are integrated into work management for planned maintenance activities as assurance that the equipment is available.

Substantial upgrades to the station emergency mitigating equipment (EME) have been undertaken including implementation of Phase 2 EME, which improves response to beyond design-basis events, and mitigates the risks of severe accidents.

Licensees are required to have real- time radiological detectors around the perimeter of their nuclear facilities, and communicate the results to the offsite authority and CNSC. OPG has real time fixed radiological detection and monitoring devices operating around the perimeter of the Pickering nuclear facility. These devices are equipped with appropriate backup power and the information is automatically available to off-site authorities in the event of an emergency.

OPG installed and implemented a new emergency personnel accounting system within the Pickering NGS protected area. The system utilizes access card scanners to enable efficient accounting of all staff on site during an emergency. This system is an effective enhancement to the safety of station staff, and the process is exercised annually through drills.

OPG implemented a program at Pickering to ensure that in the event of an extreme external event that requires essential staff to be sequestered at site, there are adequate supplies to sustain them. There are 72-hour emergency supplies that provide food, water, hygiene and sleeping requirements until outside aid can be brought in. Radiation Personal Protective Equipment (RPPE) is also maintained to ensure a 72- hour independent emergency response.

OPG, the Province, and local municipalities have clearly defined roles for responding to emergency events and protecting the public. The OPG planned exercises test and strengthen these partnerships.

### *Drills and Exercises*

Drills and exercises are an important aspect of the OPG emergency preparedness program. The conduct of vigorous drills and exercises at OPG, based on an all-hazards approach, is a critical component of maintaining this robust emergency management capability. The all-hazards approach considers technological and human-caused hazards. Pickering NGS maintains an extensive exercise program that includes the planning and conducting of drills and exercises, and critical evaluation to learn from them and drive improvements.

For example, the "Exercise Unified Response" in 2014 tested and practised the effectiveness of the integrated emergency response of OPG and agencies at the federal, provincial and municipal levels to respond to a simulated nuclear event that included an off-site radiological release at the OPG Darlington station. This exercise involved more than 2000 participants in 54 agencies over a three-day period, and demonstrated the successful integration of nuclear response plans at all levels of government. Most of the participants would fulfil similar roles in an event at the Pickering station.

In 2015, OPG conducted an exercise based on a simulated severe accident event that involved multiple reactor units at the Pickering station. Though this type of event is extremely unlikely, the exercise was designed to test OPG's ability to respond to a large-scale event using the emergency mitigating equipment.

### *Exercise Unified Control*

Most recently, in December 2017 OPG (Pickering) completed Exercise Unified Control (ExUC) to further assess the emergency preparedness of OPG, as well as emergency response agencies at the local, municipal, provincial and federal levels, to respond to a nuclear event at Pickering. This two-day inter-operability exercise involved more than a thousand participants from over 30 agencies. The exercise scenario was a severe accident at the Pickering plant leading to a significant off-site radiological release.


**Figure 8** - Deployment of EME

The ExUC was successful in meeting the objective of testing many key elements of the emergency response plans. OPG also gained some valuable lessons, while demonstrating that Pickering NGS staff and the various external agencies are well prepared and ready to work together. Relationships between all agencies were strengthened through the planning and coordinating of the major exercise, which serves to enhance the collective emergency management capability.

The exercise successfully demonstrated a number of new initiatives including:

- OPG, the Province, and the Canadian Nuclear Safety Commission successfully used the new dose assessment software (URI) to predict projected radiological effects and inform protective action decision-making by the Province;

- The CNSC and the Provincial Emergency Operations Centre utilized the new Plant Information Emergency Summary Page to obtain access to emergency information without the need to transmit manually;
- OPG demonstrated enhanced interoperability using the new P25 radio system, which is common between OPG's Emergency Response Team (ERT) and Pickering Fire Services;
- Health Canada demonstrated the capability to calculate doses with a software called ARGOS using real time weather data;
- Corporate communications participants from all organizations exercised their response to simulated public communications and learned valuable lessons on managing social media.

OPG has prepared an Exercise Report with opportunities for improvement and corrective actions identified within its own organization.This OPG After Action Report was submitted to the CNSC on January 30, 2018.

**Figure 9** - Deployment of EME

OPG, in partnership with International Safety Research (ISR), is currently facilitating development of a Joint Exercise Planning Team – After Action Report. This report will identify key findings and recommendations from an interoperability of participating organizations perspective. Once complete, the After Action Report will be shared with the CNSC and the learnings will be used to further improve the robust emergency preparedness capability to respond in the unlikely event of a nuclear emergency in Pickering.

### *Exercise GridEx IV*

As another recent example, OPG participated in Exercise GridEx IV on November 15th and 16th 2017, with over 4000 North American participants, and 99 OPG employees engaged.

The GridEx series of exercises are a biennial endeavor led by the North American Electric Reliability Corporation (NERC) meant to simulate a response to a sophisticated and coordinated cyber and physical attack scenario on the North American electrical grid. The exercise provides participants an opportunity to practice and strengthen their capability to prepare for, mitigate, respond to, and recover from simulated severe threats and incidents affecting the reliable operation of North America's Bulk Electric System. The exercises are aimed to further the resilience of the electricity industry.

With the participation of North American Reliability Coordinators, Generators, Transmitters, Distributers and Wholesale Customers, this was a significant Bulk Electric System exercise. Ontario saw collaboration with the Independent Electricity System Operator (IESO), Hydro One, Bruce Power, Toronto Hydro, Alectra Utilities Corporation, and Hydro Ottawa, to name a few.

At OPG, GridEx IV provided the opportunity to exercise three key objectives:

- Incident Management: Exercise OPG internal and inter-agency incident management capabilities for cyber and physical incidents that impact the Bulk Electric System (BES);
- Communications: Exercise internal and inter-agency communication;
- Interoperability: Exercise the interoperability between OPG and external stakeholders in incident management, as well as between OPG departments.

Overall, this was an excellent opportunity for OPG to engage in a highly sophisticated North American exercise. It tested and verified OPG's ability to effectively prepare for, and respond to, both cyber and physical threats and incidents, across a broad range of challenges. The exercise further enabled OPG to demonstrate its ability to work collaboratively with internal work groups, and external stakeholders in the management of the simulated threats and incidents.

### *Public Emergency Alerting and Protection*

OPG is aware that people may be concerned about being informed of an accident at Pickering in time to protect themselves and their families. The Regional Municipality of Durham, the City of Toronto, the Province of Ontario, and OPG are prepared with several different methods to alert members of the public in the unlikely event of an accident requiring protective action such as sheltering or evacuation. These methods include sirens, mounted on poles within three km of the Pickering site, that send out a single tone that can be heard outside. Local media, including radio, television and social media, will be provided with instructions on what to do in the event of a nuclear emergency, which they will broadcast to the public. An automated telephone system will also alert a large population in a short time, by delivering a recorded emergency message to landline home phones.

More recently, OPG has collaborated with Durham Region, the Office of the Fire Marshall and Emergency Management (Province of Ontario), Bell Canada and the Weather Network to pilot a Wireless Public Alerting System (WPAS) in the Durham Region. This system will broadcast messages through wireless (cell phone) technology about emergencies of public concern, and has been used in other jurisdictions outside of Canada. In the Durham Region pilot project, approximately 80 people were provided with WPAS-enabled cell phones and received test messages to validate the system's effectiveness. The Canadian Radio-television and Telecommunications Commission has taken steps to direct wireless service providers to implement wireless public alerting capability on their networks in 2018.

As additional support to emergency preparedness and response measures, OPG has developed an Evacuation Time Estimate study for people affected in an emergency, to provide off-site planners with an understanding of the time that would be required to evacuate affected zones around the plant. The study was formulated using census data as well as projections for future growth, to ensure that it accounts for the size of the population that could be involved.

It considers the time to evacuate schools, hospitals and other such institutions, and incorporates factors such as the time of day and day of the week, as well as other possible constraints like roadwork or special events.

OPG consults with the Province, the Region of Durham and the City of Pickering on land use policies and activities that could be relevant to emergency planning zones, to make sure that these are consistent with the implementation of any nuclear emergency plans.

To further support emergency response and public protection, OPG pre-distributed potassium iodide pills to the entire population in the primary zone (10 km radius) around Pickering NGS. Potassium iodide, or KI, protects the thyroid gland of people who may be exposed to radioactive iodine from a radiological release from a nuclear power plant. In support of the provision of KI pills, OPG conducted a communications campaign to inform the population of the distribution program, and placed information on how and when to use the pills on the product packages, which were themselves designed to be recognizable so that people who received them would store them safely.

Extensive supportive information has been provided to assist the community on the use of KI pills. Factsheets were prepared on the use of KI and distributed to local and provincial help lines and to local physicians to help them answer any questions they might get from the public. A website was created and is maintained, to provide information on the use of the pills, including FAQs in the nine most common languages that are spoken within 10 km of the plant, and allowing people within 50 km of the plant to order the pills if they desire. Information packages and KI pills are sent to new residents who move into the primary zone.

### *Update of the Provincial Nuclear Emergency Response Plan*

The Office of the Fire Marshal and Emergency Management (OFMEM) administers the Provincial Nuclear Emergency Response Plan (PNERP) on behalf of the Province and coordinates nuclear emergency preparedness and response in Ontario.

The PNERP is subject to Cabinet approval. The elements of the PNERP Master Plan are applied to each major nuclear site, trans-border emergencies and other types of radiological emergencies, and detailed provincial plans have been developed. All other major organizations that are involved (e.g., municipalities, nuclear power plants) develop their own plans consistent with the requirements of the PNERP, its implementing plans and their mandate.

Following the accident at the Fukushima Daiichi nuclear power plant, OFMEM initiated a project to review the PNERP and the planning basis for nuclear emergency response. An important part of this review process was an opportunity for the public to participate by reviewing and providing feedback on a planning basis discussion paper, which included proposed updates to the PNERP Master Plan. The document was posted publicly for review for 75 days in 2017.

A provincially established advisory group reviewed the comments received from both the public and stakeholders, and made recommendations to the Minister of Community Safety and Correctional Services on how the feedback should be incorporated in the PNERP. The advisory group was made up of independent experts in the fields of emergency management, risk assessment, nuclear and radiation safety and nuclear emergency response.

The advisory group recommendations informed the revision of the PNERP Master Plan, which was approved by Cabinet on December 13, 2017. The Province's goal with this update was to make the plan more transparent and accountable, increase alignment with national and international standards, and enhance emergency planning.

In 2018 revisions and updates to the various PNERP Implementing Plans, including the Pickering and Darlington plans, will be completed to align with the approved PNERP Master Plan. These changes will ensure that Ontario's emergency planning and response to nuclear emergencies incorporates lessons learned from recent international emergencies and best practices from leading experts.

The Pickering PNERP Implementing Plan is expected to be approved by Provincial "Order in Council" in the first half of 2018. Upon approval, OPG will conduct a gap assessment between its existing Consolidated Nuclear Emergency Plan and the updated PNERP Implementing Plans, and will create a transition plan to expeditiously revise OPG plans, as necessary, to align with the provincial plan. One significant change in the PNERP is the introduction of a new 20 km Contingency Planning Zone (CPZ). OPG is currently reviewing the requirements of this new zone, and will be engaging expert transportation engineering consultants to update the existing Evacuation Time Estimate study as required.

## 2.2 Pickering is Fit For Commercial Operation

Pickering NGS is reliable. The station has had its best forced loss rate performance in its history over the last three years, showing that Pickering NGS is continuing to achieve improved reliable operation.The station received a rating of Fully Satisfactory in annual CNSC industry evaluations, in both operating performance and overall ratings for 2015 and 2016.

The information describing the activities that support and demonstrate that Pickering is fit for service relates to the Fitness for Service SCA (Section 2.6 in the Licence Application). Information pertaining to the transition to safe storage also refers to the Predictive Effects Assessment which relates to the Environmental Protection SCA, and is described in sub-Section 2.9.10 of the Licence Application.

### Station Performance Measures

**Forced Loss Rate**

This is a measure of the lost generation due to unplanned shutdowns or load reductions. It is measured only during plant operating periods and reflects the power plant's reliability performance.

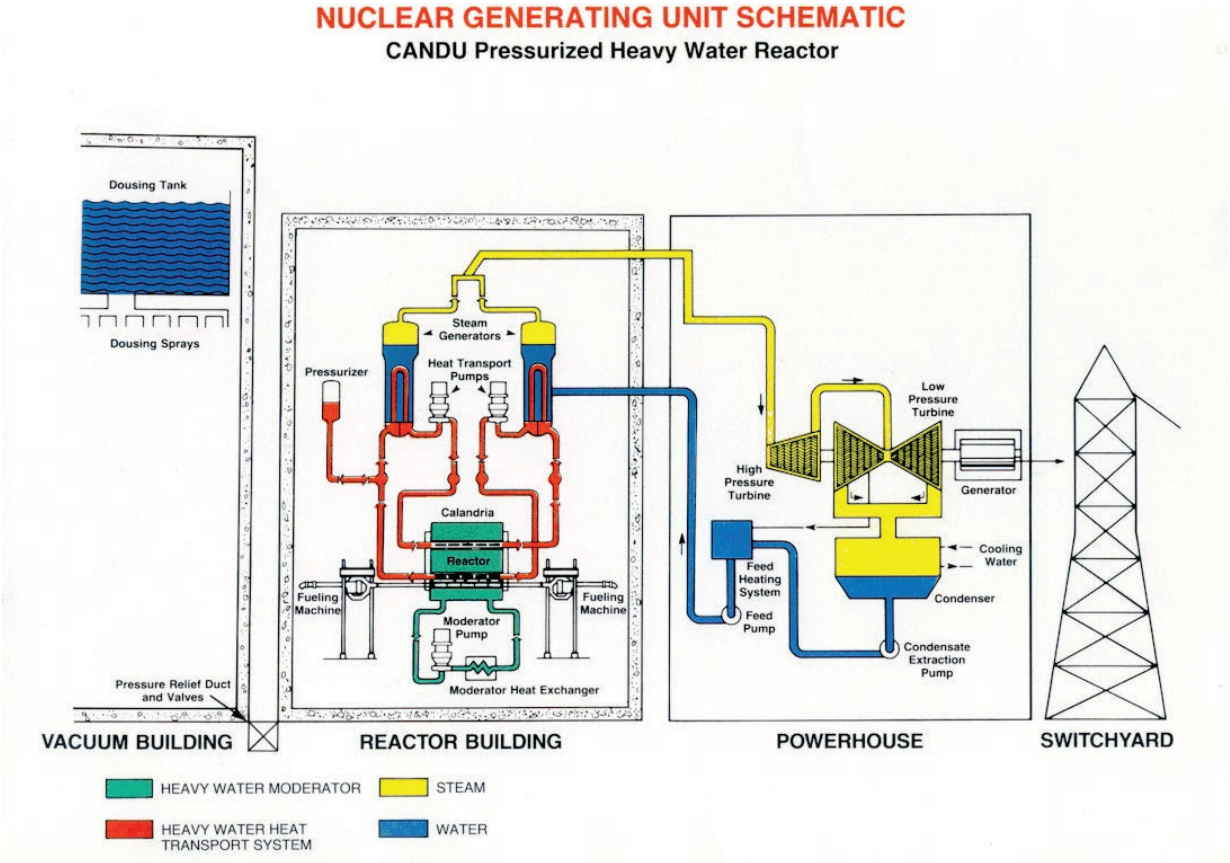



**Figure 10** - Schematic showing major components including calandria, fuel channels, steam generators and the feeder piping system

The systems, structures and components at Pickering are maintained so they will remain available, reliable, effective and consistent with design, analysis and quality control measures through the licence period. These conditions are assured through several key programs, including the Integrated Aging Management Program, the Equipment Reliability Program, the Major Components Program, and the Periodic Inspection Program.

## 2.2.1 Aging Management

Pickering is being maintained in a safe and reliable operating condition through the planned end of commercial operation in 2024, in part through the Integrated Aging Management Program. This program ensures that OPG understands the condition of structures, systems and components (SSCs) which include critical station equipment, and that the necessary activities are in place to assure the health of these SCCs through the licence period.

Integrated aging management is implemented through the coordination of several programs. These include the Equipment Reliability Program, the Major Components Program, and the Component and Equipment Surveillance Program, discussed in more detail in the following Sections.

### *Equipment Reliability*

The Equipment Reliability Program is in place to assure and improve the reliability of station equipment by ensuring that components that are important to nuclear safety and production are reliable and available for service. The program incorporates a number of activities through which plant personnel monitor and evaluate the condition and performance of important equipment; make continuing adjustments to preventive maintenance tasks and their frequencies based on equipment performance experience; and develop and implement long-term equipment health plans.

Plant personnel conduct these activities through surveillance and testing, life cycle management planning, and equipment performance and condition monitoring.

Pickering NGS uses an industry benchmarking metric called the Equipment Reliability Index (ERI) to provide an aggregate assessment of equipment reliability and programs that support it, measuring 17 key indicators of equipment reliability to produce a station score out of a maximum 100 points.Pickering's score has improved through the current licence period: for example, in 2016 the ERI was 72, exceeding the target of 70; the target for 2017 was raised to 72, and by June 2017 Pickering had exceeded that with an ERI of 74.

### *Major Components*

The Major Components Program establishes an integrated set of processes and activities to demonstrate fitness for service of several key major reactor components, and ensure that these components will perform safely and reliably through to the end of the commercial operating period. The program also develops long-term life cycle management strategies for the continued safe and reliable operation of the station. The components that are addressed under this program are the fuel channels, feeders, steam generators, and reactor components and structures.

### *Fuel channels*

OPG recognizes that there is concern with the aging of the fuel channels in the Pickering reactors, and with the condition changes that have been observed with the fuel channels. To address this, OPG has paid close attention to the continued safe operation of the fuel channels at Pickering, through many years of inspections and targeted monitoring of known degradation mechanisms, and measures to mitigate that degradation. A Fuel Channel Life Cycle Management Plan has been implemented to demonstrate that these degradation mechanisms are understood, and to employ inspections and monitoring to ensure and confirm that the fuel channels remain in an acceptable condition for continued safe operation.

On the basis of technical reviews of fuel channels on all reactor units, fuel channel aging management programs including inspections, ongoing research, and the availability of mitigating measures where these are required, OPG is confident that fuel channels are fit for service to the intended end of service in 2024.

In support of the application for a ten-year licence renewal, OPG assessed the operation of the fuel channels on all reactor units. It found that there is additional margin on fuel channel fitness for service limits that applied to the previous target service life of the reactors of December 2020. In other words there is still a lot of life left in these components. These assessments provide assurance that operation with the fuel channels is safe beyond the current limit of 247,000 EFPH. OPG further undertook an assessment of the fitness for service of the Units 5-8 fuel channels to the new target service life of December 31, 2024, based on technical reviews, established controls for managing fuel channel aging, and the availability of required mitigation measures. Observations show that slow degradation is occurring at the rates that were predicted, and no new degradation mechanisms have been identified.

OPG continues to assess fuel channel aging with industry peers and with CNSC staff, and plans for further research and testing have been submitted to the CNSC for review. OPG also continues to conduct research and development activities to enhance and demonstrate the understanding of the key degradation mechanisms, properties of materials and component fitness for service. Findings from these activities are incorporated with inspection results and industry operating experience into the fuel channel program, to ensure that adequate margins on fitness for service are maintained for the full operating life of the Pickering station.

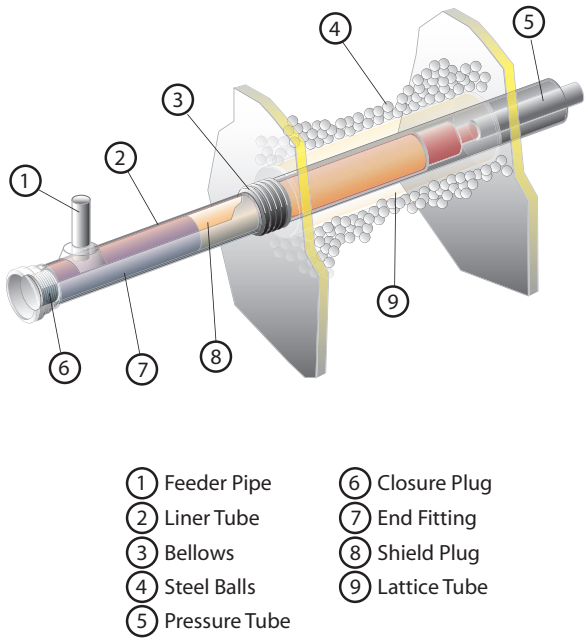



**Figure 11** - Fuel channel penetration through reactor core

The inspections, reviews, and research and development completed to date have confirmed that the Units 5-8 fuel channel fitness for service can be demonstrated up to 295,000 EFPH through existing programs, as would be required for station operation through 2024. More information on the management of the fuel channels is available in Addendum B.

## *Steam Generators*

Steam generators (SG) are boilers that heat water into steam, which drives the turbines that generate electricity. The reliable performance of steam generators through to the end of commercial operation is ensured through activities under the Steam Generator Life Cycle Management Program. These activities include an inspection program to detect and manage plausible mechanisms of degradation in these components, and monitor degradation mechanisms that could limit the life of steam generators. Due to effective inspection and maintenance strategies, there were no SG leaks during the current licence period.

This inspection program discovered a new degradation mechanism in the SGs on Pickering Unit 4 that is causing thinning of the SG tubes in some locations; this is being controlled and mitigated through effective chemistry control, inspections, detailed analysis and conservative decision-making strategies.

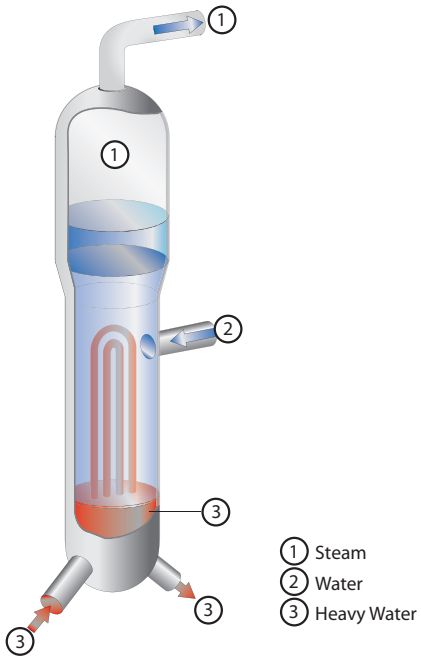



**Figure 12** - Steam generator

## *Feeders*

The feeder piping system is part of the fuel cooling system that transports heat from the fuel to the steam generators for the generation of steam that produces electricity. This system is maintained in a reliable and safe operational condition through the feeder piping system life cycle management program, and is fit for service until the end of commercial operation. This reliable condition is maintained and demonstrated through inspection and assessment activities. When inspections and analysis demonstrate a feeder is reaching its end of life it is replaced.

### Feeder Replacement Program

Feeder wall thickness decreases over time, resulting from corrosion that is accelerated by flow. In addition, feeders can suffer wear from fretting (contact with other components). Both of these degradation mechanisms are closely monitored and analyzed. Acceptance criteria for feeder degradation assessments are provided by guidelines on feeder thickness for service developed by the CANDU Owners Group (COG) Feeder Joint Integrity Project, which are used in conjunction with other industry standards and codes. The need for feeder replacement is developed from the most recent feeder thinning inspections and assessments of remaining life based on minimum required wall thickness, to demonstrate continued fitness for service. The need for replacements will continue to be assessed through to the end of commercial operation.

*Reactor Components and Structures*

Finally, the Component and Equipment Surveillance Program sets out the requirements for the surveillance of a set of key components through functions that include inspection, maintenance, certification and testing. Examples of the component programs to which surveillance activities apply include heat exchangers, check valves and power-operated valves. Equipment that is subject to inspection and testing includes pipe wall thickness, pressure relief valves and buried piping.

The Reactor Components and Structures Life Cycle Management Plan establishes the strategy for the management of the effects of aging on reactor components, and identifies actions that are necessary to manage any effects appropriately. The plan is updated annually, and assessments are incorporated into the life cycle management strategies.

Inspections and assessments of reactor components and structures continue to demonstrate that these components are fit for service. Ongoing inspections and monitoring will continue to manage degradation mechanisms effectively to the end of commercial operation.

## 2.2.2 Periodic Inspection and Testing

The periodic inspection program and the in-service inspection program are in place to ensure pressure boundary integrity, fitness for service, and effective management of aging of the nuclear plant systems and components at Pickering. Standards and criteria for the inspection programs are defined by the Canadian Standards Association (CSA), and ensure that the likelihood of a failure that could pose a danger to health and safety remains low.

**Figure 13** - Equipment inspections

There are two main periodic inspection programs: these are the Periodic Inspection of CANDU Nuclear Power Plant Components; and the Periodic Inspection of CANDU Nuclear Power Plant Containment Components. The Periodic Inspection of CANDU Nuclear Power Plant Components applies to inspections of piping and vessel welds, pumps, valves, pipe and component supports, heat exchangers and mechanical couplings, with inspections on a ten-year inspection cycle.

Containment components that are included in the inspection program include containment penetration seal welds, pipe supports, piping and ducting, valves, and containment dampers.

In-service inspections are performed for newly installed equipment, and for newly installed components that will be inspected under one of the periodic inspection programs. The in-service inspections establish the condition of the equipment or component when it was placed into service and provide an initial inspection result for comparison in subsequent inspections at 10-year cycles.

In-service inspections are also conducted on major structures including the vacuum building (VB) and pressure relief duct (PRD) containment structures. The inspections include concrete components, vacuum building joint sealant, vacuum building roof seal and pressure relief duct joint seals. OPG will continue to meet regulatory requirements for VB and PRD inspections.

### 2.2.3 Maintenance

Maintenance of plant equipment is important to support plant safety and reliability, through minimizing equipment failures as well as ensuring that safety systems remain available and operational. Preventive and corrective maintenance activities are conducted, in addition to routine inspections of system components. Maintenance programs support equipment fitness for service requirements by being aligned organizationally with the Engineering, Work Management, Operations and Supply Chain functions.

**Figure 14** - Turbine maintenance

## 2.3 Qualified and Competent Staff will be Maintained to Ensure Safe Plant Operation Through to Shut-Down

This commitment relates to the Management System SCA and the Human Performance Management SCA, which are described in Sections 2.1 and 2.2, respectively, of the Licence Application.

### 2.3.1 Staffing Management

Workforce planning looks at current staff and business plans, and makes projections to ensure that sufficient qualified staff are available to operate and maintain the stations. Staff projections for continued operations of Pickering and the end of commercial operations form part of the overall people strategy for OPG.

Key aspects of this program include knowledge management and succession planning.

OPG ensures that staff have the necessary qualifications, knowledge and skills required to perform competently. The knowledge management program complements these foundational programs by providing tools and techniques to maintain and share tacit knowledge. Given OPG's demographics, employee attrition and the lengthy training and development required for specialized roles, OPG has invested in knowledge management for ongoing operations as well as the delivery of projects and initiatives to ensure that the critical knowledge and expertise of employees are sustained. Long-term hiring strategies are also in place, and will continue to be refined, to address corporate and nuclear staffing needs through to and beyond the shut-down of the station.

OPG recognizes the importance of succession planning for the retention and transfer of knowledge to ensure that the necessary knowledge and skills are available when they are needed, and for continuity in critical roles. An additional succession planning process that is complementary to the broader OPG process is in place for the nuclear organization. This involves identifying critical positions and determining the priority of each, in order to assign a degree of management oversight of succession planning that is appropriate to the priority of each role.

As discussed in Section 1.3.4, to address the new challenges due to the transition from an operating station to the end of commercial operation a Sustainable Operations Plan (SOP) will be pro-actively developed five years before the shutdown of the first unit. The SOP will address staffing management issues to ensure safe, reliable operation of Pickering to the end of commercial operation.

### 2.3.2 Ensuring a Qualified and Competent Workforce

One component of human performance management is to ensure that positions are filled by qualified staff.

*Certification and Training*

Safe reactor operation is assured in part through the use of certified staff in safety critical positions. Under the Pickering Power Reactor Operating Licence, valid certification is required for personnel who work in the positions of Authorized Nuclear Operator, Control Room Shift Supervisor, Shift Manager, and Responsible Health Physicist.

Certification for these positions is achieved through training and certification examinations, and confirms that successful candidates have the level of knowledge and skills required to work competently in their assigned position. Certified individuals must undergo periodic requalification testing; they are also required to complete refresher training, and to update their training in accordance with changes to the plant and to procedures.

Certified operations staff, for example, undergo more than 200 hours of continuing training each year.

The CNSC specifies a minimum number of certified individuals who must be available for each of these positions; Pickering NGS exceeds the minimum required certified staff for each position, and also has training programs to prepare trainees to become certified and move into these positions.

In recent years there have been improvements in the initial certification and continuing certification training programs, with increased attention to operator fundamentals, reactivity management and emergency response, including response to beyond design basis events. Training has also been improved and made more realistic with the use of full scope main control room simulators for emergency preparedness drills and exercises.

In addition to skilled operator certification, OPG makes significant investments in training, and all employees (regular and temporary staff) are required to participate every year in training that is relevant to their work. OPG uses a Systematic Approach to Training to provide the structure, processes and tools for defining, developing, implementing, documenting, assessing and improving the training required to ensure staff have appropriate knowledge, skill, and behaviors for safe and efficient plant operation. This involves systematically evaluating the tasks involved in carrying out a role and evaluating the necessary training for each task, and applying another systematic evaluation to determine the most appropriate kind of training.

Training programs consist of initial training, re-qualification training to maintain an employee's qualifications, and refresher training. Training programs are maintained through a regular cycle of revision and updating of program content.

As an example, OPG has improved and expanded training in emergency response. In 2016, the Emergency Response Organization (ERO) Betterment Project was implemented and successfully completed. Achievements include consistent application of the systematic approach to training to all ERO role-related documentation as well as creation or revision of over 200 training documents. More information related to emergency preparedness and response training was provided in Section 2.1.4, above.

# OPG Nuclear Employee Training Programs

Engineering training includes an initial training program and a continuing training program. The initial training program has been improved, and enhanced with an additional classroom course on the design basis. The continuing training program includes a Conduct of Engineering workshop that focusses on a new topic each year, as determined by senior engineers and industry experience, and delivered to approximately 1000 engineers. Initial training for maintenance staff consists of Control and Mechanical programs, both of which provide approximately 120 days of training over a three-year period. Continuing training, which is done for 10 days each year, remains flexible in order to address key performance issues, and can be tailored to the needs of specific groups. For example, in 2015 and 2016 workshops were developed on leak management and valve assembly and were delivered to 300 maintenance staff at Pickering NGS.

Training Facility

Operations training also includes initial and continuing training programs, in which all qualified operators participate. Operator training focusses on advancing operator proficiency, to achieve an objective of error-free operation. This consists of knowledge and skills refreshers as well as re-qualification training.

The scope of operator training has expanded, as a result of lessons learned from the Fukushima accident, to include response to beyond design-basis events and the operation of emergency mitigating equipment that has been installed to mitigate the risks of severe accidents.

Leadership training is required for all leadership and supervisory roles, including those within the engineering, operations and maintenance departments. This training is wide-ranging in content and can consist of short one-day courses or others that take several months. OPG company-wide leadership training for first line managers, first line manager assistants and middle level managers was redesigned in 2015 according to international benchmarking and industry best practices. OPG also has leadership training that is specific to nuclear plant management. It developed the International Senior Nuclear Plant Manager program, and since 1996 has offered it to senior managers within the OPG nuclear organization, as well as to senior managers from major contract suppliers. This program has become internationally recognized, and OPG is now providing it in England in collaboration with EDF Energy in the United Kingdom.

### 2.3.3 Operational Staffing Policies

To ensure the safe operation of the Pickering station, OPG enforces a Minimum Shift Complement (MSC), which is the minimum number of qualified workers who must be present at all times to operate the plant safely. This also considers the staffing requirements for a response to any station emergency that may arise and ensure adequate emergency response capability for even the most resource- intensive conditions. The qualifications and staff requirements for each role to which the requirement applies are set out in procedures and comply with CNSC regulatory requirements.

Assessments of various station roles are undertaken to verify the adequacy of shift complement requirements and make any necessary adjustments. For example, an assessment of the capabilities of the Emergency Response Team, which was undertaken as a response to the lessons learned from the Fukushima accident, determined the appropriate Emergency Response Team complement for completing the necessary emergency response actions, such as deploying emergency mitigating equipment.

A set of staffing policies are implemented to ensure that all staff are fit for duty at the facility. One such procedure, Limits of Hours of Work, describes the expectations and process for monitoring and controlling the number of hours and shifts that employees work, to control the effects of fatigue per regulatory limits.

Supervisors are responsible for monitoring their employees' hours of work and for ensuring that employees are aware of their limits, while employees are responsible for being aware of their time limitations, for tracking their work hours and notifying their manager in advance of a potential violation.

An additional fitness for duty consideration pertains to staff behaviors that may indicate a risk to the security, safety, or health of employees, facilities or the public. Training under the Continuous Behavior Observation Program describes the process to be followed if a worker who reports for work is suspected of being unfit for duty; all OPG supervisors must complete this training during initial training and undergo refresher training every 36 months.

As an additional safety measure OPG Security monitors all personnel who enter the station protected area for indications of being unfit for duty or under the influence of intoxicants, and deny access to any employee who is suspected of being unfit. Periodic monitoring for drug use is carried out using canine drug monitoring, as an additional screen to ensure that all staff in the protected area are fit for duty.

CNSC has updated its requirements for hours of work and fatigue management, and for alcohol and drug testing. OPG is updating its procedures on fatigue management, and is developing plans for implementing alcohol and drug testing, in alignment with these new requirements.

### 2.3.4 Safety Culture

More than 30 years ago, nuclear power plant operators recognized that in addition to the other safety and defence in depth provisions they had in place, it was also important to emphasize that an organization must hold nuclear safety to be its top priority overriding all others.

OPG has defined the elements that make up a healthy nuclear safety culture, and the operational and organizational components by which it is implemented. These are formally defined, with performance criteria for each, as the ten Traits of a Healthy Nuclear Safety Culture. The nuclear safety culture is described in the box on page 42.

# OPG's Nuclear Safety Culture

OPG's Nuclear Safety Culture consists of three main principles, which are put into practice through the observation by all employees of a set of ten nuclear safety culture traits.

## Principles of the Nuclear Safety Culture

- Nuclear Safety shall be the overriding priority in all activities performed and shall have clear priority over schedule, cost and production;
- Nuclear safety is based on Reactor Safety, Industrial Safety, Radiological Safety and Environmental Safety;
- The Nuclear Safety Culture program provides an objective and transparent safety-focused process while continuously strengthening safety culture.

## Ten Traits of a Healthy Safety Culture

1. **Personal accountability**
   All individuals take personal responsibility for safety.
2. **Questioning Attitude**
   Individuals avoid complacency and continuously challenge existing conditions and activities in order to identify discrepancies that might result in error or inappropriate action.
3. **Effective Safety Communication**
   Communications maintain a focus on safety.
4. **Leadership Safety Values and Actions**
   Leaders demonstrate a commitment to safety in their decisions and behaviours.
5. **Decision-Making**
   Decisions that support or affect nuclear safety are systematic, rigorous and thorough.
6. **Respectful Work Environment**
   Trust and respect permeate the organization.
7. **Continuous Learning**
   Opportunities to learn about ways to ensure safety are sought out and implemented.
8. **Problem Identification and Resolution**
   Issues potentially impacting safety are promptly identified, fully evaluated, and promptly addressed and corrected commensurate with their significance.
9. **Environment for Raising Concerns**
   A safety-conscious work environment is maintained where personnel feel free to raise safety concerns without fear of retaliation, intimidation, harassment or discrimination.
10. **Work Processes**
    The process of planning and controlling work activities is implemented so that safety is maintained.

The Nuclear Safety Culture Program is overseen through a set of processes and activities, including the Nuclear Safety Culture Monitoring Panel, Nuclear Safety Review Board, self-assessments, and the Corrective Action Program. The Nuclear Safety Culture Monitoring Panel tracks indications of the health of Pickering's nuclear safety culture. The panel consists of the senior plant leadership team and meets each quarter to discuss the status of the nuclear safety culture at Pickering NGS.

OPG has used different methods to review, evaluate and critique the safety culture at Pickering NGS. For example, in 2015 Pickering NGS conducted a station-wide assessment of the perceptions, attitudes and behaviors associated with Pickering's safety culture through reviews, interviews and observations. It found that Pickering NGS has a healthy safety culture, that employees respect nuclear safety, and that nuclear safety is not compromised by production priorities. Station personnel feel they can challenge a decision without fear of retaliation; for example, Pickering has a healthy Station Condition Record (SCR) reporting culture, with employees comfortable reporting any abnormalities or deficiencies that they observe in the plant. All new SCR reports are read and dispositioned by management several times each week; while most of the SCRs are not significant or related to plant safety, some will require a corrective action plan or a root cause investigation.

The safety culture assessment also noted some areas for improvement, and actions taken to address them have been tracked. Further station-wide safety culture assessments will be conducted periodically, with the next scheduled for 2018.

## 2.4 Impacts of Pickering NGS Operation on the Public, Workers and the Environment Will Remain Low

OPG understands the fundamental importance of preventing impacts to the public, workers, and the environment as a result of normal Pickering NGS operations. The activities focused on minimizing impacts associated with normal plant operation, described below, are in addition to OPG's extensive plant safety provisions and well practised capabilities to respond to any type of emergency, which are discussed in Section 2.1, above, in this document. The programs and activities discussed in this Section relate to several SCAs: these are Radiation Protection (Section 2.7 of the Licence Application); Conventional Health and Safety (2.8 in the Licence Application); Environmental Protection (2.9 in the Licence Application); and Waste Management (2.11 in the Licence Application).

The Environmental Management Program at Pickering Nuclear is consistent with the International Organization for Standardization (ISO) 14001 Environmental Management System.

The program ensures, first and foremost, that no members of the public are exposed to any unsafe level of radiation. Pickering keeps emissions to a minimum, far below regulatory limits. Second, Pickering maintains extensive monitoring programs that measure levels of radiation in air, water, groundwater and soil, to verify that levels are low and to ensure prompt detection of any elevated levels so these can be addressed.

In addition to regular monitoring programs, risks to humans and the environment were recently assessed in an updated Environmental Risk Assessment that focused on operations of Pickering site facilities from the year of 2011 to 2015. The assessment consisted of a Human Health Risk Assessment (HHRA) and an Ecological Risk Assessment (EcoRA) for the risks of radiological and non-radiological contaminants and physical stressors associated with Pickering and its activities.

The HHRA assessed the risks of non-radiological contaminants and radionuclides, to off-site members of the public (i.e. critical groups that are used for dose calculations).

The EcoRA focused on Valued Ecosystem Components that exist on and in the vicinity of the Pickering site and near shore of Lake Ontario and includes consideration of threatened or endangered species. Findings and conclusions from these assessments are included in the discussion of the risks to human health and the environment, from radiological and conventional hazards.

Other activities that protect the public and workers from exposure to radiation are the careful packaging and transport of radioactive materials, and the safe management of radioactive waste. OPG is transparent about these activities, providing information to local communities and the public on station performance so that interested or concerned individuals can verify for themselves that levels remain low.

It is also important that the workers and the public be protected from impacts from conventional, or non-radiological, activities resulting from industrial activities on the site. Pickering's Conventional Health and Safety program is very effective. OPG received the Canadian Electricity Association President's Gold Award of Excellence for Employee Safety, in recognition of its employee safety performance for 2013-2015. In an effort to further improve employee safety beyond compliance with health and safety program rules, OPG has implemented an "iCare" safety culture to encourage all employees to protect themselves and others in their work. OPG's goal is zero workplace injuries.

As discussed in Section 1.3.4, OPG also undertook a Predictive Effects Assessment (PEA) to evaluate the potential for adverse effects to human health and the environment from the activities associated with transitioning the station from operation to a safe storage state. The PEA encompasses both the Stabilization Phase and the Safe Storage Phase. The PEA concluded that there are no predicted potential adverse effects from the stabilization and safe storage activities.

### 2.4.1 Environmental Safeguards

The goal of OPG's comprehensive environmental protection program is to continually minimize impacts from station operation to the environment and human health. This is achieved by ensuring that there are multiple barriers in place to control and minimize radioactive emissions to the environment and to ensure all emissions are monitored.

The framework to control emissions is based on the guiding principle of keeping radiation impacts to the public and the environment As Low As Reasonably Achievable (ALARA). This is achieved by establishing operational emission limits to ensure that the dose to the public does not exceed the legal limit of 1000 μSv and in fact is kept far below that limit.

The official public dose to the public from Pickering NGS has been consistently much lower than the legal limit. The annual dose to the critical group (the urban resident adult) from 2011-2016 ranged from 0.9 to 1.5 μSv, or approximately 0.15% of the regulatory dose limit for the public of 1000μSv. The protection of these most exposed critical groups ensures that other populations near Pickering NGS are protected.

## How is Public Dose Calculated?

Radiation doses to humans are measured in Sieverts, (Sv) which combine a measure of the type of radiation with the impact it has on the body. The annual legal limit for a member of the public from a man- made source of radiation is 1000μSv – a millisievert, or 1/1000 of a Sievert. These limits are consistent with recommendations by international radiation protection authorities.

The radiation dose from a nuclear plant is calculated to a set of representative people called "potential critical groups" (such as "Urban Resident (Adult))" who are defined as living in the vicinity of the plant and engaging in various activities.

The highest dose to any of these critical groups is used as the official public dose.

The Figures, 15 and 16 below, illustrate the dose from the Pickering station to a member of the public in relation to regulatory limits. Note that in figure 16, the vertical axis uses a logarithmic scale.

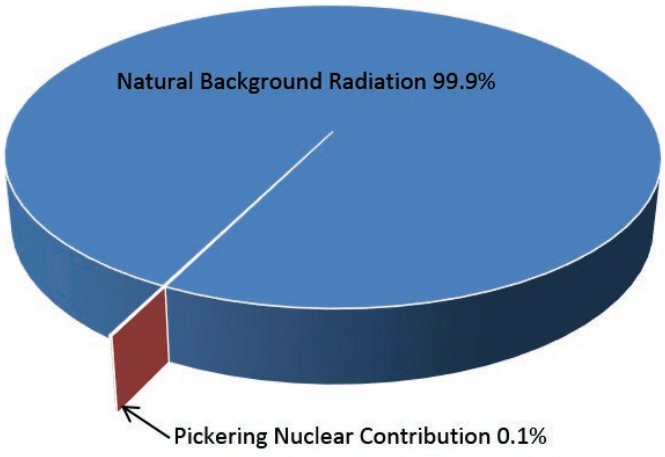



**Figure 15** - Radioactive Dose to the Public (2017 results will be available by May 2018)

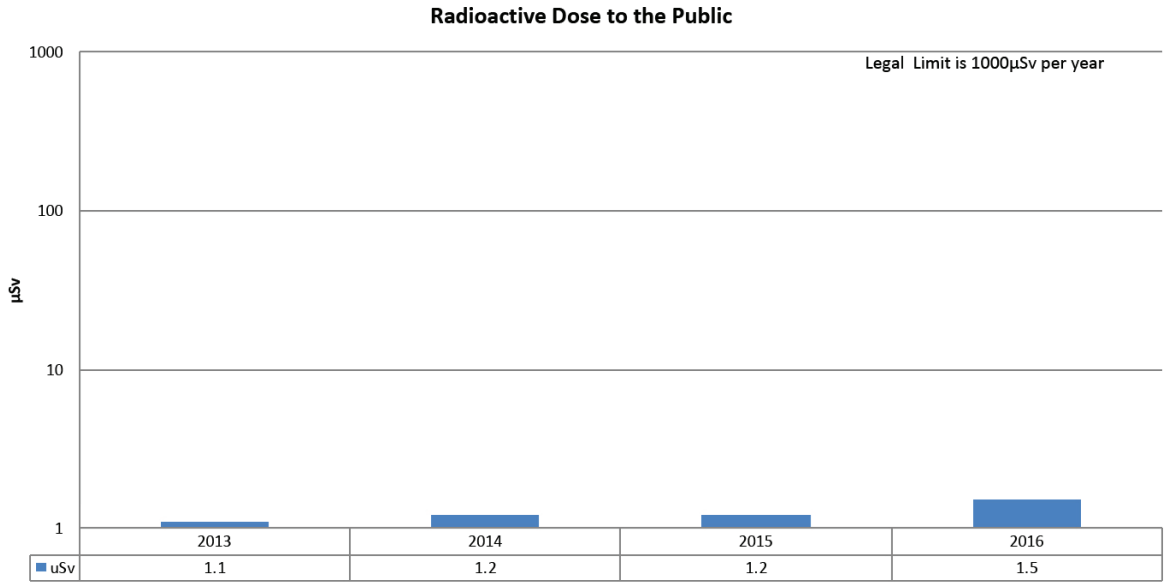



**Figure 16** - Radioactive Dose to the Public (2017 results will be available by May 2018).

The routine environmental monitoring of radiological emissions and their potential impacts on the public includes measurements of radionuclides in air, water and food products, taken near Pickering NGS as well as at other background locations in the province for comparison purposes. The measurement data are used with data on station emissions to determine the dose of radiation received by members of the public. The CNSC also conducts independent sampling and has posted results that demonstrate Pickering's safety record.

Discharges to water from the radioactive liquid waste management system are also monitored and controlled, and are reported each quarter to the Ontario Ministry of the Environment and Climate Change (MOECC).

Groundwater is also monitored for emissions of radioactive materials – primarily tritium - into and through groundwater at and near the Pickering site. Tritium in groundwater is localized within the station's Protected Area.

OPG maintains an annual groundwater monitoring program at Pickering designed to provide early detection of potential impacts to groundwater. Approximately 140 locations were sampled in 2016. The concentrations of tritium that have been observed have no adverse off-site environmental impacts. OPG continues to take actions to reduce and minimize any tritium emissions to groundwater that occur.

## 2.4.2 Conventional Hazards: Environmental Monitoring

Monitoring for non-radiological, or conventional, hazards is also carried out at Pickering NGS, in support of programs to minimize these events and their possible impacts on people and the environment.

Groundwater is monitored for petroleum hydrocarbons, benzene, toluene, ethylbenzene, xylenes and volatile organic compounds (VOCs). Some ozone-depleting substances are used at Pickering NGS in water coolers, air conditioners and refrigerators; emissions of these substances have been decreasing due to the installation of new equipment, including the replacement of older chiller equipment in Units 5-8. Emissions of these substances vary but remain low.

Pickering NGS reports the release of certain industrial substances, including hydrazine, nitrogen oxides, particulate matter and sulphuric acid, to the National Pollutant Release Inventory managed by Environment Canada. In addition, these and some other industrial chemicals are regulated by the MOECC. Discharges to water from the water treatment plant are regulated by the MOECC; all discharges during the current licence period were via approved pathways, and complied with regulations.

Pickering NGS also has extensive programs to minimize spills to the environment and to manage those that occur effectively. Spills that may cause an adverse effect are categorized as Category A (major); Category B (moderate and Category C (minor) and are reported to the Ontario MOECC. From 2013 to 2017, there were no Category A or Category B spills at Pickering. There were 12 Category C spills through that period, involving substances like ethylene glycol, different types of oils, and sewage. The number of these spills has been decreasing since 2004 due to improved environmental awareness and stricter spill control practices.

## 2.4.3 Environmental Protection: HHRA, EcoRAand Physical Stressors

The effects of Pickering NGS activities and operations on the environment are examined through an Environmental Risk Assessment (ERA) The ERA is prepared to meet the requirements of CSA N288.6-12.

The ERA is a systematic process used to identify, quantify and characterize the potential for biological effects arising from contaminants and physical stressors in the environment. It addresses potential effects on both humans and the natural environment (i.e. plants and animals) that may be exposed to contaminants and physical stressors. The contaminants of interest may be radionuclides or other chemical substances released to the environment. Physical stressors may include emissions of noise, heat, or the intake of cooling water at a nuclear power station. The ERA includes a Human Health Risk Assessment (HHRA) and an Ecological Risk Assessment (EcoRA) for biota. The outcomes of the ERA are risk-based recommendations, which may result in changes to the environmental or effluent monitoring programs.

The ERA is reviewed every five years or more frequently as major facility changes are proposed. This ongoing, iterative process ensures that the ERA accounts for changes such as new activities or processes, environmental monitoring data, scientific advances and regulatory requirements, and thereby confirms that the environment and health and safety of persons are protected through the entire life cycle of the facility.

The ERA for the Pickering site used routine environmental and effluent monitoring data for the period of 2011 to 2015. A comprehensive sampling campaign in 2015 to collect samples in a number of environmental media was also considered in this assessment.

### *HHRA Results*

Human receptors evaluated included off-site members of the public, specifically those critical groups used for dose calculations in the annual OPG Environmental Monitoring Program reports. Measured and modeled concentration of contaminants and noise levels were evaluated against screening benchmarks that are protective of human health.

For exposure of human receptors to radiological contaminants of potential concern, the relevant exposure pathways were those presented in OPG's annual public dose assessments. The annual dose to the critical group (the urban resident adult) between 2011 and 2016 ranged from 0.9 to 1.5 uSv/a, approximately 0.15% of the regulatory public dose limit of 1000 μSv and approximately 0.1% of the dose due to Canadian background radiation. Since the critical group receives the highest dose from Pickering NGS, the fact that this group is protected ensures that other receptor groups near Pickering NGS are also protected.

The HHRA results indicated that likely exposure levels for non-radiological contaminants are below benchmark values, and therefore no adverse effects on human receptors are expected.

The review of noise monitoring data indicated that sound levels were occasionally slightly above benchmark values, which is typical in populated urban areas. The occasional elevated noise levels were not attributable to Pickering NGS activities.

### *EcoRA Results*

The EcoRA identified a number of plant and animal receptors known as Valued Ecosystem Components (VECs) to be assessed at their most exposed locations near or within the Pickering NGS site. The assessment of these receptors for the EcoRA focused on the nearshore in Lake Ontario, the Pickering NGS site, and Frenchman's Bay.

In addition to evaluating the effects of Pickering NGS emissions, the EcoRA also considered the thermal effects of the cooling water discharge, and impingement and entrainment of aquatic organisms at the cooling water intake.

**Impingement** - A certain number of fish are taken up in the water and caught in the screens that keep external objects and substances out of the cooling water - which results in the loss of those fish.

**Entrainment** - Occurs when very small fish eggs and small young are able to pass through the screens and are carried through the turbine condenser system.

In general, the EcoRA showed that the exposure levels for non-radiological contaminants are below benchmark values. Where benchmark values were exceeded, the effects are highly localized and therefore the receptor populations are not expected to experience any adverse effects due to non-radiological releases from Pickering NGS operations.

Radiation doses were calculated for fish, aquatic plants or invertebrates, and riparian birds and mammals at the Pickering NGS outfall and Frenchman's Bay; and for terrestrial plants or invertebrates, and terrestrial birds and mammals on the Pickering NGS site. Calculated doses were compared to accepted dose benchmarks for aquatic and terrestrial biota. The radiation doses calculated for all VECs at all locations were well below these benchmark values.

Overall, the Environmental Risk Assessment confirms that Pickering NGS continues to operate in a manner that is protective of human and ecological receptors residing in the surrounding area.

### *Fish Protection Programs*

Pickering NGS takes cooling water (used to condense steam from the turbine) from Lake Ontario, via surface level water intakes in the lake.

Pickering monitors the fish that are impinged each week, identifying the fish species and reporting the estimated biomass of impinged fish to the CNSC each year.

To reduce the number of fish that are impinged, a fish diversion system, consisting of a net placed around the water intake, is installed in the ice- free seasons of the year. This system, shown in Figure 17, has reduced fish losses by more than 80%. The CNSC has set a target for the reduction of fish impingement, and this target has been achieved, with ongoing monitoring continuing to verify reductions in impingement.


**Figure 17** - Fish Diversion System

To offset any losses, OPG has proposed three measures: two are habitat creation projects, one that has been completed in the Big Island Wetland in the Bay of Quinte, and the second to be created in the Simcoe Point Wetland near the outlet of Duffins Creek. The third project is OPG's contribution to the stocking of the Lake Ontario Atlantic Salmon Program, to which OPG is the lead sponsor from 2016 to 2020.

OPG applied to the federal Department of Fisheries and Oceans (DFO) for authorization for its continued operations and stabilization phases of the Pickering Nuclear facility. The application for this authorization included assessments of the impacts on aquatic species after the mitigations are in place, offsets such as habitat improvement, and engagement with concerned Indigenous communities. In January 2018, the DFO granted the authorization for Pickering NGS.

Finally, the thermal plume, or the area of warmer water that is created in Lake Ontario by the return of cooling water from its cycle through the turbine condenser, is assessed for a possible impact on the survival of Round Whitefish embryos.

It was determined that the thermal plume from the Pickering NGS is not having an adverse impact on Round Whitefish embryo survival. This is on account of the water temperature for all plume stations staying below the threshold effect level of 6 °C during the spawning and egg incubation period, and the reduction in survival at the plume stations was below 10%, which is the threshold for a no-effect level for those fish.

### 2.4.4 Biodiversity and Wildlife Habitat Protection

The Biodiversity and Natural Areas Management Program has been established to protect, maintain and enhance the natural environment around the Pickering site, including species and wildlife habitat. Initiatives under this program include the enhancement of wildlife corridors across the site, protection of species such as the peregrine falcon, and enhancement of the ecological value of natural areas on and adjacent to the Pickering site.

Pickering Nuclear's biodiversity program continues to provide planting, butterfly gardens, and numerous other initiatives. More than 15,000 native trees and shrubs have been planted in the vicinity of Pickering Nuclear since 2000 by OPG staff and community volunteers. In January 2017, OPG's Nuclear Operations received "Conservation Certification" for 2017-2019 from the international Wildlife Habitat Council, and Pickering Nuclear has twice been recognized as Wildlife Habitat of the Year.

OPG also contributes to habitat enhancement off the Pickering site in partnership with Environmental Stewardship Pickering. Projects under this initiative include the creation of a wildflower garden at a local school, tree planting events and the creation of habitat for birds and pollinators (such as bees). Other community activities, such as community workshops on gardening, habitat creation and environmental stewardship are also carried out.

**Figure 18** - Tree planting activities

## 2.4.5 Waste Management

Pickering NGS has an effective waste management program that covers the management of conventional solid waste, hazardous and chemical wastes, as well as low-level radioactive waste and irradiated fuel. Solid waste materials are separated into conventional, hazardous and radioactive waste streams so that each type can be handled appropriately and impacts on humans and the environment minimized.

### *Irradiated Fuel Interim Dry Storage*

When fuel is no longer useful for generating electricity, it is removed from the reactor and placed in a strong concrete, water filled "bay" for at least ten years until it is cool enough that it can be moved to dry storage. Dry storage is a safe method of passive storage that does not require active management for safety. The storage containers are made of concrete and steel; these containers are designed to last for 50 years, though studies show they can be used safely for much longer. Once they are filled the containers are sealed shut so they comply with international non-proliferation requirements. Pickering NGS has been storing used fuel in the Pickering Waste Management Facility (PWMF) since 1996, and to date has processed more than 330,000 bundles of spent fuel in 855 dry storage containers within three storage buildings on the Pickering site.

The PWMF is subject to CNSC regulation and licensing under separate regulations, and is not part of the operating Licence Application.

However, it is managed with consideration of the future needs of the Pickering station through to the end of the requested licence extension period. It is anticipated that shutdown activities following the end of commercial operation will increase the volume and types of waste that are generated, for a short period. An aspect of the Stabilization Activities Phase Planning is therefore concerned with ensuring that all hazardous wastes are removed from the station, packaged and disposed of appropriately in order to protect workers and the environment during this transition phase.


**Figure 19** - Monitoring of waste for radioactivity

### *Low Level Radioactive Waste*

Low level radioactive waste (LLRW) is made up of material such as cleaning items like mop heads, rags, paper towels, and protective clothing that is worn for routine operations in the nuclear station.

These items have low levels of radioactivity and do not require shielding for safe handling; they are packed in plastic bags and shipped to the Western Waste Management Facilitybeside the Bruce Nuclear Power Plant in steel containers for processing and storage.

If possible LLRW is compacted or incinerated to reduce the volume that needs to be stored.

To reduce the amount of LLRW that must be handled and stored, OPG removes plastic, wood, cardboard and other packaging from equipment before bringing it into the station, thus ensuring that these materials can be handled as conventional waste or recycled. Groups that produce waste are held responsible for their waste reduction strategies, and these are under continual evaluation and improvement.

*Conventional, Hazardous and Chemical Wastes*

OPG makes efforts to reduce the amount of solid conventional (non-radioactive) waste that it generates, through activities like recycling. It participates in organic waste segregation and blue box recycling. Non-hazardous, non-radioactive waste that cannot be recycled is sent to a public landfill.

Some hazardous wastes are generated at Pickering in operational and maintenance activities. These include cleaning agents, grease, oil, waste fuels and acids, as well as batteries and PCBs. Pickering's PCB Waste Management Program was inspected by Environment Canada in 2015, and the operation was found to be in full compliance with requirements.

## 2.4.6 Packaging and Transport of Radioactive Materials

Pickering has shipped many hundreds of shipments of radioactive material without any incidents resulting in a radioactive release, or in any serious personal injury due to a conventional accident. Radioactive material that is transported includes low and intermediate level waste, tritiated heavy water, and occasionally used fuel (for testing). Other materials that are transported include cobalt-60, associated with OPG's medical cobalt-60 production program, and radioactive devices such as radiography cameras.

OPG has a set of packages for radioactive materials, and maintains them to ensure that they comply with regulations. All packages, except those that are meant for a single use only, are maintained annually.

Maintenance procedures may require disassembly, visual inspection and replacement of worn parts, and each package is tested after maintenance to ensure that its containment is effective. Some older nuclear waste transportation packages are being replaced, and newer packages incorporate industry best practice and operating experience.

Some radioactive materials packages must be certified for specific uses, and OPG must receive CNSC confirmation that its intended use of a certified radioactive materials package has been registered. At present OPG is a registered user for 12 different package designs, including packages for intermediate level waste and tritiated heavy water transportation packages, and shipping packages from external agencies for used fuel, cobalt-60 and radiation devices such as radiography cameras.

### Nuclear Transport Packages

Radioactive materials are transported in shipping containers referred to as packages. These are strong engineered containers that are built according to specifications in the CNSC's Packaging and Transport of Nuclear Substances Regulations. There are several different types of packages, which are meant to safely contain different types of radioactive substances as they are transported. For example, Type B packages for intermediate and high-level waste must be able to withstand a nine-metre drop onto an unyielding surface; a one-metre drop onto a steel pin; 30 minutes in an 800 degree celsius fire; and eight hours immersed in 15 metres of water. An example of a shipping container is shown below.

The transportation of nuclear materials must meet requirements of the Transport of Dangerous Goods (TDG) Regulations and the Packaging and Transport of Nuclear Substances Regulations. This activity at OPG is governed by the Radioactive Material Transportation (RMT) Program, operated by the Nuclear Waste Management division. As required by the TDG Regulations, employees who handle radioactive material for transport must hold a valid training certificate; and Type A and B radioactive shipments are reviewed and approved by an RMT Transportation Officer before they leave the site.

## 2.5 Pickering NGS Will Continue to be Transparent and Engage with the Public and Indigenous Communities

The activities and programs described in this Section are not related to an SCA, but to the CNSC's Licensee Public Information Program requirements, which are discussed in Section 3 of the Licence Application.

### 2.5.1 Public Information Program

OPG recognizes that members of the public, stakeholder groups, and local communities have a legitimate interest in the operations of the Pickering NGS; the way in which it is operated and managed; and the means by which OPG keeps the risks to human health and safety, and to the environment, at a low level. OPG therefore shares information on facility operations and performance with members of the public, to enable interested individuals to monitor the safety of the plant and OPG's management record. OPG also works to develop positive relationships with local communities, including those in the vicinity of the Pickering facility and Indigenous communities, as well as with stakeholder groups that have a longstanding interest in the safety of nuclear power.

These activities are of several types. First, OPG publishes facility operational and performance data from monitoring and other processes, for anyone to access. Second, it provides a large amount of background and other information on nuclear power and on the Pickering NGS operation, both online and at its facilities in Pickering, Ontario.

Third, it establishes and maintains positive relationships with the people in the nearby communities and works to improve and maintain the local environment. Finally, it has developed a program to consult with Indigenous communities that have an interest in the Pickering facility and with the land on which it lies.

*Station Reporting and Performance Data*

OPG uses its public website to provide up-to-date information on the performance of the Pickering station, on environmental assessments, projects, probabilistic safety assessment summaries, and regulatory information such as licensing hearings.

Data and other information on the Pickering NGS from environmental monitoring programs is also made available to the public through OPG's public website. Monthly environmental emissions data have been published on the OPG website since 2014. The information reported includes radiological emissions to air and water, waste management facility monitoring results, and spills to the environment. In addition, OPG's annual reports to the CNSC on the Environmental Monitoring Program are available to the public on the OPG website.

OPG Nuclear and Pickering Nuclear Performance reports are produced quarterly. OPG posts performance reports on station operations on a quarterly basis on its website, at **www.opg.com**. Information is also shared electronically with key stakeholders, and ads on station performance are placed in local newspapers. Additionally, starting in 2014 OPG developed and began issuing a quarterly Environment report in an easy to read format.

OPG regularly and proactively provides information to the public on its facility activities. For operational status changes or unscheduled operations that may cause public concern or media interest, OPG follows a protocol to provide prompt notification of key community stakeholders. OPG maintains a duty on-call position 24 hours a day, seven days a week.

In conjunction with the Durham Emergency Management Organization, OPG notifies key community stakeholders of activities or events that may be of interest to the public or media. This is to ensure that the emergency agencies (fire, police, and emergency management) and political offices are aware of events so they can respond accurately if they receive questions from constituents.

### *Background and Educational Information*

OPG provides background and educational information on many aspects of nuclear power in forms that are accessible to the public, including brochures and factsheets. The website also serves as a means of interaction with members of the public and stakeholder groups, through contact links. OPG provides a quick response to issues and questions raised by stakeholders and the public, and tracks these to become aware of interests, concerns and other emerging issues on which it may want to engage.

Pickering NGS maintains an Information Centre where members of the public and school visitors can receive information on current operations and issues, and have questions addressed by an OPG staff member. Students are offered curriculum-based educational presentations and are free to review the material in the centre.

OPG hosts annual information sessions for the local and regional communities, which are widely advertised in the community and in nearby Toronto. Staff from OPG, the Canadian Nuclear Safety Commission (CNSC), the Region of Durham, the City of Toronto Emergency Management Office, and the Office of the Fire Marshal and Emergency Management have been present to answer questions and provide information about safety and station operations. As well, Pickering Nuclear provides presentations and tours to community groups, key stakeholders, industry partners and the general public.

Ads on station activities and community events are also run in newspapers and aired on local television stations. 120,000 copies of Pickering Neighbours newsletter are distributed quarterly to all residents and businesses in the City of Pickering, Town of Ajax and Toronto East.

### *Community Consultation and Environmental Activities*

Pickering Nuclear works with the local communities on matters of interest and concern related to the nuclear station, as well as on the local environment.

The Pickering Community Advisory Council (CAC) meets monthly to exchange information and provide advice to senior plant management on issues of environmental, economic and public concern. Media attends and reports on the meetings.

Pickering Nuclear has a representative on the Durham Nuclear Health Committee (DNHC) and OPG Nuclear staff makes regular presentations to the DNHC on a variety of environmental, community outreach and operational issues.

They also discuss matters of interest with committee members and observers.

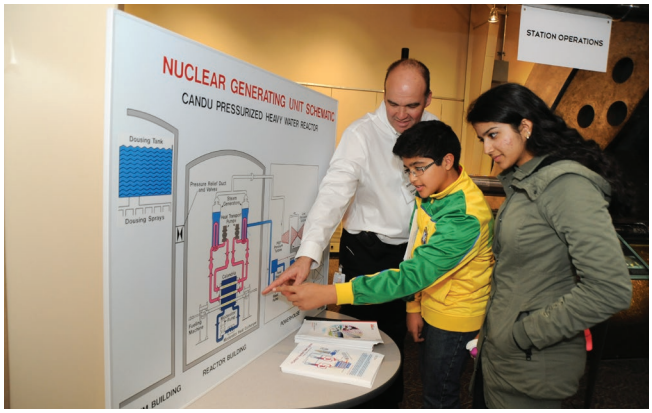



**Figure 20** - Open house and public awareness

In order to learn concerns and interests of members of the community and broader public, Pickering conducts focus groups; for example, focus groups were held in support of direct mail campaigns for emergency preparedness, and in relation to emergency exercises. The Public Information Centre is open every weekday and members of the public are welcome to drop in and talk to staff about nuclear energy and the safe operation of the Pickering station.

Pickering Nuclear also engages in more general community outreach activities as a way of becoming involved in the community in which it operates, and in which many of its staff live. OPG encourages community groups to use the Information Centre for events unrelated to the industry. Its meeting room and event space were built to help build greater ties to the community.

Since 2006, Pickering Nuclear's Corporate Relations and Communications division has provided a community-based program known as "Tuesdays on the Trail", reaching over 16,000 community members on Tuesdays throughout the summer months of July and August at Alex Robertson Park, which is adjacent to the Pickering Nuclear site. Information about station operations and public waterfront trails is distributed to new residents in the Pickering and Ajax community via the Welcome Wagon.

**Figure 21 -** Tree Planting near the Pickering site

Finally, OPG recently held external stakeholder engagement sessions with over 30 external groups including municipalities, community groups, and environmental groups. These included full-day and half-day sessions to increase awareness of Pickering relicensing efforts and to provide a forum to discuss key topics of public interest (for example, Periodic Safety Review, Emergency Preparedness, and Environment).

## 2.5.2 Engagement with Indigenous Communities

OPG acknowledges the Aboriginal and Treaty Rights of Indigenous communities as recognized in the Constitution Act, 1982. Under its Indigenous Relations Policy, OPG regularly undertakes engagement with Indigenous communities with asserted or established Aboriginal and Treaty Rights and/or interests in the vicinity of Pickering NGS. These communities include:

- Members of the Williams Treaties First Nations, including
    - Scugog First Nation
    - Hiawatha First Nation
    - Curve Lake First Nation
    - Alderville First Nation
- Mississaugas of the New Credit First Nation
- Mohawks of the Bay of Quinte
- Métis Nation of Ontario, Region 8

OPG holds regular meetings with these Indigenous communities to provide them with details of nuclear operations and reports, and to discuss interests and identify concerns over current and future operations. OPG also maintains a listing on a designated external website of all relevant documents and notices of events such as the Pickering NGS licence renewal, and notifies the communities of updates on the site when they occur.

Beginning in 2015, OPG began a renewed series of conversations on the ways in which Indigenous communities near Pickering NGS wish to be engaged. Topics of interest included the information that should be provided and discussed; the frequency of meetings; and the support needed to enable communities to understand potential impacts of station operations or concerns. The scope of the engagement was discussed and agreed upon, consultation protocols were reviewed, representatives were identified, and work objectives were outlined.

**Figure 22** - OPG staff on tour with First Nations community

As a part of OPG's overall engagement with the Indigenous community as a whole, tours have been undertaken by Indigenous communities that have rights or interests in current and planned OPG Nuclear and related operations. There were two tours for Indigenous communities in 2016 of the Pickering Waste Management Facility, with twenty-two participants. There was also a tour for Williams Treaties First Nations representatives on January 19, 2017.

At their request, OPG held community information sessions with the Williams Treaties Curve Lake and Hiawatha First Nations in August 2016. The sessions covered a number of issues, including the Pickering Waste Management Facility (PWMF) and Pickering site licensing processes.

OPG also met with representatives of the Williams Treaties First Nations, Mississaugas of New Credit, Mohawks of the Bay of Quinte and the Métis Nation of Ontario Region 8 between January and March 2017 regarding OPG's mitigation and off-set measures for fish impingement and entrainment. Further engagement on this topic and others, with an emphasis on Pickering re-licensing, was undertaken between September 2017 and February 2018.

Additionally, OPG participated in the second annual Aboriginal Apprenticeship Board of Ontario (AABO) Day in the Trades event, hosted by LiUNA Local 183 at their facility in Cobourg. Representatives from various building trades, suppliers and contractors interacted with Indigenous high school students from the communities as diverse as the Mohawks of the Bay Quinte, Curve Lake First Nation, Pikwakanagan First Nation and Durham Region Métis.

The OPG Native Circle, made up of Indigenous employees, organizes and hosts the annual National Aboriginal Day celebrations every June and oversees the John Wesley Beaver Memorial Awards for Indigenous post-secondary students. The Native Circle serves, in part, as a connection to the wider Indigenous community and participates in various Indigenous events such as the annual Indspire career fair, of which OPG is a sponsor.

Indigenous community representatives have expressed a number of concerns about operations and activities at the Pickering plant. These are described below, along with planned discussions with OPG on the issue.

- Transportation and storage of nuclear waste: OPG continues to provide information to communities, and additional information sessions are being planned on OPG's Transportation Emergency Response Plan.
- Emergency preparedness and the ability for community members to be notified: OPG has provided information on notification protocols by OPG and appropriate authorities.
- Environment and fish impact as a result of operations: OPG has made many presentations on work it has completed to reduce fish impingement and entrainment at the Pickering station.
- Potential outcomes of an event that could impact traditional First Nation and Métis territories: recognizing the close relationship these communities have with the land, OPG continues to provide information on the risks of station operations, on the lessons learned from the Fukushima event in Japan and the actions that have been applied as a result.
- A desire to remain involved in future environmental monitoring opportunities: OPG commits to ongoing, participatory engagement with communities, and to their involvement in actions that result from them. OPG will also appropriately confirm the environmental impacts of operations at Pickering.

- An expressed interest in economic opportunities through procurement and employment through OPG's nuclear operations: as part of its Silver designation from the Canadian Council for Aboriginal Business' Progressive Aboriginal Relations (PAR) program, OPG is working to improve its business procurement and employee recruitment with local Indigenous communities.

## 2.6 Continued Investments will Further Improve Pickering Safety, Reliability and Fitness for Service until 2024

Continued investment at Pickering addresses many different systems and programs including the Safety and Control Areas of the Management System (Licence Application Section 2.1), Human Performance Management (Licence Application Section 2.2), Environmental Protection (Licence Application Section 2.9), and the Security and Safeguards and Non-Proliferation SCAs (Licence Application Sections 2.12 and 2.13).

As noted above in Sections 1 and 2.1, OPG has implemented a number of safety improvements to which it committed as a follow-up to the previous Pickering licence renewal in 2013.

During that licence renewal process, OPG indicated that it would continue to invest in the Pickering plant to improve safety and reliability through to the end of commercial operation. At that time, in addition to the regulatory work to ensure safe operation of the fuel channels, OPG committed to including $200M in the business plan, for reliability improvements (Reference 9). Over the course of four years from 2011 - 2014, OPG completed reliability improvements to equipment, material condition improvements to the plant, and additional inspection and maintenance activities to confirm fitness for service of major components in the life extension period. Additionally, 2000 reliability and material condition improvements were completed, including 129 pumps, 106 motors, and 688 valves. Completion of this maintenance helps to ensure that the station will operate reliably to deliver important, low-cost virtually carbon free power until the end of commercial operation.

As part of the current Licence Application process, OPG continues to commit to ongoing investments in the Pickering plant as required and reasonable to further mitigate the already low plant risk and to add reliability enhancements. For example, investments of $307 M are planned from 2017 to 2020 for additional equipment inspections, the implementation of the PSR2 modifications (eg., Pickering 1,4 fire water supply to the steam generators, heat transport system, and the interconnection of Pickering 1,4 and 5-8 fire water systems) and equipment reliability upgrades.

Investments to improve environmental protection include the completion of a dyke associated with the emergency coolant injection system to reduce the risk of oil spills, and the installation of improved sewage sump pumps with an additional switch to prevent overflows. Mitigation measures to minimize fish impingement through the use of the fish diversion system will continue, as will verification of its effectiveness. OPG has committed to fisheries productivity offsetting measures, with the construction of a habitat creation project in the Simcoe Point Wetland and the ongoing salmon stocking program.

Nuclear security will also be maintained, with initiatives to enhance the Security Monitoring Room by 2019 in order to improve response capability.

There will also be continued investments in nuclear safety emergency preparedness drills and exercises.

In accordance with the emphasis on the safety and reliability of the Pickering plant through the licence period, OPG will continue to commit resources and invest in plant operations and improvements. Innovation will continue to be encouraged and supported through the operating period. Employees in the X-Lab have recently developed innovative technologies for application in equipment maintenance and repair, battery monitoring and maintenance, and training programs. These innovations will improve safety, effectiveness and efficiency in many areas of station operations.

Sufficient qualified staff required to operate the station and to maintain safety at the plant will be retained through to the end of commercial operation. This includes the maintenance of certification training and examination resources, and training programs that are provided regularly to all workers.

# 3. Safety and Control Areas

The 14 Safety and Control Areas (SCAs) are a set of technical areas that the CNSC uses to assess, evaluate, review, verify and report on regulatory requirements and performance. The performance of Pickering NGS in meeting the requirements of each SCA is discussed in detail in the Licence Application (Reference 1). A summary is provided in this document.

OPG also provided supplementary information in support of the Licence Application in response to CNSC staff requests for additional information (Reference 2). It was noted in that submission that the Licence Application, together with the supplementary document, contains the information to demonstrate that Pickering NGS meets all of the legal requirements of the NSCA and the associated regulations, and demonstrates that OPG is qualified to carry on the licensed activities and makes adequate provisions to protect the health, safety and security of persons, and the environment and maintain international obligations.

The following provides a brief description of the SCAs, highlights strengths and noteworthy achievements in these areas, and updates information contained in the Licence Application to reflect 2017 results. The updated information is provided under Licence Application heading titles and numbers. These SCA Sections should be read in conjunction with the full information provided in the Licence Application.

## 3.1 Management System

The OPG Nuclear Management System provides a framework that establishes the processes and programs required to ensure OPG achieves its safety objectives, continuously monitors its performance against these objectives, and fosters a healthy safety culture. Monitoring of OPG's performance takes place at several levels, including at the industry level where experts from various utilities worldwide perform a peer review of their nuclear stations. Internally, OPG has a well-established corrective action program, incorporating self-assessments, benchmarking, and independent audits through its Nuclear Oversight Division.

These elements of the management system, including the organizational structure which supports it, are discussed in further detail in Section 2.1 of the Licence Application.

Pickering's management system meets or exceeds all regulatory requirements and related objectives: it is mature and effective, enabling OPG to monitor and manage performance against performance and other safety objectives, and to maintain a healthy safety culture.

### Highlights

OPG's Management System ensures high performance...

- ✓ Strong safety culture is fostered and periodically evaluated
- ✓ Effective internal and external oversight
- ✓ Centre-led organization for efficiency and accountability

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section number and heading are reproduced below, followed by the updated information.

*Licence Application Section 2.1.11 – Business Planning*

*Major Projects*

OPG document, OPG-PROG-0039, Project Management replaces document N-PROG-AS-0007, Project Management.

## 3.2 Human Performance Management

Human performance management includes the activities that enable effective performance of staff, through the development and implementation of processes that ensure a sufficient number of licensed personnel in all relevant job areas with the necessary knowledge, skills, procedures and tools to carry out their duties. Additional information on Human Performance Management can be found in Section 2.2 of the Licence Application.

The Human Performance Management Program is intended to ensure safe and reliable station operation, and minimize and reduce the frequency and severity of events of consequence. The strategy involves the use of systematic approaches to reducing human error, and methods to achieve zero events of consequence.

## Highlights

OPG's human performance programs ensure...

- ✓ Consequential events resulting from human error are prevented
- ✓ Training provides staff with required knowledge and skills
- ✓ Industry demographic challenges are addressed through knowledge management and retention strategies

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section number and heading are reproduced below followed by the updated information.

### *Licence Application Section 2.2.1 - Human Performance Management Program*

As seen in the Figure 23, in 2016, Pickering had 1 Site Event Free Day Reset (SEFDR) event against a target of 2. The 2017 SEFDR target remained at 2, but after a strong first half of the year 5 SEFDRs occurred in a three-month span (Aug - Oct 2017). Notwithstanding the recent spike in these events, the overall reduction in SEFDR over the past licensing period speaks to the improvements implemented under the human performance strategic plan and the ability of the Station Leadership Team to recognize weaknesses and address them.

**Site Event Free Day Resets (SEFDR)**

The SEFDR value is the number of human performance errors that result in events with significant consequences within a given period; it is an industry-wide measure of the effectiveness of organizational safety and other human performance programs.

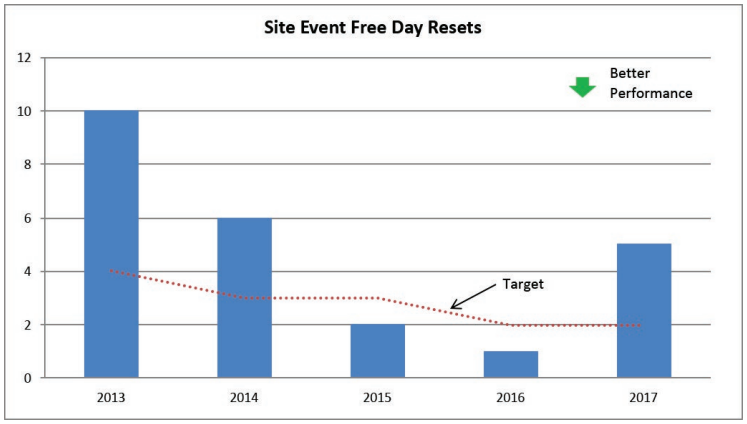



**Figure 23** - Pickering Site Event Free Day Resets

### *Planned Improvements*

As a result of the 2017 performance trend Pickering initiated a station wide stand down to highlight the significance of these events to staff, and increased Human Performance communications involving a "back to basics" campaign.

In addition, focus groups are used to identify opportunities for improvement and lessons are shared within the broader station team.

### *Licence Application Section - 2.2.2 Personnel Training*

### *Operations Training*

At the end of 2017, there were 384 qualified operators at Pickering including 64 supervising nuclear operators and 20 field shift operating supervisors. There are 72 operators in the initial training program, and all qualified operators participate in the continuing training program

### *Licence Application Section - 2.2.7 Applicable OPG Documents*

Effective August 2017, procedure N-PROC-OP-0047, Limits of Hours of Work replaced the previous procedure, N-PROC-HR-0002, Limits of Hours of Work.

## 3.3 Operating Performance

The Operating Performance SCA includes an overall review of the conduct of the licensed activities and the activities that enable effective operating performance. Pickering's Operations Program ensures that plant operation is safe and secure, and gives appropriate and adequate attention to health, safety, security, radiation protection and environmental protection. More information on the Operating Performance SCA is available in Section 2.3 of the Licence Application.

Operations leadership establishes safe, uniform and efficient operating practices and processes at Pickering NGS to enable nuclear professionals to operate the facility in accordance with the Licence, Operating Policies and Principles, and applicable regulations and requirements. It does this through a series of standards and procedures for safe reactor operation.

Plant Operational Focus, defined as organizational behaviours that are necessary for highly safe and reliable operation, is used at Pickering to ensure that Operations leaders are providing appropriate oversight of work management processes. This ensures the risks to plant operation due to equipment deficiencies are appropriately addressed.

### Highlights

Pickering has improved operating performance...

- ✓ Committed to continuous improvement
- ✓ Supervisors and managers reinforce high standards
- ✓ Reliable operation resulting in low forced loss rate

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section number and heading are reproduced below followed by the updated information.

*Licence Application Section - 2.3.2 Plant Status Control*

One measure of plant status control is a misposition, which refers to a component being off its baseline position without documented approval; a component is operated incorrectly; or the incorrect component is operated. Mispositions are reviewed to learn the organizational or individual reasons behind the event and to identify actions to prevent similar events in the future.

Misposition events are categorized as Level 1, Level 2 or Level 3 events, with Level 1 being the most significant. Pickering has experienced a significant reduction in Level 1 and Level 2 mispositions over the last five years.

Figure 5 in Section 2.3.2 of the Licence Application shows Pickering performance regarding misposition events for 2013 to 2016. For 2017 Pickering has achieved the following performance: 0 Level 1 events; 2 Level 2 events; and 32 Level 3 events.

## 3.4 Safety Analysis

OPG maintains and routinely updates the safety analysis that supports the overall safety case for Pickering NGS. This safety analysis consists of a systematic evaluation of the potential hazards associated with the operation of Pickering NGS, and considers the effectiveness of preventative measures and strategies in reducing the effects of these hazards. Deterministic safety analysis demonstrates compliance with CNSC public dose limits for internal and external design basis events, such as piping failures and seismic events. Probabilistic safety assessment is a comprehensive set of models of plant systems and operator actions in response to postulated abnormal events. This analysis demonstrates that the public risk from Pickering NGS remains low. More information on the Safety Analysis SCA is available in Section 2.4 of the Licence Application.

## Highlights

OPG has demonstrated that Pickering is a safe plant...

- ✓ Comprehensive safety analysis demonstrates likelihood of a serious accident remains very low
- ✓ PSA concludes low and continued reduction in public risk
- ✓ Emergency Mitigating Equipment significantly reduces risk

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section number and heading are reproduced below followed by the updated information.

### *Licence Application Section - 2.4.2 Deterministic Safety Analysis*

The deterministic safety analysis is being updated in compliance with a new REGDOC-2.4.1, Deterministic Safety Analysis approved during the last licence period, by including an appendix for common cause events (CCE) analysis in the Pickering Safety Reports. The two new Safety Report appendices for CCE analysis were completed and submitted to the CNSC in December 2017 (Reference 10) to address the single largest enhancement required for REGDOC-2.4.1. OPG's REGDOC-2.4.1 Implementation Plan was also updated to cover the period of 2018 - 2021 to focus on aspects for which safety margins can be improved. OPG has considered the Darlington experience during implementation of REGDOC-2.4.1 when determining the potential analysis upgrades for Pickering, as reflected in the revised REGDOC-2.4.1 Implementation Plan submitted to the CNSC in November 2017 (Reference 11).

### *Licence Application Section - 2.4.5 Probabilistic Safety Assessment (PSA)*

### *Probabilistic Safety Assessment*

In the PSA framework, risk is characterized in terms of the frequency of two event categories: "severe core damage" and "large release."

Severe core damage refers to a category of events whereby failure of both fuel and fuel channels can occur. Large release refers to a category of events that can lead to a significant radiological release to the environment. Large release requires severe core damage with coincident failure of containment.

"Safety Goals" refer to a set of numerical values, expressed in terms of the frequency of severe core damage or large release events, against which the safety of nuclear reactors can be judged. These goals represent the high standards of safety and reliability for nuclear power plant operations and are summarized below in Table 2.

| OPG Safety Goals | | |
|---|---|---|
| | Administrative Safety Goal | Safety Goal |
| Severe Core Damage Frequency (per hazard, per unit) | $10^{-5}$ | $10^{-4}$ |
| Large Release Frequency (per hazard, per unit) | $10^{-6}$ | $10^{-5}$ |

**Table 2** - OPG Safety Goals Expressed as a Frequency

Both the Pickering A (Units 1 and 4) Risk Assessment (PARA) and Pickering B (Units 5 to 8) Risk Assessment (PBRA) are performed in accordance with CNSC Standard S-294, Probabilistic Safety Assessment (PSA) for Nuclear Power Plants. The S-294 compliant PBRA was first completed in 2012 and the S-294 compliant PARA was first completed in early 2014.

The Pickering B PSA was updated and submitted in 2017. The updated 2017 PBRA addresses Level 1 and Level 2 PSA aspects for various internal and external events, for both at-power and outage operating conditions, including internal events, internal fire, internal flood, seismic, high winds, as well as an external and internal hazard screening assessment.

The PBRA reports submitted to CNSC staff in 2017 demonstrate that Pickering B satisfies safety goals for all internal and external hazards, and hence represents very low public risk.

The 2018 PARA update is currently in progress. The previously submitted PSA results satisfied OPG's safety goals and it is expected that the 2018 PARA will also satisfy OPG's safety goals for all internal and external hazards considered.

OPG continues to meet industry best practices through periodic updates to account for operating experience and changes at the station.

### *Summary of 2017 PBRA Update*

The baseline 2017 PBRA update incorporates enhancements under the OPG Fukushima Action Plan, in particular Phase 1 emergency mitigating equipment (EME). The impact of Phase 2 EME has also been considered as a sensitivity case as Phase 2 modifications have been recently implemented.

The severe core damage frequency (SCDF) and large release frequency (LRF) values shown below are within the safety goals for each of the internal and external hazards considered in the 2017 PBRA update. The benefits of EME are incorporated into the baseline 2017 PBRA results for SCDF and LRF as shown in Tables 3 and 4, respectively.

### *Summary of 2018 PARA Update*

The baseline 2018 PARA update will incorporate enhancements under the OPG Fukushima Action Plan, in particular Phase 1 emergency mitigating equipment (EME). The impact of Phase 2 EME will also be considered in a sensitivity cases as Phase 2 modifications are implemented.

The SCDF and LRF values shown below are within OPG's safety goal for each of the internal and external hazards. Since the 2018 PARA is in the process of being updated, the values summarized in the tables below are the most current baseline results available for PARA.

| Severe Core Damage Frequency (x $10^{-5}$ per reactor-yr) | | |
|---|---|---|
| **PSA Hazards** | **2017 PBRA Baseline (with EME)** | **Current PARA Baseline (with EME)[1]** |
| Internal Events at Power | 0.10 | 0.88 |
| Internal Events during Outage | 0.06 | 0.66 |
| Fire at Power | 0.06 | 1.5 |
| Flood at Power | 0.02 | 0.56 |
| Seismic Event at Power | 0.10 | 0.18 |
| High Winds at Power | 0.12 | 0.30 |
| Safety Goal | 10 | 10 |

**Table 3** - Severe Core Damage

| Large Release Frequency (x $10^{-5}$ per reactor-yr) | | |
|---|---|---|
| **PSA Hazards** | **2017 PBRA Baseline (with EME)** | **Current PARA Baseline (with EME)[1]** |
| Internal Events at Power | 0.08 | 0.17 |
| Internal Events during Outage | Approx. 0 | 0.01 |
| Fire at Power | 0.04 | 0.23 |
| Flood at Power | 0.01 | 0.09 |
| Seismic Event at Power | 0.10 | 0.04 |
| High Winds at Power | 0.10 | 0.07 |
| Safety Goal | 1 | 1 |

**Table 4** - Large Release Frequency

**Footnote** [1] The current PARA baseline results are taken from the later of 2013 S-294 PSAs or the 2014 Fukushima Action Plan updated PSAs. The exception is Level 1 Internal Events At-Power, which has been updated for 2018, and the Internal Fire for At-Power results, which are from the Pickering risk improvement action plan assessments.

*Whole-Site Risk*

Standard current PSAs, and safety goals, are based on a single reactor unit. However, at Pickering's 2013 licence hearing, views were expressed that the risks should be assessed and reported for incidents involving more than one unit at a station, (i.e., providing one risk number for all units on the site). Such a risk estimate is referred to as "whole-site" risk estimate.

OPG has recently completed a whole-site risk assessment for Pickering, fulfilling a commitment to the CNSC to conduct such an assessment by the end of 2017. The conclusions of this assessment provide further support to the assurance that the risk of the whole Pickering site is low. Further details are provided in Section 2.1.2 of this document and in Addendum C.

*Licence Application Section - Appendix F – CANDU Safety Issues*

A safety issue is defined as an issue related to the design or analysis of a nuclear power plant that has the potential to challenge safety functions, safety barriers or both.

An initial list of issues was developed by the CNSC using the IAEA TECDOC-1554 "Generic Safety Issues for Nuclear Power Plants with Pressurized Heavy Water Reactors and Measures for their Resolution", and each issue was classified by the CNSC in 2007 into one of three categories:

- Category 1: Not an issue in Canada.
- Category 2: The issue is a concern in Canada. However, the licensees have appropriate control measures in place to address the issue and to maintain safety margins.
- Category 3: The issue is a concern in Canada. Measures are in place to maintain safety margins, but further experiments and/or analysis are required to improve knowledge and understanding of the issue, and to confirm the adequacy of the measures.

The CNSC confirmed that the safety case for CANDU reactors was not in question but identified control measures for these categories to address any residual concerns on nuclear safety.

At present, Pickering has four Category 3 issues pending CNSC re-categorization. One issue is on Non-Large Break Loss of Coolant Accident (LBLOCA) and three issues are related to LBLOCA.

OPG continues to work with the CNSC to address the outstanding CANDU safety issues to improve knowledge and understanding of the issue and confirm the adequacy of the measures in place to maintain safety margins.

## 3.5 Physical Design

The Physical Design SCA includes activities that impact the ability of structures, systems and components to meet and maintain their design basis, given new information arising over time, and taking changes in the external environment into account. OPG has a program to maintain the design basis that assures that the structures, systems and components at Pickering remain available, reliable, effective and consistent with design, analysis and quality control measures. Additional information on this SCA is available in Section 2.5 of the Licence Application.

There are no significant recent changes in plant design to update since the Licence Application, however Addendum A on the PSR outlines changes to be made in plant design during the upcoming licence period.

**Highlights**

Pickering's design proven to be solid...

- ✓ Defence in depth approach
- ✓ Rigorous process for plant modifications

## 3.6 Fitness for Service

OPG has several programs in place to ensure systems, structures, and components credited in licensing documents are fit for service and continue to satisfy their design intent over time in accordance with applicable CNSC regulatory documents and CSA standards. These programs ensure all equipment is available to perform its intended design function when called upon to do so.

Routine on-power maintenance activities are performed on a daily basis, while other more complex tasks or inaccessible equipment require a unit shutdown, or 'outage' to perform required repairs or inspections. Various programs address long-term equipment reliability, including component surveillance, work management, and aging management programs. Major components such as fuel channels, feeders, and steam generators have specific life cycle management plans to address aging issues and code requirements, which are communicated to CNSC staff on a routine basis. The various elements of the overall OPG fitness for service program are discussed in further detail in Section 2.6 of the Licence Application.

## Highlights

Fitness for service of major components is confirmed...

- ✓ Equipment is well maintained to ensure performance requirements are met throughout life of plant
- ✓ Fuel channels are fit for service to end of station life
- ✓ Periodic inspections confirm major components remain fit for service

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section and heading are reproduced below followed by the updated information.

*Licence Application Section - 2.6.1 Equipment Reliability*

The Equipment Reliability Index (ERI) is an industry standard indicator used to reflect overall station equipment reliability, and assess the health of a plant reliability program.

Pickering's ERI score for the fourth quarter of 2017 was 78 against a target of 81. This represents a 4-point increase from the 2017 third quarter performance. Efforts to reduce the corrective maintenance backlog on key components to zero, and improvements to the preventive maintenance program through station initiatives like value based maintenance, have helped Pickering improve ERI performance over the licence period as shown in Figure 24 below.

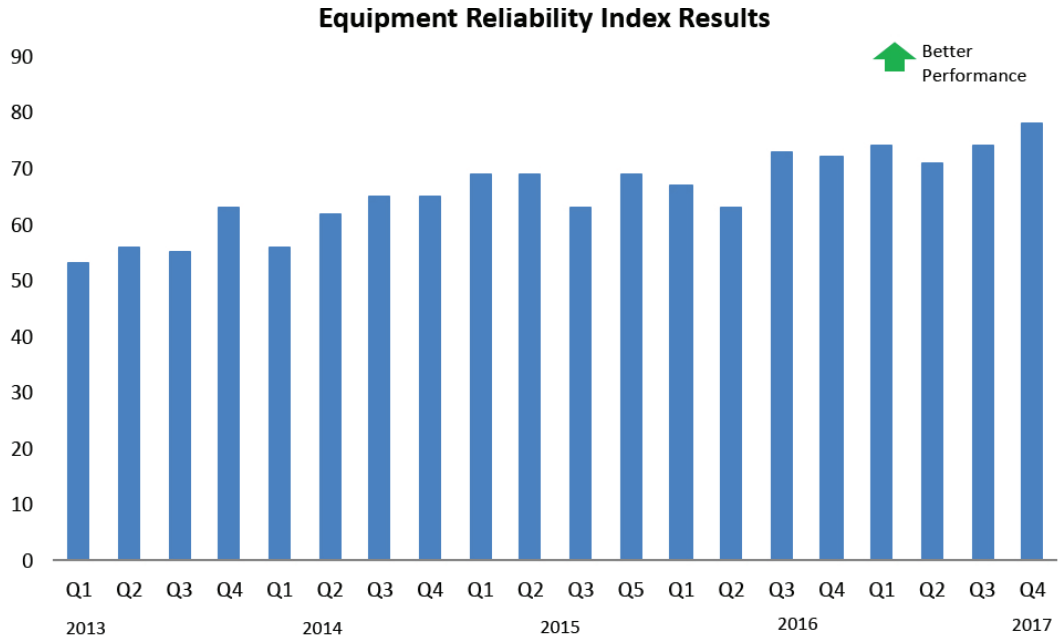



**Figure 24** – Pickering Equipment Reliability Index 2013 - 2017

An improved ERI score is also reflected in an improvement (reduction) in forced loss rate (FLR), a measure of the amount of unplanned production losses in a period of time. Three straight years of strong performance (2015 to 2017) for Pickering NGS (with 2015 the best in the history of the plant) demonstrates how much the investments made can and will enable strong performance to the end of life.

### *Licence Application Section - 2.6.6 Chemistry Control*

The Chemistry Performance Index (CPI) compares the concentration of selected impurities and corrosion products to corresponding limiting values, with focus on the steam generator demineralized water system chemistry.

As shown in the Figure 25 below, the trend shows improving performance. This is a reflection of combined efforts to improve the demineralized water treatment plant performance, as well as to improve start-up chemistry and outage practices, and to eliminate lake water getting into the steam generator demineralized water system via the steam condensers.

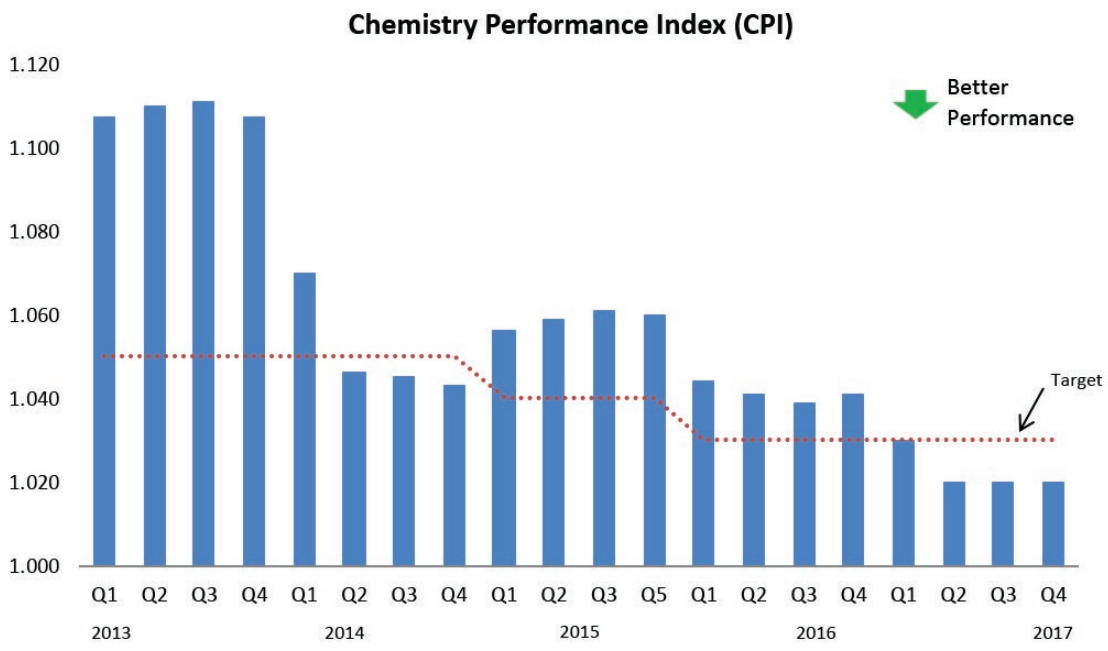



**Figure 25**

### *Licence Application Section - 2.6.8 Fuel Handling Reliability*

Pickering NGS Fuel Handling developed a reliability plan in 2012/2013 focused on specific equipment areas. From 2014 onwards, annual self-assessments have been performed to analyze the overall effectiveness of the plan. This plan has been modified over the years to best reflect the station's needs.

The unplanned loss of production due to fuel handling equipment being unavailable is a primary indicator of fuel handling equipment reliability. The forced loss rate related to fuel handling equipment in 2016 was 1.54%, and 2.32% in 2017. This is historically good performance for OPG's fuel handling equipment that shows OPG can improve plant reliability to the end of planned operation.

*Licence Application Section - 2.6.9 Maintenance Backlog*

It is a priority to ensure that the backlog for Corrective Critical (CC) and Corrective Non-Critical (CN) maintenance tasks remains low, so that important preventive maintenance programs can be conducted and system redundancy maintained.

Figure 8 in Section 2.6.9 of the Licence Application shows Pickering performance regarding backlogs for 2013 to 2016. The Corrective Critical and Corrective Non-Critical work orders per unit at the end of 2017 is 24.5 against a target of 28 (i.e., better than target).

## 3.7 Radiation Protection

The over-riding objective of the Radiation Protection Program at Pickering is the control of occupational and public exposure to radiation. For the purposes of controlling doses to workers, this program has four implementing objectives:

- Keeping individual doses below regulatory limits
- Preventing unplanned exposures
- Keeping individual risk from lifetime radiation exposure to an acceptable level
- Keeping collective doses As Low As Reasonably Achievable (ALARA), social and economic factors taken into account

The various elements of the Radiation Protection Program are discussed in detail in Section 2.7 of the Licence Application.

OPG's Radiation Protection Program ensures...

- ✓ Pickering's radiation safety performance among industry best
- ✓ Employee radiation dose always kept well below regulatory limits

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section and heading are reproduced below followed by the updated information.

*Licence Application Section - 2.7.2 Application of ALARA*

ALARA – keeping risks As Low As Reasonably Achievable, taking social and economic factors into account – is a risk control strategy that is applied in the nuclear industry and other industrial settings. It focuses on reducing risks as low as practicably possible, even when regulatory limits have already been achieved.

The Pickering ALARA strategy includes the setting of annual targets for collective doses – the aggregated doses received by all workers and staff, as well as contractors and visitors - from all work at Pickering, and the identification of actions and programs for the achievement of these targets. Annual targets take into account planned maintenance outage scope, past performance, and anticipated dose savings from planned initiatives and application of ALARA techniques. As work is planned in more detail, collective dose projections are reviewed and actions taken to ensure dose is ALARA. Actual performance against targets is reviewed and corrective actions taken where expectations are not met. Figure 26 below shows a summary of results over the current licence term.

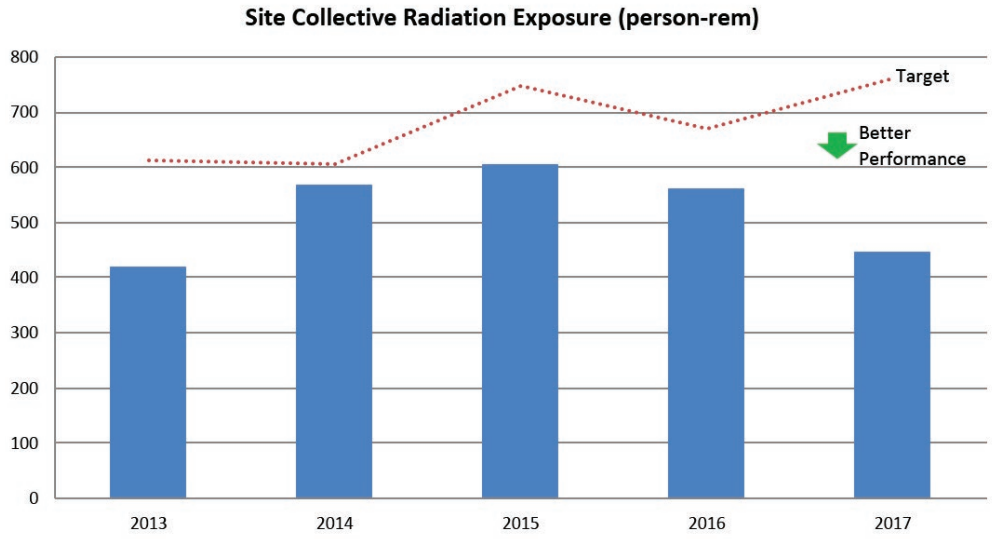



**Figure 26** – site collective radiation exposure Note that 100 rem is equivalent to 1 Sv.

## *Licence Application Section - 2.7.3 Worker Dose Control*

Since 2013, there has been continued strong performance in the performance indicators related to worker dose control such as the number of Electronic Personal Dosimeter (EPD) dose alarms (alerting a worker to a higher than expected radiation exposure in a task) and unplanned tritium uptakes (so-called "precursor events) (see Figure 27 and Figure 28 below). These indicators are a measure of how effectively low- level events are used to identify and correct behaviours, or improve radiation work plans, thus preventing more significant events from occurring.

This excellent performance is attributed to improved personal and organizational accountability, careful planning of tritium exposure, and focus on consistently knowing the radiation level a worker is working in and taking all appropriate precautions.

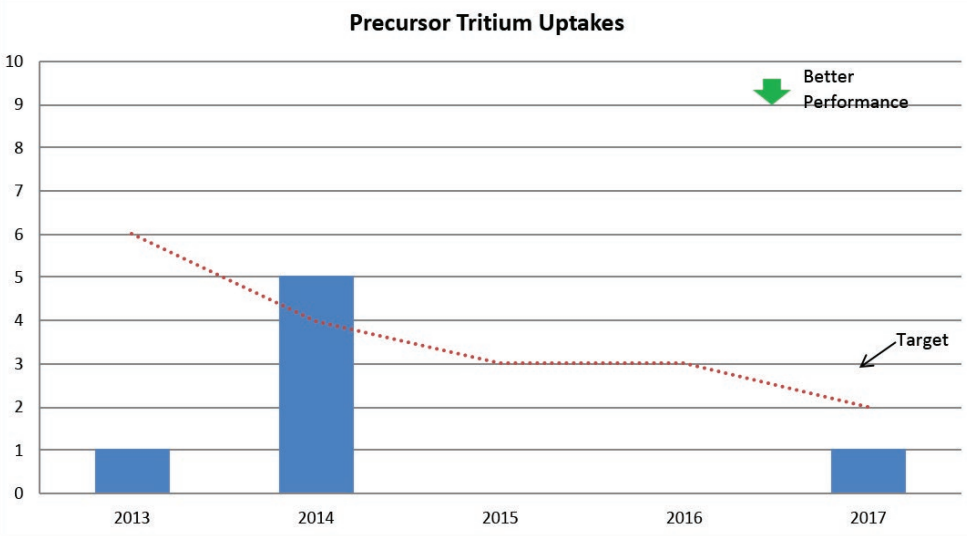



**Figure 27** – Precursor Tritium Uptakes

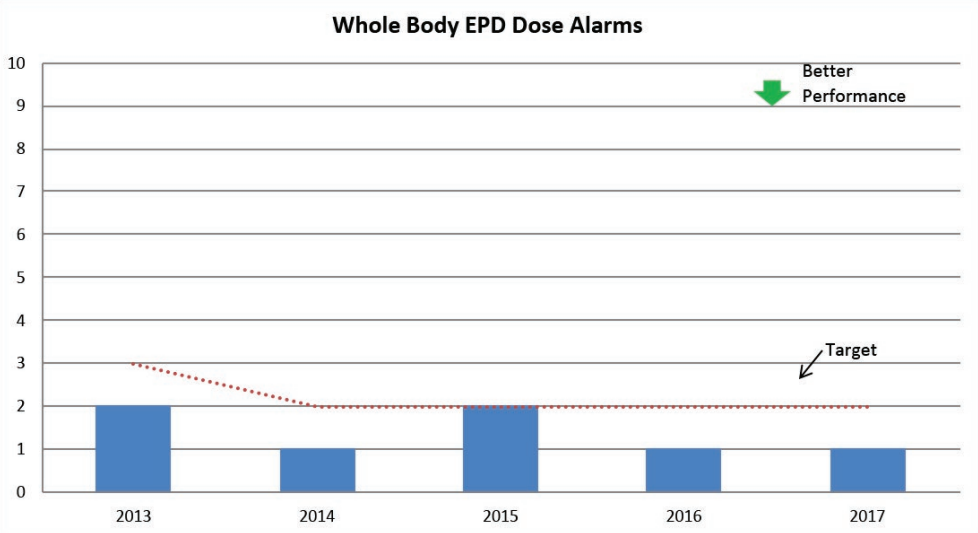



**Figure 28** – Number of Whole Body EPD Dose Alarms 2013- 2017

## 3.8 Conventional Health and Safety

The Conventional Health and Safety SCA involves the implementation of a program to protect personnel and manage work- place non-radiation hazards. Detailed information is provided on this subject in Section 2.8 of the Licence Application.

Pickering had very strong safety performance through the current licence period. In 2014 Pickering reached 11 million person-hours without a lost time accident, with an All Injury Rate of 0.22, the best performance achieved by the station to that point. OPG received the Canadian Electricity Association's President's Gold Award of Excellence for Employee Safety in 2016, in recognition of the company-wide All Injury Rate and Accident Severity Rate performance for the years 2013 to 2015.

### Highlights

OPG recognized as a leader in promoting worker health and safety...

- ✓ All Injury Rate of 0.06 in 2017 best ever in Pickering's history
- ✓ Total Health program promotes health and well-being for all employees
- ✓ Numerous awards and recognition from external associations

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section and heading are reproduced below followed by the updated information.

*Licence Application Section - 2.8.1 Conventional Health and Safety program*

As shown in Figure 29, all injury rate , the 2017 All Injury Rate for Pickering was 0.06 which is better than the 0.22 target. This is the best ever safety performance in this metric at Pickering.

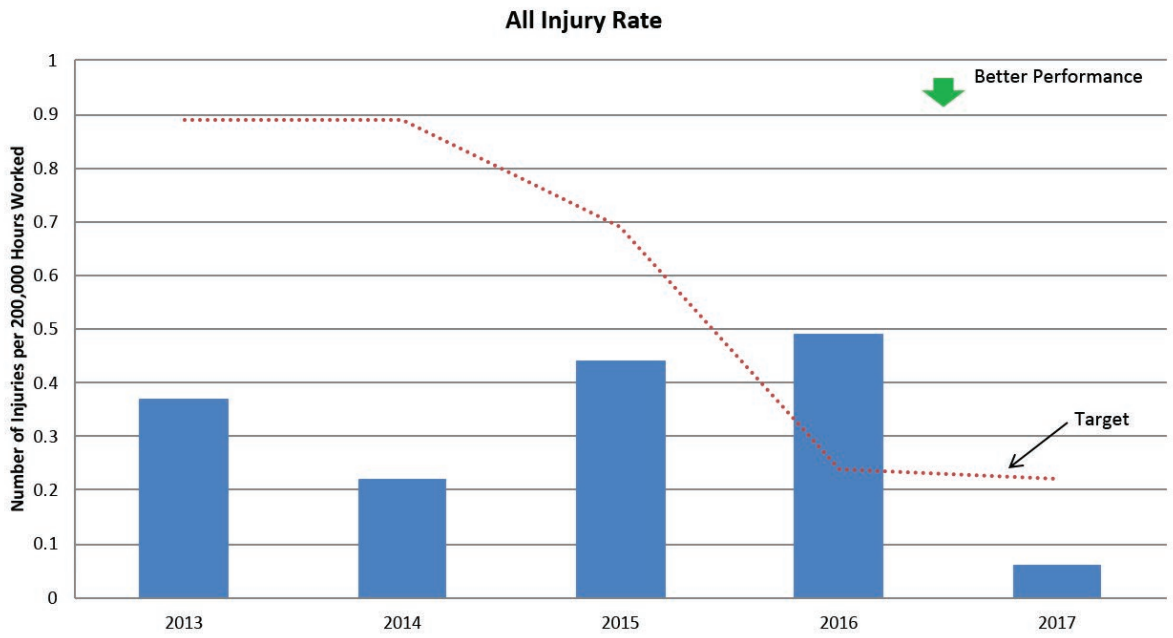



**Figure 29** - Pickering NGS All Injury Rate 2013-2017

## 3.9 Environmental Protection

The Environmental Protection SCA includes the programs that identify, control and monitor all releases of radioactive and conventional hazardous substances and effects on the environment as the result of licensed activities. Pickering NGS has an effective environmental protection program that meets or exceeds all applicable regulatory requirements and related objectives. All reasonable precautions are taken to ensure that adequate provisions for the protection of the environment are maintained. OPG ensures that impacts of plant operation on the public, workers, and the environment will continue to be of low risk and adequately mitigated. Additional and more detailed information on the activities conducted to protect human health and the environment can be found in Section 2.9 of the Licence Application.

### Highlights

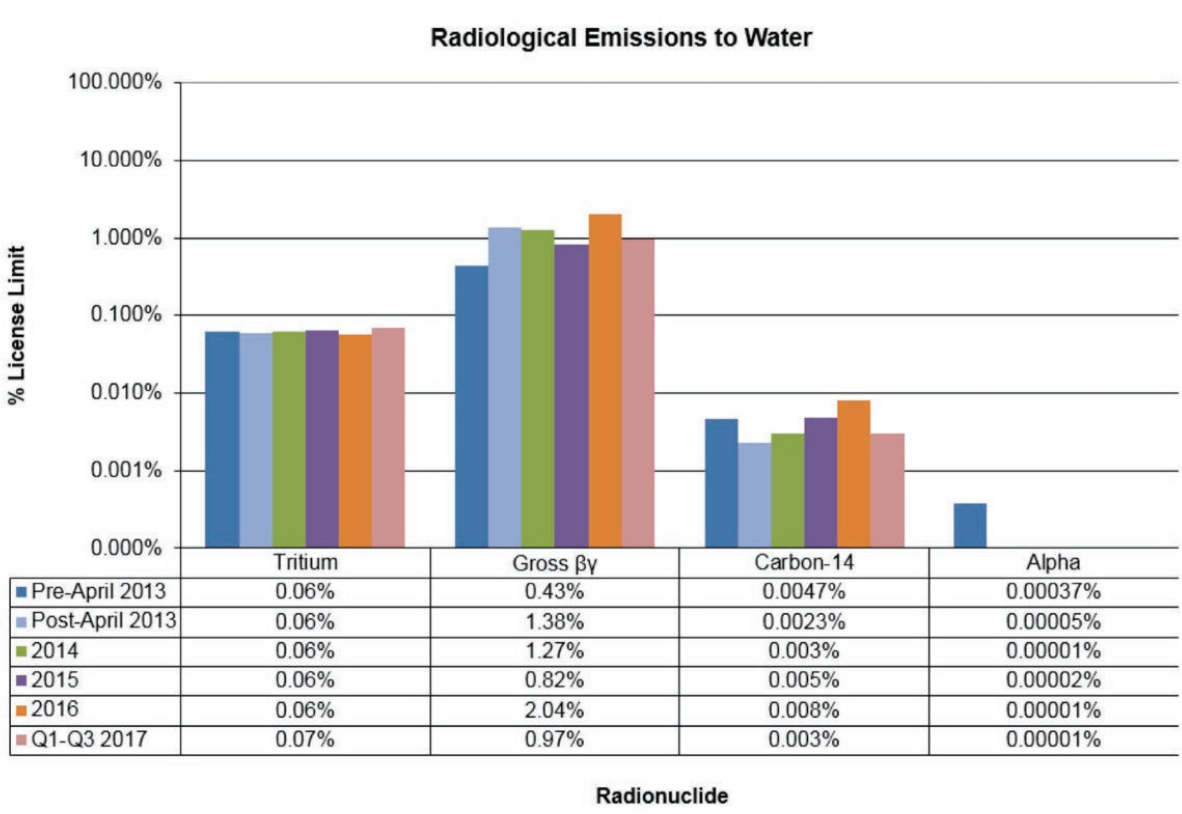
- ✓ OPG understands the importance of environmental stewardship...
- ✓ Internal performance targets are more stringent than regulatory requirements
- ✓ Public dose remains a tiny fraction of the regulatory limit
- ✓ Environmental releases are monitored, and results made available to the public
- ✓ Programs to support wildlife diversity and habitat

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section and heading are reproduced below followed by the updated information.

*Licence Application Section - 2.9.3 Protecting the Public Radiological Emissions to Water*

During the current licence period, there were no derived release limit (DRL) or action level exceedances for tritium, beta/gamma, carbon-14 or alpha emissions to water on an annual basis. See Figure 30 for a historical summary. The DRL's were updated in 2013 which changed the historical values; therefore data are included as a percentage of the DRL before and after the revision.

The DRL is the amount of radiation which if released for an entire year could result in the most exposed member of the public receiving a dose at the legal limit.




| | Tritium | Gross βγ | Carbon-14 | Alpha |
|---|---|---|---|---|
| Pre-April 2013 | 0.06% | 0.43% | 0.0047% | 0.00037% |
| Post-April 2013 | 0.06% | 1.38% | 0.0023% | 0.00005% |
| 2014 | 0.06% | 1.27% | 0.003% | 0.00001% |
| 2015 | 0.06% | 0.82% | 0.005% | 0.00002% |
| 2016 | 0.06% | 2.04% | 0.008% | 0.00001% |
| Q1-Q3 2017 | 0.07% | 0.97% | 0.003% | 0.00001% |

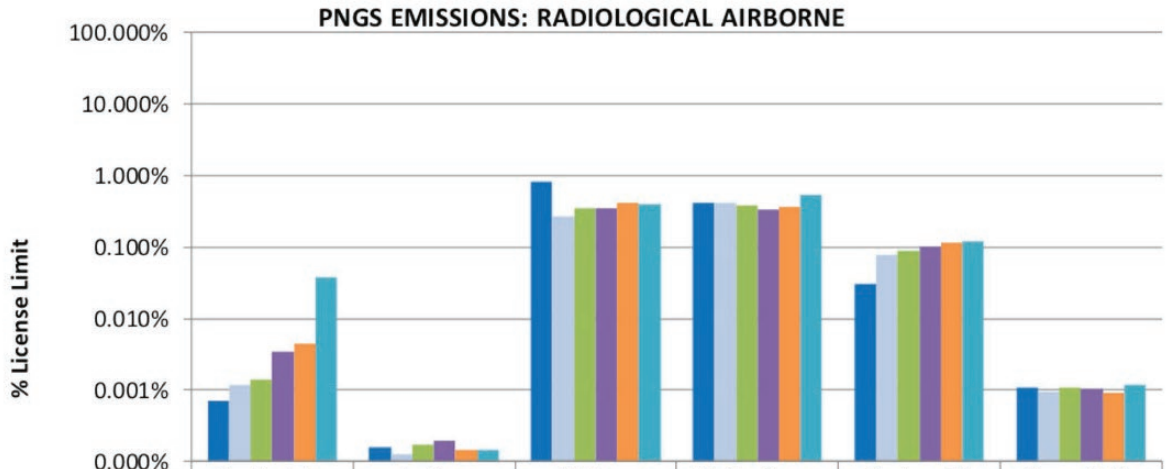
**Figure 30** - Radiological Emissions to Water

### *Radiological Emissions to Air*

During the current licensing period, Pickering Nuclear has not exceeded the derived release limit (DRL) or the action level for any radiological emission to air on an annual basis. Details of the emissions can be found in Figure 31 Radiological Airborne Emissions; as shown, all emissions have been well below the licence limit.

Tritium emission values can be attributed primarily to leaks and spills inside the reactor building as well as reactor building ventilation dryer performance issues. A tritium airborne reduction team is currently in place to progress airborne tritium reduction strategies throughout 2018. Prioritizing leak repairs and improvements to dryer reliability are key focus items of the airborne high impact team.

An increase in airborne particulate emissions in 2017 was due primarily to two isolated events where maintenance was performed on the Chemistry lab ventilation ductwork. Dust and particulate were dislodged during maintenance of fan/ducting system, which caused spikes in the levels of particulate releases. Emissions returned to normal levels following the maintenance events.




| | Particulate | Iodine | Tritium | Noble Gases | Carbon-14 | Gross Alpha |
|---|---|---|---|---|---|---|
| Pre-April 2013 | 0.0007% | 0.00016% | 0.82% | 0.42% | 0.03% | 0.0011% |
| Post-April 2013 | 0.0012% | 0.00013% | 0.27% | 0.41% | 0.08% | 0.0010% |
| 2014 | 0.0014% | 0.00017% | 0.35% | 0.39% | 0.09% | 0.0011% |
| 2015 | 0.0034% | 0.00019% | 0.35% | 0.34% | 0.10% | 0.0010% |
| 2016 | 0.0045% | 0.00015% | 0.43% | 0.37% | 0.11% | 0.0009% |
| Q1-Q3 2017 | 0.0379% | 0.00015% | 0.40% | 0.54% | 0.12% | 0.0012% |

***Note:** License Limit adjusted in April 2013. Data may appear positiviely skewed prior to License Limit adjustment.

**Figure 31** - Radiological Airborne Emissions

### *Groundwater Monitoring Program*

The Pickering Nuclear groundwater monitoring program was established to confirm the predominant on-site groundwater flow characteristics of the site. Monitoring is designed to detect changes to on-site groundwater quality to ensure timely detection of releases. The overall objective of the program is to ensure no adverse off-site impacts from groundwater.

In the last year, the cleaning and/or replacement of the RB foundation drainage sumps non-return valves and pumps have been completed. This will improve the groundwater quality in the vicinity of the Unit 5 to 8 reactor buildings.

In this licence period low levels of tritium in groundwater were observed at the Pickering Units 5-8 irradiated fuel bay area. OPG initiated a project to repair the Pickering Units 5-8 irradiated fuel bay liner and its collection sumps, to reduce the potential for the bay water to negatively impact site groundwater quality. The collection sumps have now been repaired. The liner repair tooling has been fabricated, tested and Phase I of the repair is complete. Phase II (additional scope) is planned to start in April 2018. Surveillance will continue to track the movement of tritium in groundwater in this area.

The release of contaminated groundwater from the site is through monitored release paths. This monitoring confirms that the level of tritium in the discharge is well below regulatory limits and thus has no adverse environmental impact.

### *Licence Application Section - 2.9.4 Spill Management Program*

The following spill mitigation initiatives have been completed driven by OPG's adherence to continuous improvement:

- The Units 1, 2 sewage sump pumps have been replaced with more robust grinder style pumps for improved availability. An additional level switch was also installed to prevent sump overflows. (Completed December 2017).
- Replaced all 4 sodium bisulphite solution storage tanks with one double walled stainless steel tank on Pickering 058. (Completed November 2016)
- All of the Pickering 058 seal oil drain lines to the local water tundish have been cut and capped in order to remove any flow path from the seal oil heat exchangers to the environment. (Completed December 2014)
- Installation of underflow weir system to the existing spill containment surrounding the main output transformers located on all 4 units of Pickering Units 058. (Completed December 2016).
- Upgraded spill containment in the new water treatment plant chemical addition area. (Completed April 2014)

### *Planned Improvements*

A project has been established to design and construct a new overflow tank with inclusive secondary containment associated with the emergency coolant injection system, to reduce the risk of spills to the environment. This project is in the planning stages with design option development targeted for December 2018.

### *Licence Application Section - 2.9.6 Regulatory Compliance*

Pickering operates under numerous environmental regulations governing plant operations. The primary regulators from an environmental perspective are the CNSC and the Ontario Ministry of Environment and Climate Change (MOECC).

During the period 2013 to 2017 there were no major infractions of environmental regulations that resulted in Significant Environmental Events.

Pickering Nuclear had a total of 25 other infractions over the period of 2013 – 2017 (approximately 5 year period), decreasing to 1 infraction in 2016 and 2 infractions in 2017.

*Licence Application Section - 2.9.12 Fisheries Act Authorization*

Pickering submitted an application for authorization from the Department of Fisheries and Oceans under Section 35 (2)(b) of the Fisheries Act.

OPG has obtained the authorization from the Department of Fisheries and Oceans.

## 3.10 Emergency Management and Fire Protection

The Emergency Management and Fire Protection SCA covers emergency plans and emergency preparedness programs for emergencies and for non-routine conditions. Emergency preparedness measures and fire protection response capabilities are in place at Pickering NGS to prevent and mitigate the effects of nuclear and hazardous substances releases, both onsite and offsite, and fire hazards in order to protect workers, the public and the environment. Detailed information on this SCA can be found in Section 2.10 of the Licence Application.

### Highlights

Expect the unexpected, and be prepared for it...

- ✓ OPG has robust emergency preparedness plans integrated with the Province / Municipality/ international partners
- ✓ "Exercise Unified Control" demonstrated readiness on a large scale
- ✓ Distribution of KI pills completed
- ✓ State of the art fire training facility

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section and heading are reproduced below followed by the updated information.

*Licence Application Section - 2.10.1 Fire Protection and Conventional Emergency Preparedness and Response*

OPG is partnering in the Durham Regional NextGen public safety radio system and is installing new radio system infrastructure at the site. This will allow seamless integration and interoperable communications with City of Pickering Fire Service responders using their own radios in the plant. Phase I of the installation is complete, providing coverage throughout the Pickering powerhouse structure. Phase II will provide enhanced site wide coverage and link the site to the regional system. Installation of Phase II is partially complete with remaining installation and commissioning scheduled to be completed by the spring of 2018.

*Licence Application Section - 2.10.2 Nuclear Emergency Preparedness Program*

An update regarding the multi-agency interoperability exercise 'Exercise Unified Control' that was held on December 6-7, 2017 and the Provincial Emergency Response Plan (PNERP) is provided in Section 2.

As discussed in Section 2.1.4 of this document, OPG completed Exercise Unified Control in December, 2017. This was a two-day exercise involving more than 1000 participants in over 30 municipal, provincial and federal agencies, in a severe accident scenario at Pickering which simulated a significant off- site release.

It also included participation of international partners in the nuclear community (eg. The World Association of Nuclear Operators). A number of new initiatives were used successfully, including new dose assessment software to project radiological effects to inform the Province's protective action decision-making, and the calculation of public doses by Health Canada with computer codes using real time weather data. Operational and public communications improvements were also demonstrated, including enhanced interoperability for OPG Emergency Response Team and Pickering Fire Services, with the new P25 radio system, and the use of social media in public communications.

## 3.11 Waste Management

The Waste Management SCA covers internal waste-related programs that form part of the facility's operations, up to the point where the waste is removed from the facility to a separate waste management facility. This area also covers the planning for decommissioning. Pickering's waste management program includes processes and procedures for the specific handling of different waste streams.

It is audited in order to control and minimize the volume of nuclear waste that is generated by the facility. More detail on the waste management program and processes can be found in Section 2.11 of the Licence Application.

Pickering continually strives to improve on safely managing and reducing the amount of Low- and Intermediate-Level Waste (L&ILW) produced, to reduce both the amount and the types of materials that enter the radiation waste stream, and to ultimately reduce the station's environmental footprint now and in the future. Focus is placed on:

- Minimizing the amount of waste generated by making a plan on how to minimize and manage the waste for each job during pre-job briefs.
- Proper segregation of waste at the point of generation into the three waste categories: incinerable, compactable, and non-processible, prior to shipping to the Western Waste Management Facility (WWMF) beside the Bruce Nuclear Power Plant for processing:
    - Incinerable waste is further reduced by as much as 95% through the incineration process.
    - Compactable waste is also volume reduced by as much as 75%.
    - Non-processible waste cannot be incinerated or compacted and needs to be stored. Pickering sets business planning targets to drive down the generation of non-processible waste.

Emphasis in these activities is placed on performing them safely and at the lowest possible dose to workers and the public.

### Highlights

OPG has a well established Nuclear Waste program...

- ✓ Committed to safely managing nuclear waste in a responsible manner
- ✓ Committed to ensuring future generations are not unduly burdened with managing today's waste
- ✓ Investing to ensure costs of future decommissioning are fully covered

## 3.12 Security

The Security SCA covers the programs that are required to implement and support the security requirements stipulated in the Regulations, and the Licence.

The Nuclear Security Program ensures the safe and secure operation of the station, maximizing protection against threats to security through the use of equipment, personnel and procedures.

The Pickering NGS Security Program is intended to prevent the loss, theft or sabotage of nuclear material and the sabotage of the nuclear facility. More detailed information on the Nuclear Security Program can be found in Section 2.12 of the Licence Application.

### Highlights

OPG ensures the Pickering site is safe and secure by...

- ✓ A highly trained security staff that includes both armed and unarmed nuclear security officers
- ✓ Extensive and integrated security drills and training
- ✓ State-of-the-art security equipment deployed throughout the site
- ✓ Cyber security program that protects computer systems and software programs

The following updates information contained in the Licence Application to reflect 2017 results. The Licence Application Section and heading are reproduced below followed by the updated information.

*Licence Application Section - 2.12.1 Nuclear Security Program*

OPG documents the specific regulatory security requirements for the security program in OPG report, 8690-REP-61400-10003, Pickering Site Security Report. This security protected report has been updated in 2017.

*Licence Application Section - 2.12.2 Drills and Exercises*

As noted above, under Section 3.10, OPG is partnering in the Durham Regional NextGen public safety radio system and is installing new radio system infrastructure at the site. This will allow seamless integration and interoperable communications with Pickering Fire Service responders using their own radios in the plant. Phase I of the installation is complete providing coverage throughout the Pickering powerhouse structure. Phase II will provide enhanced site wide coverage and link the site to the regional system. Installation of Phase II is partially complete with remaining installation and commissioning scheduled to be completed by spring, 2018.

## 3.13 Safeguards and Non-Proliferation

The Safeguards and Non-Proliferation SCA includes the programs and activities that are required for the successful implementation of the obligations arising from the Canada / International Atomic Energy Agency (IAEA) safeguards agreements, as well as all other measures arising from the Treaty on the Non-Proliferation of Nuclear Weapons. OPG's safeguards and non-proliferation program enables Pickering to meet Canada's international obligations under the IAEA agreements, and other measures that arise from the Treaty. Additional detail on these measures can be found in Section 2.13 of the Licence Application.

Pickering has met all safeguards conditions in its operating Licence, and staff have cooperated with the IAEA and facilitated the achievement of IAEA safeguards goals.

### Highlights

OPG meets its international safeguards obligations...

- ✓ Maintain accounting of fuel at all times
- ✓ Timely support of IAEA inspections
- ✓ Facilitate upgrades to IAEA equipment on site

## 3.14 Packaging and Transport

The Packaging and Transport SCA is concerned with programs that cover the safe packaging and transport of nuclear substances to and from the licensed facility. The packaging and transport of radioactive substances are controlled through regulations, specifically the Packaging and Transport of Nuclear Substances and the Transport of Dangerous Goods Regulations. The Radioactive Material Transportation Program is owned by OPG's Nuclear Waste Management Division.

The objective of the Radioactive Material Transportation Program is to ensure that shipments of radioactive material are performed safely and in accordance with the regulations.

Details on the packaging and transport of radioactive substances can be found in Section 2.14 of the Licence Application.

### Highlights

OPG's radioactive material transportation program ensures...

- ✓ Safe transport of nuclear materials for over 40 years
- ✓ CNSC and Transport Canada requirements are met
- ✓ Drills conducted routinely to validate transportation emergency response plans

# 4. Other Matters of Regulatory Interest

## 4.1 Program for Cobalt-60

In addition to electric power, Pickering NGS also produces cobalt-60, a radioisotope that has a range of beneficial industrial, medical and food processing applications.

The cobalt-60 that is harvested from the reactor units is shipped to off-site users in accordance with Transport of Dangerous Goods Regulations, and the Packaging and Transport of Nuclear Substances Regulations. Pickering does not receive cobalt-60 from off-site commercial facilities.

## 4.2 Financial Guarantee

Canadian Nuclear Power Plant operators are required to establish and maintain a financial guarantee to assure that sufficient funds are collected and administered for the management of all liabilities associated with the operating and decommissioning of all their nuclear facilities, both owned and leased. OPG's financial guarantee makes specific provisions for the decommissioning of the Pickering NGS. It also covers financial provisions for the long-term management of all operational and decommissioning waste, including both storage and eventual disposal of used fuel wastes and low-level and intermediate-level radioactive wastes.

OPG prepares its financial guarantee on a five-year cycle, as required by CNSC regulations, and also provides an annual guarantee report to the CNSC that details the status of the guarantee and compares the amount of the liabilities and financial resources available to discharge the obligations. The financial guarantee provisions for Pickering demonstrate that the current level of funding is sufficient for decommissioning the station and returning the site to an end state that has been agreed with the regulators.

The 2018-2022 financial guarantee is based on OPG's 2016 cost estimates for decommissioning and operational waste management; it was submitted to the Ontario Finance Authority, and approved in December 2016, and to the CNSC in the spring of 2017 and approved in December 2017.

OPG will continue to provide annual financial guarantee reports to the CNSC, detailing the status of the guarantee including the amounts accumulated in segregated funds.

## 4.3 Nuclear Liability

Under the Nuclear Liability and Compensation Act, OPG is required to maintain $650 million in nuclear liability insurance for the Pickering NGS in 2017. The liability limit increases to $750M, $850M, and $1B in 2018, 2019 and 2020, respectively; OPG will purchase insurance in accordance with legal requirements. Nuclear property insurers conduct inspections at Pickering every 18 months, with conventional insurers who inspect the non-nuclear side of the station.

The current Certificate of Insurance for Nuclear Liability Insurance can be found in Appendix B of the Licence Application.

## 4.4 Cost Recovery

OPG pays the CNSC fees every quarter, as specified in the Canadian Nuclear Safety Commission Cost Recovery Fees Regulation.

# 5. References

[1] Letter, R. Lockwood to M. Leblanc, "Application for Renewal of Pickering Nuclear Generating Station Power Reactor Operating Licence", August 28, 2017, P-CORR-00531-05055.

[2] Letter, R. Lockwood to M. Leblanc, "Supplementary Information to the Application for Renewal of the Pickering Nuclear Generating Station Power Reactor Operating Licence", December 11, 2017, P-CORR-00531-05223.

[3] Fisheries and Oceans Canada, Paragraph 35(2)(b) Fisheries Act Authorization for Pickering Nuclear Generating Facility, January 17, 2018, PATH No.: 16-HCAA-00256.

[4] Letter, P. Pasquet to T.E. Schaubel, "Pickering B: Submission of the Pickering B Continued Operations Plan – CNSC Action Item 2010-8-05", September 29, 2010, NK30-CORR-00531-05693.

[5] Letter, R. Lockwood to A. Viktorov, "Pickering NGS – Risk Improvement Plan Update", February 26, 2018, P-CORR-00531-05278.

[6] Letter, B. McGee to A. Viktorov, "Pickering NGS Stabilization Activity Plan (SAP) – 2016 Annual Update", December 2, 2016, P-CORR-00531-04880.

[7] Letter, S. Granville to K. Glenn, A. Viktorov and M. Santini, "Submission of Preliminary Decommissioning Plans", January 30, 2017, N-CORR-00531-18384.

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[15] CNSC letter, A. Viktorov to R. Lockwood, "Pickering NGS: CNSC Staff Acceptance of Pickering NGS Periodic Safety Review 2 (PSR2) Integrated Implementation Plan (IIP) Revision 1", March 2, 2018, CD# P-CORR-00531-05333.

# Addendum A
# Pickering Periodic Safety Review (PSR2)

**Pickering PSR2**

- ✓ Completed in accordance with CNSC REGDOC 2.3.3, and IAEA SSG-25
- ✓ Comprehensive assessments completed by external companies over several years
- ✓ Purpose was to determine reasonable, practicable safety enhancements that could further enhance safety
- ✓ Supports continued safe operation of Pickering NGS to the end of 2024

OPG has completed a Periodic Safety Review for the Pickering station in accordance with CNSC Regulatory Document 2.3.3, *Periodic Safety Reviews,* and International Atomic Energy Agency's (IAEA) Safety Standards Series, Specific Safety Guide No. SSG-25, *Periodic Safety Review for Nuclear Power Plants*.

The purpose of a PSR is to determine reasonable and practicable safety enhancements that could further enhance safety at the associated nuclear facility.

The safety of Pickering NGS is regularly and thoroughly assessed, verified and assured through several processes that are part of the current licensing framework. OPG also applies routine comprehensive safety assessment and improvement programs that deal with specific safety issues, significant events and changes in standards and operating practices as they arise. These programs allow assessment of safety and plant operation to be improved on a continuous basis that can be correlated to all of the PSR Safety Factor review areas. They include programs that ensure safe operations, effective configuration management, equipment reliability, life cycle management, aging management, periodic inspection and maintenance. Programs are also in place in the area of organizational management and safety culture that focus on safety-related behaviours and accountability.

Pickering's PSR, referred to as PSR2 as it builds on earlier safety assessments, confirms that the design, operation and safety-significant structures, systems and components support continued safe operation of the Pickering units to the end of 2024. The earlier assessments collectively referred to as Pickering PSR1 were:

1. **The Pickering B Integrated Safety Review (ISR)**, completed in 2009 and performed in support of the proposed refurbishment and continued operation (at that time planned for an additional 30 years) of Pickering NGS Units 5-8.
2. **Pickering NGS 1,4 integrated safety assessments** performed during the Pickering A Return to Service (PARTS) work (circa 2000), in support of approval to restart Units 1 and 4. Outstanding actions from the ISR were subsequently documented in a Continued Operations Plan (COP) for which annual updates have been submitted to the CNSC.
3. **Darlington ISR:** The relevant programmatic aspects of the Darlington ISR completed in 2013 in support of refurbishment and continued operation of the Darlington units (programmatic parts are applicable to Pickering where programs and practices are common for the OPG fleet).

CNSC REGDOC-2.3.3 and IAEA SSG-25 identify that subsequent PSRs should focus on changes in requirements, facility conditions, operating experience and new information, rather than repeating activities conducted in previous safety reviews. As such it is forward looking, focusing on: changes to requirements since the last applicable assessment, confirmation that the condition of Pickering NGS supports the additional years of commercial operation, and new operating experience since the last assessments.

## Pickering PSR2 Overview

The PSR2 review period was to the end of 2028 to correspond to the requested licence period and to cover those systems and components that would be required to remain in service after the end of commercial operation.

The process that was followed for completing the PSR2 is shown in Figure A.1 and comprised of the following four key elements which are explained in the Sections that follow:

1. PSR2 Basis Document
2. Safety Factor and Complementary Reviews
3. Global Assessment
4. Integrated Implementation Plan

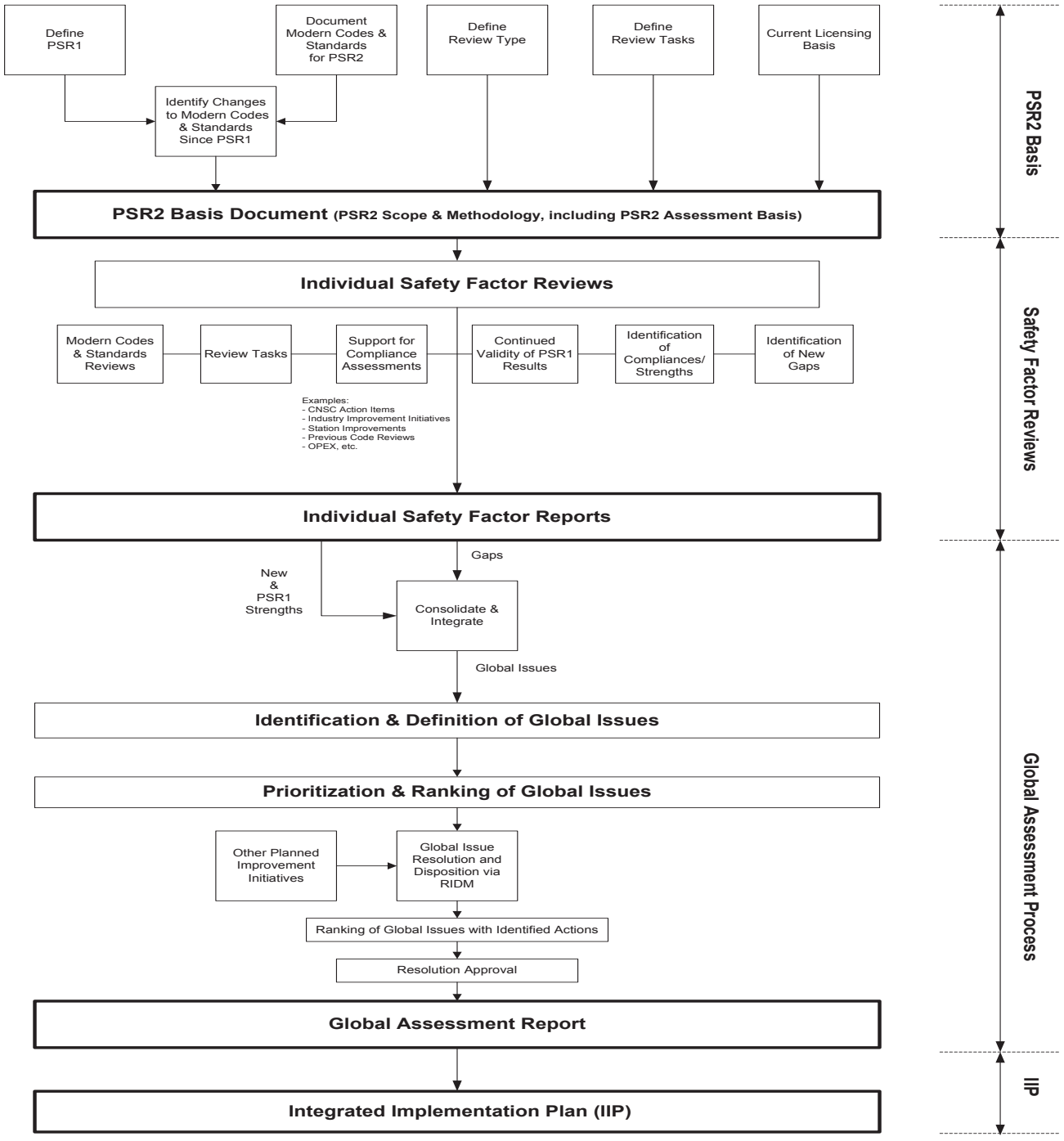


**Figure A.1** - Pickering PSR2 Process Flowchart

## PSR2 Basis Document

**Basis Document**

- ✓ Prepared by OPG
- ✓ Documents how the PSR2 was to be conducted
- ✓ Defined the applicable versions of Laws, Regulations Codes & Standards
- ✓ CNSC staff acceptance received July 2016

The Pickering PSR2 Basis Document, prepared by OPG and accepted by the CNSC in References A.1 and A.2, defined the approach for completing the PSR2:

The PSR2 Basis Document contained the following

- The proposed operating strategy of the facility;
- Scope and methodology, including the conduct of Safety Factor reviews and identification of compliances and gaps;
- The process for categorizing, prioritizing, tracking and resolving gaps arising from the Safety Factor reviews;
- Conduct of the Global Assessment;
- The methodology for preparing the Integrated Implementation Plan;
- Applicable current versions of Laws, Regulations, Codes and Standards;
- The major milestones, including the freeze date for document revisions; and
- The project management and quality management processes.

## Current Laws, Regulations, Codes and Standards Applicable to PSR2

The PSR evaluates the extent to which the plant meets current laws, regulations, codes and standards. The process to identify those documents that are applicable to the PSR2 assessment basis involved first creating a broad list from multiple sources (potential candidate laws, regulations, codes and standards) and then filtering them to identify those that are most significant, and that are applicable to the PSR2 scope.

## Structures, Systems and Components within the Scope of the PSR2 Review

The structures, systems and components (SSC) within the scope of the PSR2 review encompass the systems important to safety (SIS) and the safe operating envelope (SOE) systems (i.e., systems credited with a safety function following postulated accidents).

## Safety Factor and Complementary Reviews

### Safety Factor Reviews

- ✓ 15 Safety Factor, 2 Complementary Reviews completed by AMEC-Foster-Wheeler and Tetra-Tech
- ✓ Associated reports submitted by OPG for CNSC staff review
- ✓ No fundamental safety issues were identified
- ✓ Concludes that OPG has in place effective programs and processes for continued safe operation of the Pickering NGS until 2024.
- ✓ Identified findings used as input to the Global Assessment

In accordance with REGDOC-2.3.3, fifteen Safety Factors Reviews covering the full range of important nuclear safety topics were completed and associated reports submitted for CNSC staff review.

## Safety Factor Reviews

**Safety Factor Review: Plant Design**

**Objective:**
The objective of the Plant Design review was to determine the adequacy of the design of the plant and its documentation by assessment against the current licensing basis and national and international standards, requirements and practices.

**Conclusion:**
This review confirmed, by assessment against the current licensing basis and applicable standards, requirements and practices that the physical design and documentation supports continued safe operation of Pickering NGS.

**Safety Factor: Actual Condition of Structures, Systems and Components Important to Safety**

**Objective:**
The objective of the Actual Condition of Structures, Systems and Components Important to Safety review was to determine the actual condition of SSCs important to safety and to consider whether they are capable and adequate to meet design requirements, throughout the period of PSR2. In addition, the review should verify that the condition of SSCs important to safety is properly documented, as well as reviewing the ongoing maintenance, surveillance and in-service inspection programs, as applicable.

**Conclusion:**
This review concluded that the plant's SSCs are in good condition and support safe extended station operation to 2024, no major concerns have been identified and the SSCs Important to Safety continue to operate as per the design basis requirements.

**Safety Factor Review: Equipment Qualifications (Environmental and Seismic)**

**Objective:**
The objective of the Equipment Qualification review was to confirm that the plant equipment important to safety has been properly qualified (including for environmental conditions) and that this qualification is being maintained through an adequate program of maintenance, inspection and testing that provides confidence in the delivery of safety functions throughout the period of the PSR.

**Conclusions:**
This review confirmed that the Pickering NGS equipment important to safety has been properly environmentally and seismically qualified and that these qualifications are being maintained through maintenance, inspection and testing programs.

**Safety Factor Review: Plant Aging**

**Objective:**
The objective of the Aging Safety review was to determine whether aging aspects affecting systems, structures and components important to safety are being effectively managed and whether an effective aging management program is in place so that all required safety functions will be delivered for the design lifetime of the plant.

**Conclusions:**
This review confirmed that aging aspects affecting systems, structures and components important to safety are being effectively managed and that an effective aging management program is in place.

**Safety Factor Review: Deterministic Safety Analysis**

**Objective:**
The objective of the deterministic safety analysis review was to determine to what extent the existing deterministic safety analysis is complete and remains valid when the following aspects have been taken into account:

- The actual plant design, including all modifications of SSCs since the last update of the safety analysis report or the last PSR;
- Current operating modes and fuel management;
- The actual condition of SSCs important to safety and their predicted state at the end of the period covered by the PSR;
- The use of modern validated computer codes;
- Current deterministic methods;
- Current safety standards and knowledge (including research and development outcomes); and
- The existence and adequacy of safety margins.

**Conclusions:**
This review confirmed that the deterministic safety analysis programs and procedures at OPG are comprehensive, resulting in a systematic and disciplined approach to identifying, prioritizing and addressing any safety analysis related issues.

**Safety Factor Review: Probabilistic Safety Assessment**

**Objective:**
The objective of the Probabilistic Safety Assessment (PSA) review was to determine:

- The extent to which the existing PSA study remains valid as a representative model of the plant;
- Whether the results of the PSA show that the risks are sufficiently low and well balanced for all postulated initiating events and operational states;
- Whether the scope (which should include all operational states and identified internal and external hazards), methodologies and extent (i.e. Level 1, 2 or 3) of the PSA are in accordance with current national and international standards and good practices;
- Whether the existing scope and application of PSA are sufficient.

**Conclusions:**
This review confirmed that the PSA programs and procedures at OPG are comprehensive, resulting in a systematic and disciplined approach to identifying, prioritizing and addressing safety analysis related issues. Pickering has in place a PSA for Pickering Units 1,4 and Units 5-8 that is compliant with CNSC regulatory document S294.

**Safety Factor Review: Hazard Analysis**

**Objective:**
The objective of the Hazard Analysis review was to determine the adequacy of protection of the plant against internal and external hazards, with account taken of the plant design, site characteristics and the actual condition of the systems, structures and components important to safety and their predicted state at the end of the period covered by PSR2, and current analytical methods, safety standards and knowledge.

**Conclusions:**
This review confirmed that Pickering NGS has robust protection against internal and external hazards, taking into account the plant design, site characteristics, and the actual condition of the SSCs important to safety.

**Safety Factor Review: Safety Performance**

**Objective:**
The objective of the Safety Performance review was to determine whether the plant's safety performance indicators and records of operating experience, including the evaluation of root causes of plant events, indicate any need for safety improvements.

**Conclusions:**
This review confirmed that the safety performance indicators and records of operating experience, including the evaluation of root causes of plant events, exist and are utilized.

**Safety Factor Review: Use of Experience from Other Nuclear Power Plants and Research Findings**

**Objective:**
The objective of the Use of Experience from other Nuclear Power Plants and Research Findings review was to determine whether there is adequate feedback of relevant experience from other nuclear power plants and whether research findings are used to introduce reasonable and practicable safety improvements at the plant.

**Conclusions:**
This review confirmed that for Pickering NGS there is adequate feedback of relevant experience from other nuclear power plants and from findings of research, and that this is used to introduce reasonable and practicable safety improvements at the plant or in the operating organization.

**Safety Factor Review: Organization, Management Systems and Safety Culture**

**Objective:**
The objective of the Organization, Management System and Safety Culture review was to determine whether the organization, management system and safety culture are adequate and effective for ensuring the safe operation of the plant.

**Conclusions:**
This review confirmed that the Pickering NGS organization, management system and safety culture are effective.

**Safety Factor Review: Procedures**

**Objective:**
The objective of the Procedures Safety review was to determine whether the operating organization's processes for managing, implementing and adhering to operating and working procedures and for maintaining compliance with operational limits and conditions and regulatory requirements are adequate and effective and ensure plant safety.

**Conclusions:**
This review confirmed that the Pickering NGS processes for managing, implementing and adhering to operating and working procedures and for maintaining compliance with operational limits and conditions and regulatory requirements are adequate and effective and ensure plant safety.

**Safety Factor Review: Human Factors**

**Objective:**
The objective of the Human Factors review was to evaluate the various human factors that may affect the safe operation of the nuclear power plant and to seek to identify improvements that are reasonable and practicable.

**Conclusions:**
This review confirmed that the various human factors that may affect the safe operation of Pickering NGS have been appropriately addressed, and are effective.

**Safety Factor Review: Emergency Planning**

**Objective:**
The objective of the Emergency Planning review was to determine:

a. whether the operating organization has in place adequate plans, staff, facilities and equipment for dealing with emergencies; and

b. whether the operating organization's arrangements have been adequately coordinated with the arrangements of local and national authorities and are regularly exercised.

**Conclusions:**
This review has confirmed that OPG Nuclear has in place adequate plans, staff, facilities and equipment for dealing with emergencies. In addition, arrangements are in place for regular emergency training and exercises, and interaction and coordination with local and national authorities.

**Safety Factor Review: Radiological Impact on the Environment**

**Objective:**
The objective of the Radiological Impact on the Environment review was to determine whether the operating organization has an adequate and effective program for monitoring the radiological impact of the plant on the environment, which ensures that emissions are properly controlled and are As Low As Reasonably Achievable.

**Conclusions:**
This review confirmed that Pickering NGS has in place an effective program for monitoring the radiological impact of the plant on the environment, which ensures that emissions are properly controlled and are As Low As Reasonably Achievable.

**Safety Factor Review: Radiation Protection**

**Objective:**
The objective of the Radiation Protection review was to confirm that Radiation Protection has been adequately accounted for in the design and operation of the reactor facility, that radiation protection provisions (including design and equipment) provide adequate protection of persons from the harmful effects of radiation, and ensure that contamination and radiation exposures and doses to persons are monitored and controlled, and maintained As Low As Reasonably Achievable.

**Conclusions:**
This review has confirmed that radiation protection has been accounted for in the design and operation of Pickering NGS, and that radiation protection provisions (including design and equipment) protect workers from radiation and ensure that contamination and radiation exposures and doses to persons are monitored and controlled and maintained As Low As Reasonably Achievable.

As a subsequent PSR, the PSR2 Safety Factor reviews focused on changes in requirements (Laws, Regulations, Codes and Standards), updated plant conditions, operating experience and information from research, rather than repeating the activities of previous reviews. The methodology for performing the Safety Factor reviews takes full account of the safety assessments and Law, Regulation, Code and Standard compliance work previously completed by OPG.

## Complementary Reviews

In accordance with the PSR2 Basis Document, the following Complementary Reviews were also completed and associated reports submitted for CNSC staff review:

**Complementary Review: Continued Operations Plan (COP) Re-Assessment**

The COP Re-Assessment reviewed the COP actions pertaining to the 2009 Pickering Units 5-8 Integrated Safety Review for implications given the intent to operate through to the end of 2024. In addition, implications for Pickering Units 1, 4 were also reviewed. Twenty-six items were identified for inclusion into the PSR2.

**Complementary Review: Fukushima Action Plan Re-assessment**

Following the event at Fukushima Daiichi nuclear plant, the CNSC issued Fukushima Action Items (FAI) to the Canadian Nuclear Utilities to ensure that the lessons learned from this event were appropriately incorporated into Canadian nuclear operations.

OPG was recognized for its achievements in operational and management excellence in its response to the Fukushima Daiichi event and confirmed that its stations remain safe with systems and procedures in place to deal with Beyond Design Basis Events.

The key lessons learned from the Fukushima event have been incorporated and plant modifications were implemented to further enhance the safety of OPG's nuclear facilities.

As part of PSR2, the FAIs pertaining to Pickering were reassessed to determine if the basis for their closure in 2015 remained valid in the context of extension for commercial operations of the station beyond 2020. The FAI Re-assessment did not identify any findings for PSR2.

All fifteen Safety Factor and two Complementary reviews concluded that there are no fundamental safety issues and that OPG has in place effective programs and processes for continued safe operation of the Pickering NGS through to the end of 2024.

Findings, referred to as "gaps", from these Safety Factor Reviews were input to the Global Assessment process described below.

## Global Assessment

### Global Assessment and Report

- ✓ Conducted by Candesco (a Division of Kinectrics), submitted by OPG for CNSC staff review
- ✓ Results from Safety Factor and Complementary reviews consolidated into Global Issues, prioritized and proposed resolutions developed which were ranked
- ✓ Concludes that the current plant design, operation, processes and management system will ensure continued safe operation of the station both in the short term, and for extended operation.
- ✓ Resulted in 23 Global Issues with 35 Proposed Resolutions.
- ✓ CNSC staff review concluded that the Global Assessment satisfied regulatory requirements of REGDOC-2.3.3 (Reference A. 4).

The objective of the Global Assessment was to provide an overall assessment of the safety of the Pickering station and to arrive at a judgement of the plant's suitability for continued operation.

The Global Assessment took its input from the Safety Factors and Complementary Review findings that covered the plant's design, operation, management, safety analysis, radiological impact on the environment and radiation protection.

The Global Assessment was conducted by an interdisciplinary team with appropriate expertise in operations, design and plant safety, including appropriate participants from the Safety Factor reviews, and members who are independent from the safety factor review teams.

**The Global Assessment Process consists of the following elements:**

1. Identification and consolidation of Strengths and Safety Factor Review findings.
2. Identification of Global Issues and proposed resolutions.
3. Assessment of interfaces between the various Safety Factors, aggregate impact of Global Issues.
4. Prioritization of Global Issues.
5. Development of Resolutions / Dispositions of Global Issues (and gaps).
6. Consideration of defence-in-depth and aggregate impact of residual Global Issue resolutions.
7. Ranking of Global Issues with proposed resolutions.
8. Senior Management Scope Review Board approval of proposed modifications for the purposes of PSR2.
9. Assessment of overall acceptability of operation of the plant over the period considered in PSR2.
10. Preparation of the Global Assessment Report to summarize the assessments, and document the Global Assessment.

## Prioritization of Global Issues

PSR2 global issues were prioritized with respect to their importance to nuclear safety in support of resolution evaluation method and the outcome of the resolution process. This methodology was consistent with OPG prioritization processes used in previous Integrated Safety Reviews and industry practice.

The safety significance level considered deterministic and probabilistic safety analysis impact, as appropriate. The assignment of safety significance values for prioritization was derived based on OPG experience and takes into account the priority values from the OPG guidelines for evaluating and prioritizing Safety Report Issues and the OPG station condition record categorization process. Probability levels selected for delineation between categories are based on significance and engineering judgement, and are as used in previous Integrated Safety Reviews. These values account for overall safety impact and align, where appropriate, with requirements and limits in relevant safety standards. The relationship between safety significance level and impact on nuclear safety is shown in the table A.1.

| Safety Significance Level | Impact on Nuclear Safety |
|---|---|
| 1 | High |
| 2 | Medium |
| 3 | Low |
| 4 | Very Low |

**Table A.1 -** Relationship between Safety Significance Level and Impact on Nuclear Safety

## Development of Resolutions/Dispositions of Global Issues

Proposed Resolution options to address the Global Issues were developed and assessed using risk-informed decision making techniques utilizing the following considerations:

- Evaluation of the Global Issue to understand the safety basis, and intent of the requirement.
- Defence in depth elements and the overall safety significance.
- Consideration of the possible options for resolution/mitigation, safety significance and defence in depth elements.
- Evaluate options with respect to effectiveness, cost, schedule, and practicality. For potential plant modifications, this may require an evaluation of the safety impact, via both deterministic and probabilistic methods. If it is not practicable to fully resolve a Global Issue, other mitigation options will be considered for enhancements.
- Practicality of a proposed resolution was evaluated in terms of cost, resources, schedule in relation to the overall safety impact.
- Items of High or Medium impact on nuclear safety (safety significance levels 1 and 2) required more in-depth analysis to fully understand the issue and potential impact, and to develop the proposed resolution/mitigation. In some cases this required deterministic and/or probabilistic assessments to determine the nuclear safety impact of modifications and more detailed evaluation of the cost/practicality of proposed resolutions.
- Items of Very Low Impact on nuclear safety (safety significance level 4) were generally deemed as “Acceptable Deviations” within the context of PSR2.

- While these very low impact items will not be tracked beyond the Global Assessment, they will be shared with the accountable organizations for consideration as potential enhancement initiatives for their future work program planning purposes. A similar treatment was applied for items of low impact on nuclear safety (safety significance level 3) for which a practicable solution was not readily evident.
- In some cases, the development of resolutions/dispositions to the global issues was part of an OPG or industry initiative already underway or planned. In others, the resolution and development of options may require more detailed analysis and assessment, extending beyond the timelines for submission of PSR2. In these instances, the status of the initiative and plans was included in the disposition. The work was included in the Global Assessment to facilitate continued tracking.

## Consideration of Defence in Depth and Aggregate Impact of Acceptable Deviations

An important element of the development of proposed recommendations was to assess the overall defence in depth and aggregate impact of the low safety significance issues and acceptable deviations. After evaluating a range of resolutions for global issues, and determining a recommended resolution to be selected, the impact on defence in depth, considering both deterministic and probabilistic elements, was evaluated to assess the aggregate impact on overall safety.

## Ranking of Global Issues with Identified Actions

All global issues whose resolution involves identified actions were ranked from 1 through N, where N represented the total number, in accordance with overall safety significance. This was based on expert judgement applied by the assigned Global Assessment team. The ranking process considered factors such as the priority previously determined (safety significance level), the contribution to defence in depth, the significance of the source (e.g., the type of document that generated the gap(s) leading to the global issue). The ranking process also accounted for the extent of impact on multiple safety factors or areas.

## Senior Management Scope Review Board Approval of the Proposed Modifications for the Purposes of the PSR2

OPG Senior Management reviewed the PSR2 Acceptable Deviations and No Further Action statements, confirmed the best available options were recommended, or proposed changes to enhance safety where such improvements are identified.

This review ensured alignment with the Resolution Plans proposed, their basis and context, and provided concurrence that the proposed enhancements are practicable and effective. This process also allows the senior management team to consider potential realignment of priorities based on the insights from PSR2.

## Assessment of Overall Acceptability of Operation of the Plant over the Period Considered in PSR2

As a final step in the assessment process, the team confirmed the overall acceptability of operation of the plant over the period considered in the PSR2. This entailed a review of the results of the Safety Factor and Complementary Reviews, a consideration of enhancements planned (both newly identified in PSR2 and from existing station initiatives) and a consideration of plant performance.

## Global Assessment Report

The Global Assessment results, including a conclusion about overall acceptability of continued commercial operation of Pickering NGS, were documented in a Global Assessment Report P-REP-03680-00032-R001 that was submitted for CNSC staff review in February 2018 (Reference A.3). The CNSC staff review concluded that the GAR satisfied the regulatory requirements of CNSC REGDOC-2.3.3 and reflected the work performed under PSR2 (Reference A.4).

## Integrated Implementation Plan

**Integrated Implementation Plan**

- ✓ IIP Rev. 0 prepared by RCM Technologies, submitted by OPG for CNSC staff acceptance
- ✓ Transformed 35 Proposed Resolutions from the GAR into 63 IIP Actions with corresponding implementation schedule.
- ✓ Represents OPG's commitment for addressing the results of the PSR2
- ✓ Completion of the IIP Actions will further enhance safety
- ✓ CNSC staff review concluded that the Integrated Implementation Plan (IIP) fulfils the regulatory requirements of REGDOC-2.3.3 and is acceptable (Reference A.6).

The Integrated Implementation Plan (IIP) represents the final step in the comprehensive PSR2 process.

The IIP, P-REP-03680-00031-Rev 1, prepared by RCM Technologies, defines Resolution Actions derived from the Resolutions Statements to address the Global Issues identified in the Assessment. The IIP was submitted by OPG for CNSC staff acceptance in November 2017. CNSC review comments have been addressed in a revised IIP that was submitted to the CNSC (Reference A.5) and subsequently accepted (Reference A.6) in March 2018.

## IIP Structure

The IIP has been structured to provide an understanding of the implementation and basis for the plan. Appendices A, B and C of the IIP define the Resolution Actions and supporting IIP Actions with their target completion dates. The IIP Actions include new initiatives derived from the Global Assessment and existing initiatives that were integral to the overall assessment of safety.

## IIP Resolution Actions

Appendix B of the IIP documents the 23 Global Issues (from the Global Assessment) having 35 corresponding Resolution Actions (some Global Issues have more than one Resolution Action). These 35 Resolution Actions, in turn have 63 specific IIP actions to address the Resolution Action. Unique to the Pickering PSR2 IIP is that each of the 35 Resolution Actions has a corresponding specific and measurable Completion and Success Criteria to assist with managing the IIP going forward.

## Completion Criteria

The Completion Criteria define precisely the measurable activities that OPG is required to perform for the Resolution Action to be considered complete. Once completed, OPG will notify the CNSC and request closure of the Resolution Action.

Completion Criteria may include completed and documented analysis, system inspections, or installed modifications.

Resolution Action completion criteria define the measure that the Resolution Action, supported by IIP Actions, has been successfully completed.

## Success Criteria

The Success Criteria define precisely measurable objectives of the IIP Resolution Action that will be used for closure of the IIP Resolution.

## IIP Schedule

The 63 documented IIP Actions have been developed to address the Proposed Resolution Statements for 23 Global Issues identified in the Global Assessment. The 63 IIP Actions, based on current planning assumptions, have completion dates distributed over the next three years as shown in Figure A.2.

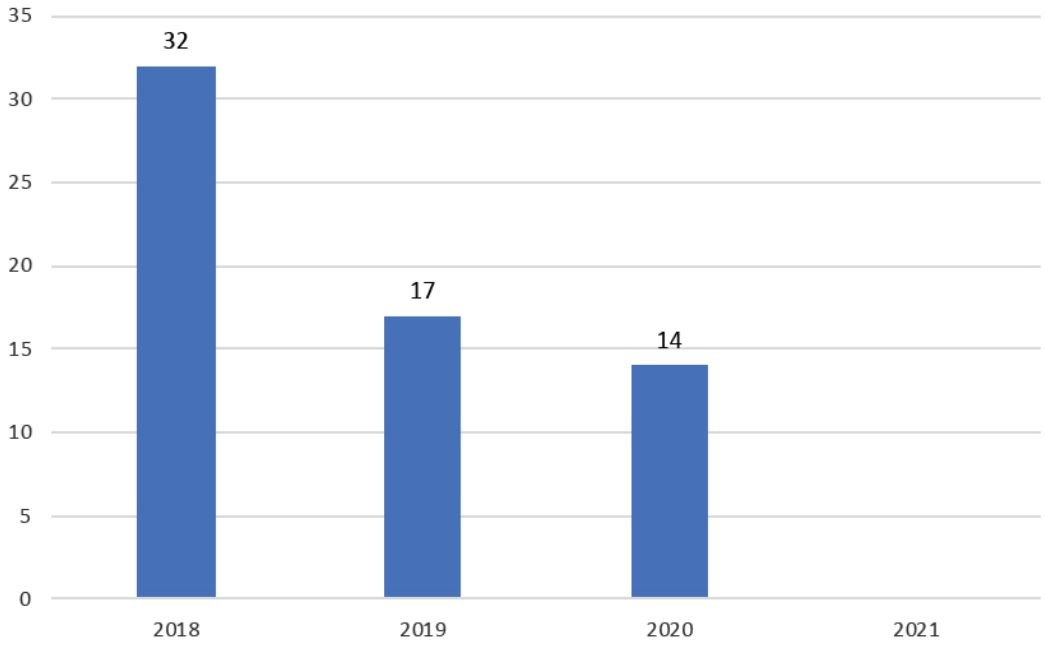


**Figure A.2 -** Distribution of IIP Actions and Timeline for Completing Actions

## IIP Administration

In accordance with CNSC REGDOC 2.3.3, an IIP change management instruction was developed which is documented in an IIP Administration Instruction. Although changes to the Resolution Actions and schedule are not planned, the change management instructions will ensure that the Resolution Actions are effectively managed per the schedule.

The IIP Administration Instruction also specifies quarterly and annual reporting requirements, and interactions between OPG departments and the CNSC.

A structured oversight organization has been established to assign accountability for the IIP and IIP Action ownership, and to ensure that the IIP is resourced to mitigate risks, and enable program success.

## Pickering Safety Enhancements

In addition to implementing programmatic improvements, the IIP contains actions for Plant Modifications, Fitness for Service, and Safety Analyses. The IIP listing of enhancements include those resulting from the Global Assessment, including both new modifications and existing planned station modifications that were integral to the overall assessment of safety. The following key IIP Actions are highlighted due to their safety significance for continued operation to the end of 2024.

## Firewater System Enhancement (GI-48)

Canadian Standards Association (CSA) standard CSA N293-12, Fire Protection for Nuclear Power Plants, requires independent electrically and diesel driven firewater supply pumps. This is a new requirement that did not previously exist. On Pickering NGS Units 1,4 this requirement is already satisfied. However, a PSR2 gap was identified for Pickering NGS Units 5-8, as firewater is supplied only from electrically driven pumps with redundant power supplies. To address this gap, changes to the existing firewater system are included in the IIP scope to allow the firewater from Pickering NGS 1,4 diesel driven firewater pumps to supply Pickering NGS Units 5-8 through station interconnection. This interconnection will allow the Pickering site fire protection system to meet the most modern standards (CSA N293-12) for the redundancy and diversity of firewater supply.

## Pickering NGS Units 1, 4 Probabilistic Safety Assessment (GI-27)

Even though Pickering PSA Safety Goals are met, OPG has set more challenging expectations through Administrative Safety Goals. To meet the more challenging goals, OPG has implemented Fukushima lessons learned that have enhanced plant safety. Following Fukushima lessons learned action implementation, Pickering NGS Units 5-8 meet the Administrative Safety Goals in all areas.

Pickering NGS Units 1,4 PSA large release frequency (LRF) is already better than the Safety Goal. To ensure Pickering NGS Units 1, 4 also meet the more challenging Administrative Safety Goal, IIP Actions have been established to install piping modifications on Pickering NGS Units 1, 4 to provide emergency make-up water to Unit 1 and Unit 4 calandria, heat transport system and steam generators to ensure continuous post-BDBA fuel cooling and protection of containment.

Following the completion of these enhancements as per the IIP Actions, Pickering NGS Units 1, 4 PSA estimated LRF will be better than the Administrative Safety Goal, further improving on already implemented Fukushima lessons learned actions, as shown in Figure A.3.

## Beyond Design Basis Accident (BDBA) Accident Management (GI-40)

OPG's response to the Fukushima accident included completion of:

1. Phase-1 emergency mitigation equipment (EME) to provide additional barriers for the prevention of severe accident progression following a sustained station loss of power.
2. Phase-2 EME to restore critical containment functions by providing an emergency back-up source of power to:
    a. The boiler room air conditioning units inside each reactor building to assist with BDBA pressure suppression;
    b. hydrogen igniters to prevent post-BDBA hydrogen concentrations reaching explosive levels;
    c. Independent back-up power to the filtered air discharge system (FADS) to allow use of FADS for containment venting.

Safety analysis and assessments demonstrate that public risk from accidents at Pickering NGS was already very low. The leadership team at OPG continues to invest in Pickering NGS and has committed in the Pickering PSR2 IIP further safety enhancements that will arrest accident progression that could challenge containment integrity following a BDBA, further reducing the risk.

The specific IIP design enhancements provide emergency back-up water from the Pickering Firewater System to the Pickering Units 1 and 4 steam generators, heat transport system and calandria vessel.

These modifications will not only reduce the probabilistic safety assessment (PSA) calculated large release frequency (LRF) for Pickering Units 1, 4 by approximately 50% achieving OPG's Administrative Safety Goal, they will also assure the accident terminates at the in-vessel retention state allowing the use of the existing FADS. The public safety benefit of these modifications is similar to what a Containment Filtered Venting System would have provided.

A sensitivity study was completed which concluded that these modifications combined with modelling refinements will reduce the probabilistic safety assessment (PSA) calculated large release frequency (LRF) for Pickering Units 1, 4 by approximately 50% achieving OPG's Administrative Safety Goal and will result in a similar public safety benefit as a containment filtered venting system would have provided.

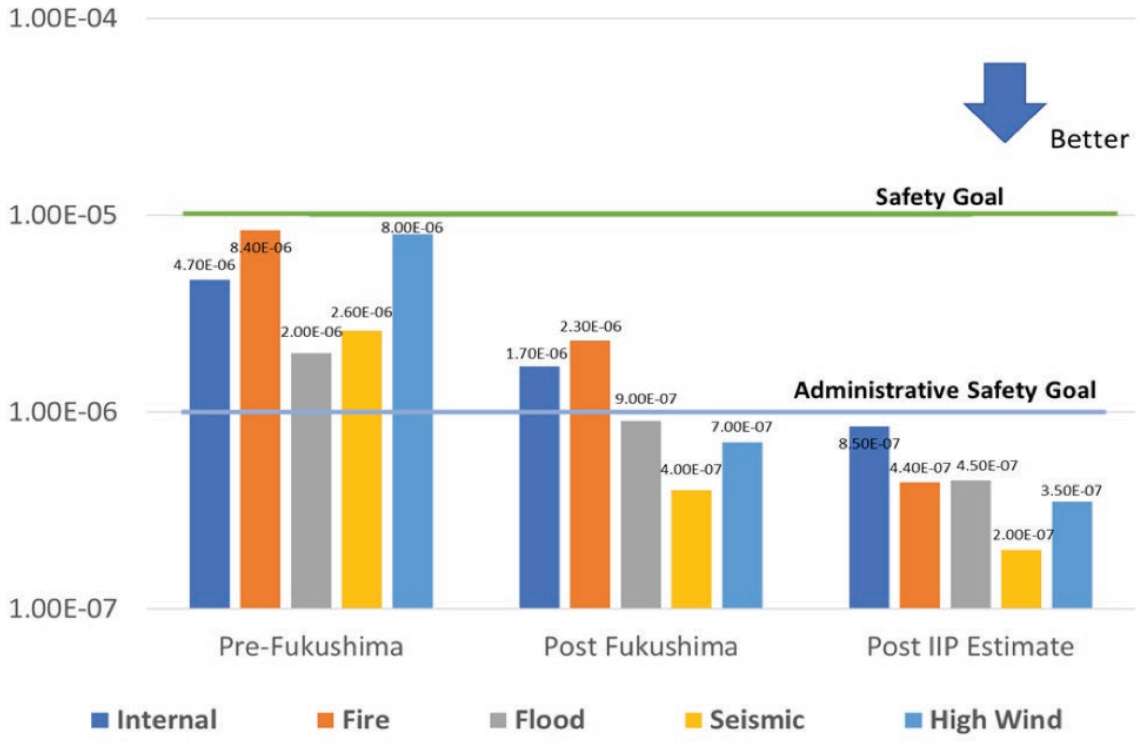


**Figure A.3 -** Pickering NGS 1, 4 PSA Large Release Frequency Improvements Over Time (Pre-Fukushima, Post-Fukushima mods and Estimated Post-IIP)

## Expert Panel

A third-party technical Expert Panel to support the PSR2 Global Assessment process was established consisting of experienced individuals with familiarity with the design and operation of Pickering NGS (and other nuclear plants) and who have demonstrated leadership in the nuclear industry, participating in external review committees and initiatives.

The Expert Panel was subsequently requested to review the IIP and concluded that the IIP provided a balanced and comprehensive set of activities which addresses the results from the Global Assessment. The Expert Panel also concluded that the IIP had been prepared in a manner consistent with the regulatory requirements in accordance with the PSR Basis Document and that successful IIP implementation will ensure that the Pickering station will be safe to operate both in the short term, and for extended operation.

## Pickering PSR2 Conclusions

The PSR process was thoroughly conducted over a two year period by external companies employing industry experts. The process identified plant modifications that will further enhance safety and reliability, and has highlighted where additional work is required to support commercial operation to the end of 2024. The PSR reviews confirmed that there are no management program gaps.

From an integrated public risk perspective, OPG concludes that the most effective means of protecting containment and minimizing large releases resulting from a BDBA is to prevent an accident from progressing to the point of challenging containment. The modifications that are currently being implemented and committed in the IIP will provide additional barriers to prevent such accident progression.

With a robust design, established mature programs in place that meet or exceed industry standards, and a leadership team that is committed to safety and continuous improvement, Pickering NGS will continue to operate safely and reliably through 2024.

## References

A.1 OPG Letter, B. McGee to H. Khouaja, “Submission of Pickering NGS Periodic Safety Review 2 Basis Document Revision 002”, July 6, 2016, CD# P-CORR-00531-04780.

A.2 CNSC Letter, H. Khouaja to B. McGee, “Pickering NGS: CNSC Staff Acceptance of Pickering NGS A-1 Periodic Safety Review 2 (PSR2) Basis Document”, July 8, 2016, e-Doc 5037314, CD# P-CORR-00531-04789.

A.3 OPG Letter, R. Lockwood to A. Viktorov, “Pickering NGS Periodic Safety Review 2 - Submission of Global Assessment Report Revision 1”, February 12, 2018, CD# P-CORR-00531-05292.

A.4 CNSC letter, A. Viktorov to R. Lockwood, “Pickering NGS Periodic Safety Review 2 – CNSC Review of OPG Global Assessment Report (GAR) Revision 1”, February 19, 2018, CD# P-CORR-00531-05322.

A.5 OPG Letter, R. Lockwood to A. Viktorov, “Pickering NGS Periodic Safety Review 2 - Submission of Integrated Implementation Plan Revision 1”, March 1, 2018, CD# P-CORR-00531-05311.

A.6 CNSC letter, A. Viktorov to R. Lockwood, “Pickering NGS: CNSC Staff Acceptance of Pickering NGS Periodic Safety Review 2 (PSR2) Integrated Implementation Plan (IIP) Revision 1”, March 2, 2018, CD# P-CORR-00531-05333.

# Addendum B
# Assurance of Fuel Channel Fitness For Service

## Executive Summary

OPG can confidently state that the fuel channels will remain fit for service up to their intended service life of 295,000 EFPH. This confidence is derived from a mature, well- defined life cycle management program that is based on years of operating experience and supporting research. This program produces fitness-for-service assessments that are aligned with all licensing requirements. Based on the established programmatic controls for managing fuel channel aging, which include an extensive reactor inspection program, sound technical assessments, and the implementation of mitigating measures where required, OPG is confident that Pickering fuel channels will remain fit for service to the end of 2024. OPG is documenting, in a Pickering 2024 readiness plan, the key life cycle management actions needed to support safe operation to end of 2024.

## 1 Introduction

OPG has requested approval from the Canadian Nuclear Safety Commission (CNSC) for a licence renewal for a ten-year term, from September 1, 2018 to August 31, 2028, and approval for operation beyond the current operating limit of 247,000 Equivalent Full Power Hours (EFPH) up to 295,000 EFPH for the lead Pickering unit, which corresponds approximately to the intended end of commercial operation (December 31, 2024). Projected EFPH for each unit at the intended end of commercial operation is provided in Table B.1.

| Pickering Unit | Projected Unit EFPH as of December 31st 2024 |
|---|---|
| Unit 1 | 192,000 |
| Unit 4 | 167,500 |
| Unit 5 | 287,500 |
| Unit 6 | 295,000 |
| Unit 7 | 287,000 |
| Unit 8 | 274,000 |

**Table B.1** – Projected EFPH for Pickering Units

OPG is committed to safe and reliable operation of the Pickering Nuclear Generating Station (NGS). OPG has programs and provisions in place to assure fitness for service (FFS) of fuel channel components on all Pickering units to the assumed service life targets.

## 2 Fuel Channels Overview

Fuel channels support the fuel bundles inside the reactor and are an integral part of the heat transport system that removes heat from the fuel. The fuel channels are located inside the calandria vessel assembly, as shown in Figure B.1. At Pickering NGS, Units 1 and 4 each contain 390 fuel channels, while Units 5 to 8 each contain 380 fuel channels. All fuel channel pressure tubes at Pickering units are made of a zirconium-niobium alloy.

Pressurized heavy water coolant is circulated through the fuel channels, transporting the heat produced by the nuclear fission process in the fuel to the boilers, in order to produce high-pressure steam. The pressure tube forms the primary pressure boundary containing the fuel bundles and heat transport system coolant.

Fuel channels consist of two end fittings, four annulus spacers, a calandria tube, and a pressure tube as shown in Figure B.2. The fuel channels are surrounded by heavy water, which is used to moderate the fission process within the calandria vessel. Dry carbon dioxide gas flows in the annulus space between the pressure tube and the calandria tube, and provides a thermal barrier for the heat transport system and also moisture detection capability in the unlikely event of a pressure tube leak.

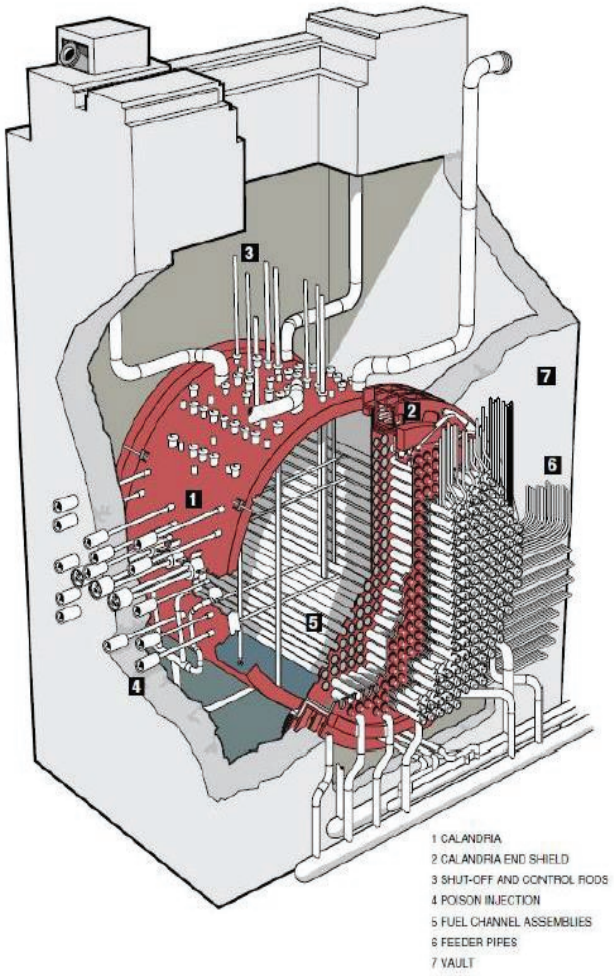


**Figure B.1:** Section View of CANDU Calandria Assembly

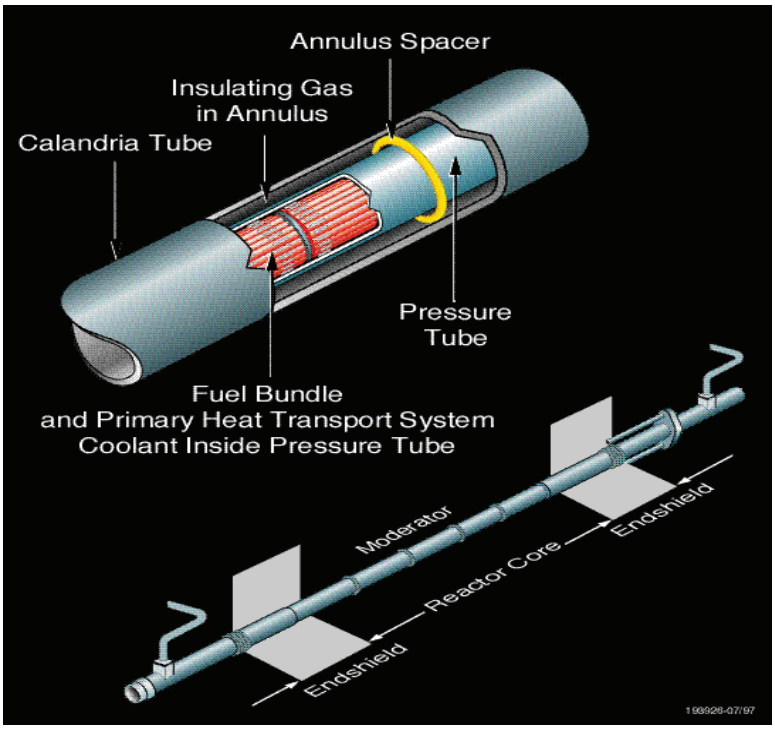


**Figure B.2:** Section View of Fuel Channel Assembly

# 3 Defence in Depth - Barriers to Fuel Channel Failure

Safe operation of fuel channels, as facilitated by the CANDU reactor design, utilizes a defense in depth framework. Defense in depth provides multiple overlapping barriers to lessen the chance of a fuel channel failure and reduce the possibility of harmful effects on the public or the environment. For pressure tubes, research and development (R&D) and testing is performed to understand degradation; inspection and surveillance is conducted to monitor for progression of degradation; degradation assessment methods are employed to demonstrate retention of design margins; heat transport system operating procedures mitigate postulated degraded conditions; and leak detection enables safe reactor shutdown and depressurization prior to pressure tube rupture. As a final set of barriers, in the unlikely event of fuel channel failure, alternative and diverse means of cooling the fuel are provided through safety systems (e.g. emergency coolant injection) and post-Fukushima modifications and emergency mitigation equipment. In the event all other measures fail, the containment system is available to limit radiation release and dose to the public and environment. The approach to defense in depth is depicted in Figure B.3.

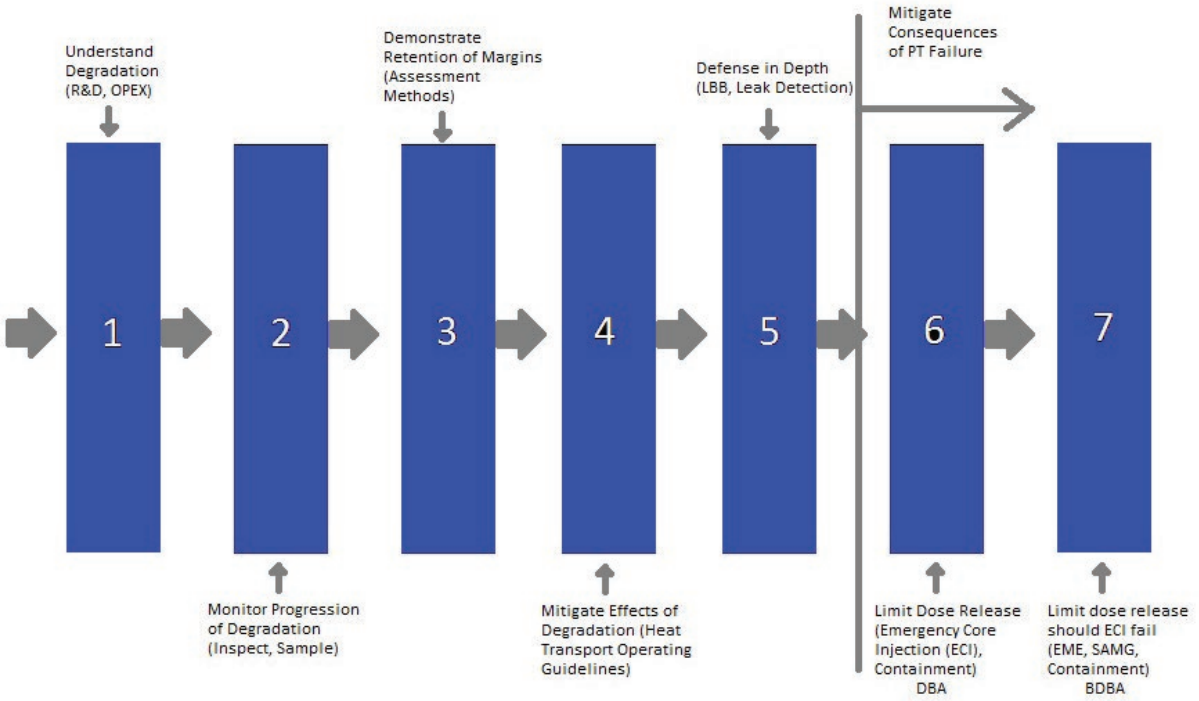


**Figure B.3** – Defense in Depth Framework Employed by OPG- Barriers to Fuel Channel Failure and Mitigation of Consequence in Event of PT Failure

# 4 Aging Management Programs

The fuel channels are a major component in CANDU reactors and OPG utilizes an Aging Management Program compliant with IAEA Safety Guide NS-G-2.12 and CNSC REGDOC 2.6.3 to ensure fuel channel integrity is well managed throughout the operational life of the plant. This is accomplished by establishing an integrated set of programs and activities that ensure fuel channel performance and fitness for service requirements are satisfied on an ongoing basis. This program also requires preparation of life cycle management plans and condition assessments, which are discussed in Sections 5.0 and 6.0 below.

Aging Management considerations are applicable throughout the plant life cycle, including design, construction, commissioning and operation. Critical aging management considerations are included and addressed in each of these phases. The basic framework for the Aging Management process is "Plan-Do-Check-Act". This framework (illustrated in Figure B.4) ensures that planning is in place; the plant is operated in accordance with this plan; the plant condition is monitored; and that action is taken to manage the effects of aging.

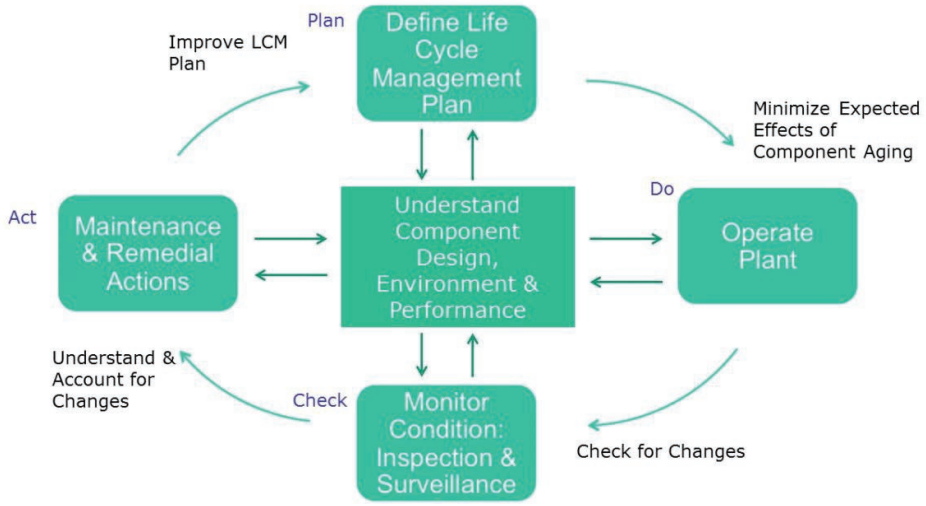


**Figure B.4:** Integrated Aging Management Process

The Aging Management Program and the activities it drives are key to ensuring critical equipment aging is managed such that operation of the nuclear power plant remains within the licensing basis of the facility and allows for station safety and operational goals to be met. OPG produces and regularly updates a Fuel Channels Life Cycle Management Plan (FCLCMP) which ensures deliverables are well defined and that activities are planned and coordinated. The plan is optimized based on current understanding and routine assessment of component condition. Execution of the plan allows projections to be made regarding remaining life of the components. This process ensures the effects of component aging can be minimized allowing for operation of the reactor to target end of life, with mitigating actions implemented as required.

# 5 Overview of Fuel Channel Fitness for Service (FFS)

To ensure safe operation and FFS of fuel channels, life cycle management activities are rigorously performed in accordance with industry standards.

The Canadian Standards Association (CSA) Standard N285.4 (Reference B.1) prescribes requirements for monitoring fuel channel conditions via periodic inspections of multiple fuel channels. This standard also prescribes material surveillance which requires harvesting both small (thin scrape) and large (removal of entire pressure tube (PT)) samples of PT material for subsequent destructive testing at a specialized laboratory facility to confirm material properties. The CSA Standard N285.4 standard defines acceptance criteria that must be met for given fuel channel conditions. If a fuel channel condition satisfies these acceptance criteria then that condition is considered unconditionally acceptable, as the fuel channel remains within the design basis.

OPG produces and regularly updates a Fuel Channels Life Cycle Management Plan (FCLCMP) which documents planned inspection and surveillance activities for planned reactor inspection outages. The planned periodic inspections of PTs are conducted to assess degradation and monitor for change. These inspections typically exceed CSA Standard N285.4 minimum requirements.

OPG utilizes specialized engineered tooling to perform fuel channel inspections; one example is the ANDE / CIGAR hybrid inspection system tool (Advanced Non-Destructive Examination / Channel Inspection and Gauging Apparatus for Reactors). This inspection tool incorporates multiple non-destructive examination techniques, including ultrasonic testing (UT) and eddy current testing (ECT), and is deployed inside the pressure tube after the channel has been defueled.

The tool is designed to inspect the full volume of the tube along the full length of the PT, including flaw detection, sizing and characterization; measurement of PT diameter and wall thickness; measurement of PT deflection (sag); measurement of the gap between the PT and calandria tube (CT); and confirmation of annulus spacer locations. An image of the ANDE / CIGAR hybrid inspection head and a schematic of pressure tube characteristics are shown in Figure B.5.

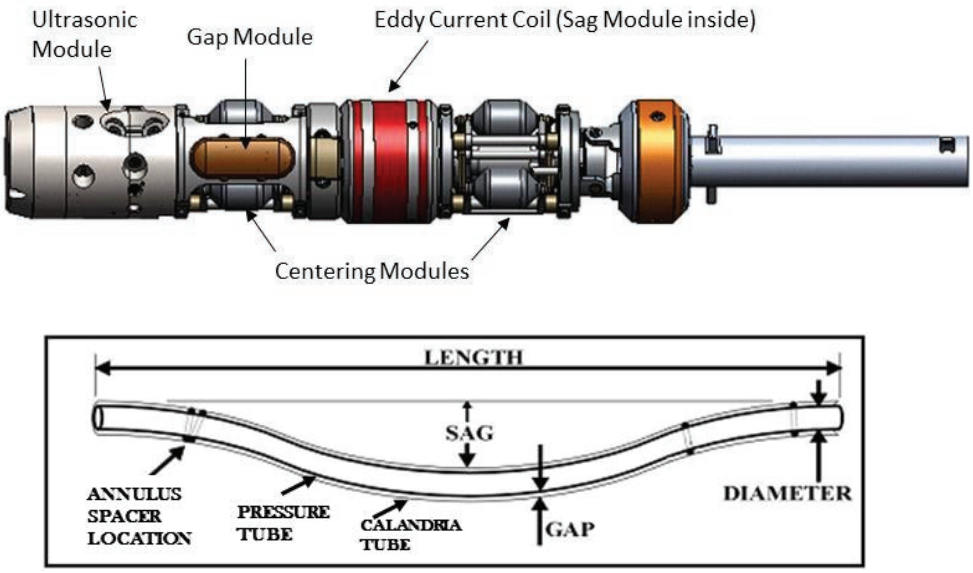


**Figure B.5** – ANDE / CIGAR hybrid Inspection Tool Head used for inspection of CANDU fuel channels (top image) and schematic of fuel channel characteristics (bottom diagram not to scale, channel characteristics shown are for illustrative purposes)

When in-service inspection detects a condition (e.g. flaw, dimensional or material condition) that does not satisfy the acceptance criteria of CSA Standard N285.4 (Reference B.1), OPG must comply with the technical requirements of CSA Standard N285.8 (Reference B.2) to demonstrate continued fitness for service. CSA Standard N285.8 requires assessment of known as well as projected conditions, evaluation of material properties including any observed changes, and risk assessment of uninspected population of PTs in the reactor core. This process of evaluation requires a disposition that must be submitted to the CNSC for acceptance, as required by CSA Standard N285.4. The predictive models and assessment methodologies used to assess FFS are supported by accumulated knowledge obtained from continuing industry research and development activities, and they ensure predicted conditions remain acceptable.

The FFS assessment approach in Reference B.1 ensures that PTs have adequate integrity for continued service and that OPG continues to operate its reactors safely and within the licensing basis. Figure B.6 graphically depicts the FFS approach. The FFS framework also ensures that, through periodic inspection, OPG continually understands the condition of the fuel channels, and is able to predict fuel channel condition and ensure future operation remains within the acceptable FFS envelope.

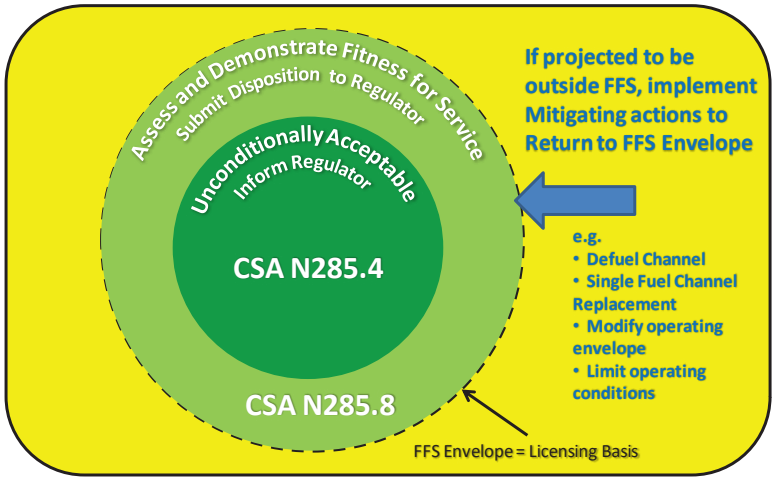


**Figure B.6** - Fuel Channel Fitness For Service (FFS) Assessment Approach

If projections of fuel channel conditions suggest future departure from the FFS envelope, mitigating actions are available and will be implemented in order to remain within the envelope. For example, single fuel channel replacement may be employed in a postulated extreme case where assessment of a given pressure tube flaw is unable to satisfy FFS criteria.

# 6 Condition Assessment of Fuel Channels

The condition assessment process is used to evaluate the health of critical components and establish actions necessary to maintain component health and assure continued fitness-for-service (FFS) for planned future operation. This process seeks to identify and understand aging mechanisms, collect data, conduct analyses, and evaluate component condition by comparison with defined acceptance criteria. The condition assessment of fuel channels is satisfied by several FFS assessments.

Condition assessments for pressure tubes involve monitoring all of the aging mechanisms affecting fuel channels. As shown in Figure B.7, fuel channel aging mechanisms are grouped into three main categories; PT deformation, changes to PT material properties, and PT flaws. These mechanisms can result in crack initiation in the PT material. By operating in accordance with operating guidelines, the potential for crack initiation is extremely unlikely. As a defense in depth measure, crack propagation is postulated and evaluated to prepare for the unlikely event that a crack initiates in the PT. Procedures are in place to assure that a leaking crack can be detected (via moisture detection equipment) and to safely shut down the reactor prior to the postulated crack growing to a length exceeding the critical limit of stability. As described above in Section 3.0, in the unlikely event of pressure tube failure, mitigating systems are employed to provide necessary cooling to maintain integrity of the reactor core, and containment systems are in place to prevent a release of radiation to the public. OPG has not observed a leaking crack in the current generation of installed pressure tubes. This is attributed to operation within defined procedures, design improvements and application of rigorous aging management processes, in accordance with OPG's aging management governance.

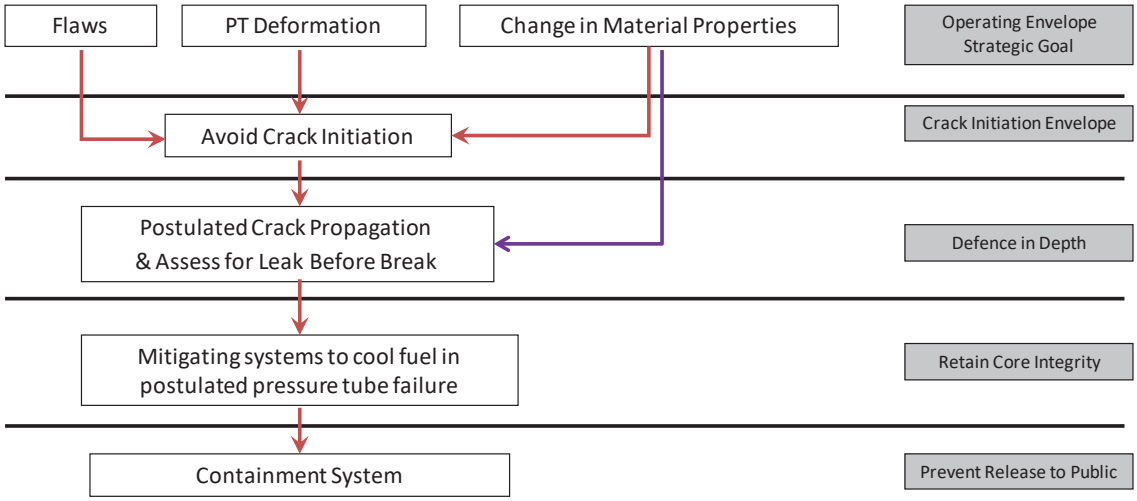


**Figure B.7** - Management of Fuel Channel Aging and Defense in Dept

A summary of aging mechanisms associated with Pickering fuel channels is provided in Reference B.3. OPG has assessed the effects of fuel channel aging on all units, and confirmed that planned aging management strategies, including application of available mitigation options as required, will provide additional margin on fuel channel fitness-for-service limits for operation of the Pickering units to their assumed service life targets.

Furthermore, OPG performs in-service inspections in planned outages to verify its understanding of the condition of the core and to confirm that the unit is fit for service for the planned operating period prior to the next planned inspection. If at any time emerging results, research findings, or industry operating experience challenges the validity of existing fitness for service assessments, OPG will evaluate the impact of these results, in accordance with internal corrective action processes and licensing basis requirements.

# 7 A Review of Technical Issues Related to Assurance of Fuel Channel Fitness for Service

CNSC has provided comments (Reference B.4) on OPG's submission (Reference B.3) regarding assurance of fuel channel fitness for service for the planned operating period of Pickering units. OPG has a mature aging management program and tools in place to inspect and assess the condition of fuel channel components. CNSC has provided a list of issues and related additional activities required to confirm that structural integrity margins will be maintained up to the expected end of commercial operation in December 2024. A summary of the issues expressed, their relation to fuel channel degradation mechanisms and establishment of fitness for service, and OPG's responses, are provided in the following Sections.

## 7.1 Deuterium Ingress and Hydrogen Isotope Concentration [Heq] Measurement

The increase of hydrogen isotope equivalent concentration, [Heq] in the PT, (due to deuterium ingress) is a known aging mechanism that occurs slowly and predictably over the operating life of the plant. During reactor operation the surface of PTs is subject to corrosion. This electrochemical corrosion process results in the production of zirconium oxide and deuterium, with the primary source of deuterium being from the heavy water coolant of the heat transport system.

Some of the deuterium produced from corrosion is absorbed by the PT. The accumulation of deuterium in the PT impacts the resistance to crack initiation from in-service flaws and affects pressure tube material properties (such as fracture toughness, a measure of material resistance to propagation of a growing crack) over the life of the reactor.

Deuterium ingress is well characterized. The [Heq] level is higher at the rolled joint (RJ) regions of the fuel channel as two sources of deuterium ingress are possible in addition to ingress across the inner surface of the PT. They are: deuterium ingress from the stainless steel end fitting interacting with the pressure tube due to galvanic corrosion; and deuterium ingress from the galvanic cell that can establish in the crevice between the pressure tube and the end fitting. The locations of highest expected [Heq] represent a relatively small portion of the PT, at the rolled joint regions, and are shown in Figure B.8.

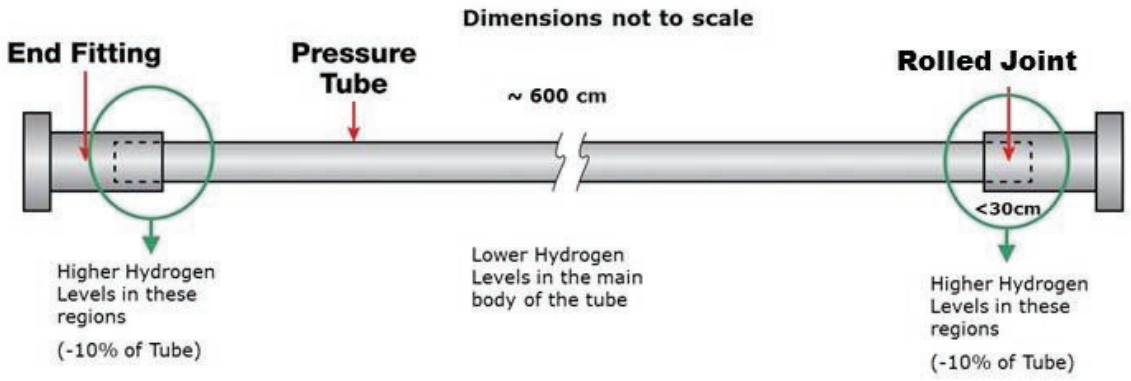


**Figure B.8** – Fuel Channel schematic depicting relative level of [Heq] for given locations along a given pressure tube

The [Heq] within pressure tubes is routinely monitored by material surveillance activities which involve scraping a thin sample of the inside surface of the pressure tube in both the body of tube (BOT) and rolled joint (RJ) regions during inspection outages when the reactor is in a shutdown state. Hydrogen and deuterium concentrations are also measured in pressure tubes periodically removed from the reactor. CSA Standard N285.4 (Reference B.1) has established acceptance criteria, for measured hydrogen concentration, [Heq] in the form of maximum hydrogen concentration values and maximum allowable rate of change in hydrogen concentration.

CNSC staff provided comments related to the deuterium ingress models used by industry and the measurement of [Heq] in Reference B.4, the majority of which are related to deuterium/protium[1] measurement practices and deuterium ingress modeling methodology, which are generic issues for the CANDU industry. OPG provided responses to CNSC comments and a schedule of planned future updates in Reference B.5, and is working with its industry partners and other CANDU utilities to resolve these comments. CNSC staff responded in Reference B.6.

OPG continues to participate in the Fuel Channel Research and Development (R&D) program through the CANDU Owners Group (COG) and provides annual updates of planned work activities to CNSC. R&D related to deuterium ingress is performed with a focus on understanding the mechanisms influencing deuterium ingress in pressure tubes, and how these mechanisms change over the reactor operating life, and incorporating emerging knowledge into improved models to ensure predicted conditions remain appropriately conservative. OPG will provide a report to the CNSC, in accordance with REGDOC-3.1.1 requirements, if any emerging R&D results or industry operating experience appear to challenge the validity of existing fitness for service assessments, and will also initiate the actions necessary to ensure that fitness for service is maintained.

[1] Protium is an isotope of hydrogen, having one proton in the atomic nucleus. Deuterium is an isotope of hydrogen with a nucleus of one proton and one neutron., The primary source of ingress is from the heavy water coolant.

OPG is confident that deuterium ingress is well managed by ongoing in-service and ex-service pressure tube material surveillance and R&D activities. Accordingly, through the execution of the Life Cycle Management Plan activities, assessment of deuterium ingress will provide the information needed to manage the fitness for service and safe operation of Pickering fuel channels.

## 7.2 Fracture Toughness and the Predictive Models

Fracture toughness is a material property that represents the ability of a material to resist unstable crack propagation and fracture. Pressure tube fracture toughness reduces with pressure tube operating time as a result of irradiation, and accumulation of deuterium/hydrogen. Understanding the progression of this reduction in fracture toughness properties is essential in the demonstration of fitness for service of pressure tubes as fracture toughness properties directly influence the ability to demonstrate pressure tube leak-before-break (LBB) and protection against fracture.

The protection against fracture and LBB assessments conservatively postulate the existence of a through-wall flaw in the pressure tube as the starting point of the evaluation. These evaluations are used to establish operating envelopes and operating procedures which include a tolerance for postulated flaws. Several CANDU reactor units in Canada have achieved in excess of 30 years of operation. There have been no through-wall leaking cracks found in either in-service inspections or by online leak detection systems for the current set of tubes installed in these reactors. Previous leak events in early CANDU operational history were associated with either rolled-joint or manufacturing flaw issues. These issues were subsequently addressed through improvements to rolled-joint assembly practices, material fabrication, and inspection procedures. All reactors with historical rolled joint issues have had their pressure tubes replaced and have implemented improved rolled joint assembly processes.

Fracture toughness properties are influenced by operating temperature, irradiation damage, and material impurities (particularly hydrogen in the form of precipitated hydrides, and chlorine in the form of Zr-C-Cl complexes). As is the case with many other metals, zirconium exhibits a reduction in fracture toughness from upper shelf (ductile behaviour) to lower shelf (brittle behaviour) as a function of temperature. Upper shelf fracture toughness properties have been observed experimentally at temperatures associated with reactor power operation ($T > 250°C$).

As the [Heq] in the PT increases with increasing corrosion (deuterium ingress), the total hydrogen equivalent content [Heq] can exceed the solubility limit for hydrogen, at which point the hydrogen above the solubility limit can no longer remain in solution and precipitates as a localized zirconium-hydride platelet. The amount of hydride precipitates is affected by the local temperature (solubility increases with temperature) and the local concentration of hydrogen (amount of hydrogen above the solubility limit). For a given local concentration of hydrogen, there will be more hydride precipitates present at cold shutdown conditions than at hot operating conditions. The presence of hydride platelets within the zirconium metal results in small localized areas that are less resistant to fracture. As more hydride platelets are present in the metal (at high hydrogen concentrations) there is lower overall fracture toughness in the material. The morphology (shape and structure), orientation and amount of hydride platelets can influence the resultant fracture toughness of the pressure tube material.

In 2009, fuel channel experts recognized the potential for reduced pressure tube fracture toughness at high [Heq]. At that time, OPG proactively created a test program to investigate fracture behaviour in the presence of hydrides, develop a means of artificially hydriding ex-service pressure tubes (without altering the effects of irradiation damage) to produce test specimens representative of end of life pressure tube conditions, and develop engineering models to support fitness-for-service assessments.

One advantage of the CANDU PT design is that it is possible to assess fracture toughness by burst testing full size sections of pressure tube that have been removed from a reactor. With this laboratory test configuration, no correction for dimensions, specimen shape or stress state needs to be made when assessing the test results. A typical burst test is performed using a section of pressure tube material roughly 0.5m in length that is artificially hydrided to a desired target [Heq], representing future conditions. A substantial starter flaw is artificially introduced to initiate crack propagation during increasing applied pressure. Rising internal pressure is applied until the sample bursts. The burst pressure and additional measurements determine the fracture toughness of the PT material in the test specimen. An example of a PT section burst test is shown in Figure B.9.

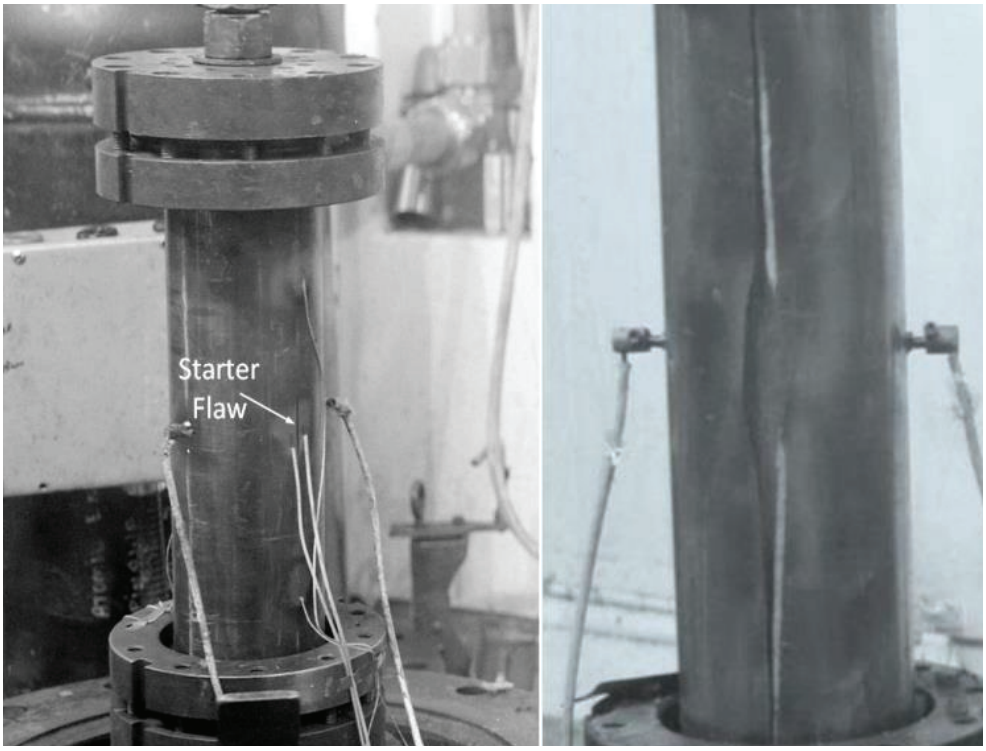


**Figure B.9** – Typical example of ex-service pressure tube burst test showing start of tests (left) with artificial starter flaw noted and at test completion after tube has burst (right)

By 2014, multiple artificially hydrided ex-service irradiated pressure tube sections from different tubes had been completed at multiple test temperatures, on test specimens with [Heq] concentrations ranging between 60 to 126ppm. The results of these tests and associated observations and analysis of pressure tube metallography led to the development of new fracture toughness models for high hydrogen content. One model was created for the upper shelf, or fully ductile fracture region, which covers operation at normal operating conditions (≥ 250°C). A second model was developed for the lower shelf and transition region, which covers heat-up and cool-down of the reactors (<250°C). The lower shelf and transition region model is referred to as the Cohesive-Zone model as the reduction in fracture toughness due to bulk hydrides was simulated by a reduction in cohesive-zone restraining stress due to hydride fracture. Figure B.10 illustrates a simplified version of the fracture toughness model, illustrating the effect of high hydrogen content on the lower bound fracture toughness values.

In 2013, these improved models which account for hydrogen content were independently reviewed by third parties and determined to be adequate for current use. Industry incorporated these new models into the 2015 edition of CSA Standard N285.8 and OPG has implemented the model in updated fuel channel FFS assessments.

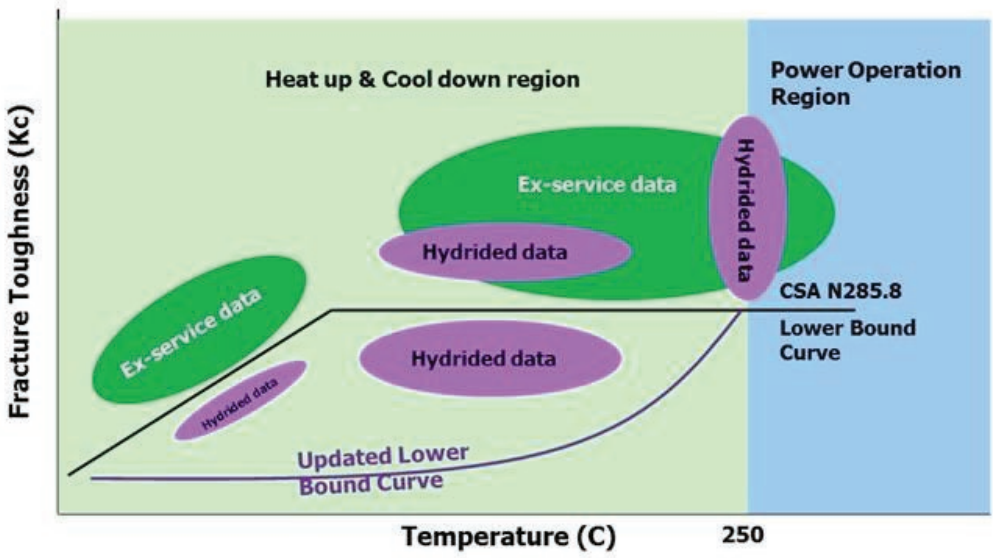


**Figure B.10** – Updated Lower Bound Fracture Toughness Curve accounting for high Hydrogen Content

Using the pressure tube fracture toughness model incorporated into CSA Standard N285.8, OPG has implemented changes to operating envelopes and procedures to support continued demonstration of fracture protection and LBB for the full service life of the plant. The pressure-temperature envelope establishes a safe envelope for protection against fracture for the case of a postulated severe flaw.

Based on projected hydrogen isotope concentration levels at end of service life and the new fracture toughness model (Figure B.11), OPG has assessed the impact and implemented modifications to the pressure–temperature operating envelope, and associated operating procedures for primary heat transport system heat-up and cool down during reactor start-up and shut down (Figure B.12). The modified operating procedures have been implemented to manage the brief time period (typically a few hours) in transitioning from full power operation to reactor shutdown, and return from shutdown to at-power operation. It should be noted that for the vast majority of time (more than 99 percent), the reactors are either in full power operation or in safe shutdown state, when the fracture toughness of the pressure tubes is not of concern.

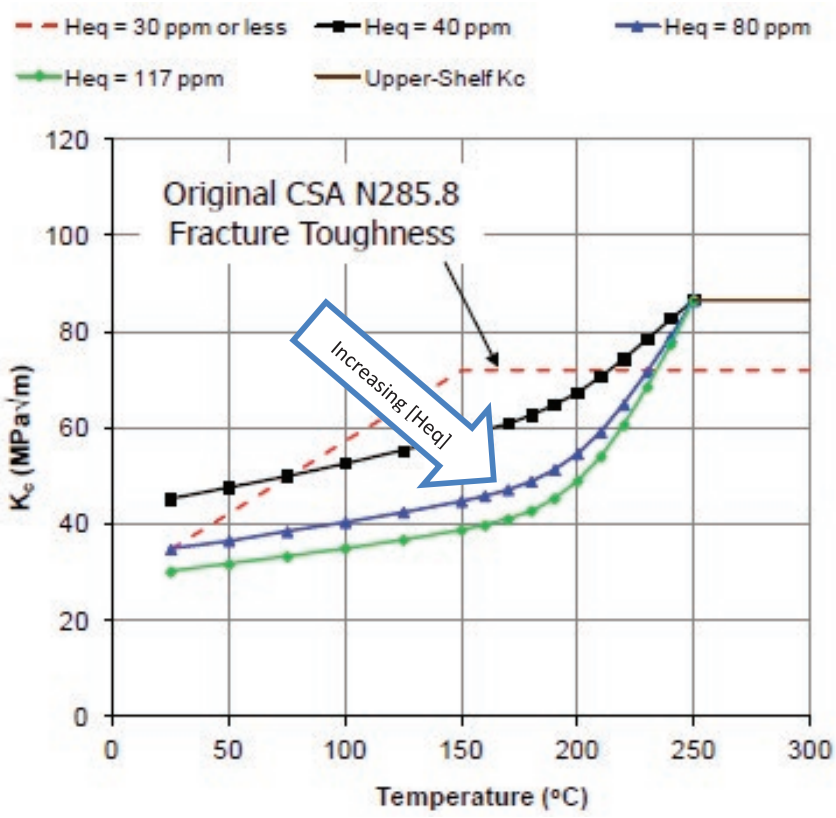


**Figure B.11** – Comparison of previous CSA N285.8 Fracture Toughness Model with Cohesive Zone model predictions. 97.5% lower prediction bound on fracture toughness curves with [Heq] using Chlorine concentration of 5 ppm.

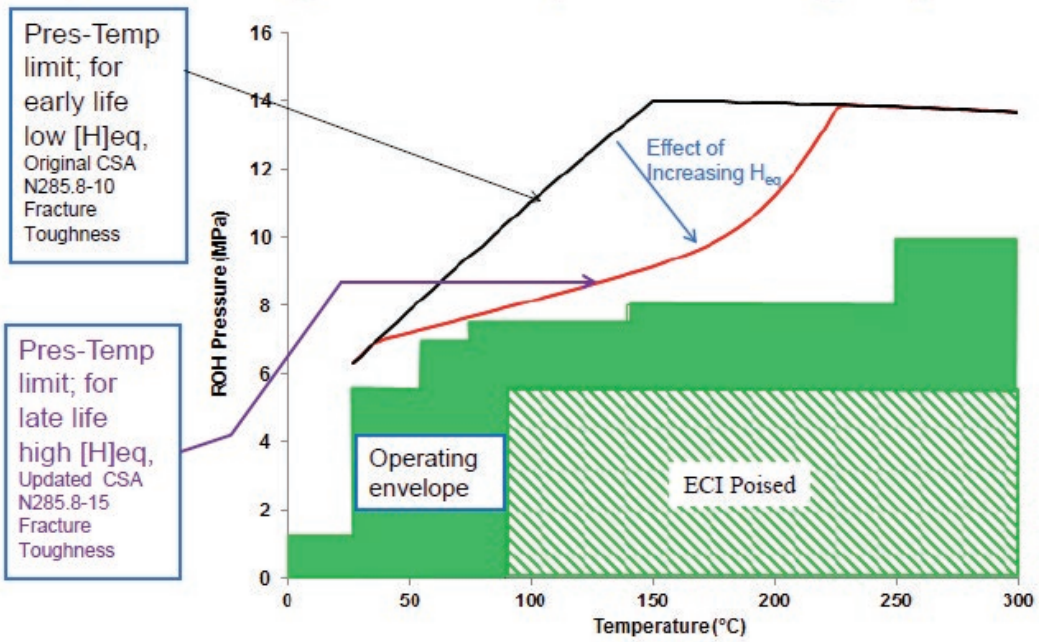


**Figure B.12** – Illustrative example of revised allowable operating pressure-temperature envelope (green) as a result of a revised flaw stability curve for a postulated through-wall flaw (red) using updated lower bound fracture toughness curve for late life high [H]eq pressure tube.

Since the time of model incorporation into the CSA Standard N285.8-15, OPG has continued to perform additional tests as part of the COG Fuel Channel Life Management (FCLM) project, which is co-funded by Bruce Power and Canadian Nuclear Laboratories. The FCLM project planned and conducted two series of tests to support fracture toughness model development. The purpose of the Series 1 tests was to validate the Cohesive Zone model in the range of transition temperatures between 150°C and 250°C. The purpose of the Series 2 tests was to assess fracture toughness under end of life conditions targeted by project partners. OPG has also performed additional R&D work in response to feedback received from CNSC staff and third party reviewers to demonstrate continuing conservatism of the model and determine potential improvements.

OPG routinely communicates updates on work progress, including burst test results, to the CNSC under an OPG Action Item 2014-OPG-4782. In Reference B.4 CNSC staff requested that OPG provide a path forward to address the impacts of recent burst tests on the validity of the Cohesive Zone model. One of the recent burst tests (identified as BT-29) on ex-service tube material artificially hydrided to 100 ppm [Heq] had a fracture toughness value below the lower bound predictions of the Cohesive Zone model. This is the only irradiated burst test conducted since creation of the Cohesive Zone model in 2013 to have had a fracture toughness value below the lower bound prediction. The burst test program to date has been performed using a conservative set of conditions for hydriding and testing tube sections. As a result, OPG considers the predictions from the models that were built using the test data to be conservative. OPG evaluated the BT-29 test result and determined that existing FFS assessments remain valid on the basis that the [Heq] and sample preparation conditions used for the test were more severe than conditions expected for pressure tubes in Pickering Units for the planned operational life (up to 295k EFPH). Specifically, preparation of the BT-29 sample yielded hydride morphology and orientation more severe than anticipated in the Pickering fuel channels to the end of the planned operational life.

Industry experts on pressure tube fracture toughness judged that improved fracture toughness properties would be expected at lower [Heq], and results from subsequent burst test samples that are more reflective of late-life conditions have confirmed fracture toughness properties within the models that are in use in current fitness for service assessments. OPG has increased the number of planned burst tests to further validate the existing Cohesive Zone model at [Heq] expected prior to target operational life. OPG provided a detailed response to the CNSC in Reference B.5 regarding continuing plans for additional burst tests to further validate the existing Cohesive Zone model, with tests to be performed in 2018, 2019, and 2020. These additional tests will also support ongoing efforts for the development of an improved model that explicitly accounts for actual variation of hydride morphology and hydride orientation from pressure tube inlet to outlet. This improved model, which will include enhancement of mechanistic parameters influencing fracture toughness, is planned to be completed in 2018.

OPG is confident that planned activities provide for appropriate management of pressure tube fracture toughness in support of continuing demonstration of fuel channel fitness for service for the planned operating period of Pickering units.

## 7.3 Fuel Channel LCMP Compliance with REGDOC-2.6.3 Aging Management

OPG's aging management program and the FCLCMP have been based on the attributes of REGDOC-2.6.3, Aging Management (Reference B.8). REGDOC-2.6.3 sets out CNSC requirements for managing aging of structures, systems, and components of a power reactor facility, and also provides guidance as to how these requirements may be met. The REGDOC-2.6.3 document is built upon industry best practices, IAEA Safety Guide NS-G-2.12 (Reference B.9) and supersedes CNSC documents RD-344 (Reference B.10) on aging management.

One of the outputs of Pickering's Periodic Safety Review is an action to update the structure and comprehensiveness of OPG's Fuel Channel Life Cycle Management Plan (FCLCMP) to better demonstrate compliance with REGDOC-2.6.3.

OPG has developed Integrated Implementation Plan (IIP) actions to provide an update to the FCLCMP and related supporting technical basis documentation.

In support of Pickering operation to 2024, OPG is preparing a Readiness Plan that complements the FCLCMP, and which will contain a REGDOC-2.6.3 compliance roadmap to demonstrate that OPG's aging management program for fuel channel components satisfies the requirements of the REGDOC for effective aging management. The Plan will also include detailed assessments of all fuel channel degradation mechanisms and action plans for completing the activities necessary to support fitness for service assessment to the end of 2024. The Readiness Plan will be issued in March 2018 and submitted to CNSC for a regulatory determination, and will be updated on an annual basis.

OPG will also update the structure of the FCLCMP in the next planned update of the plan, to clearly demonstrate that the requirements outlined in REGDOC-2.6.3 are satisfied. To this end the FCLCMP will incorporate aging management actions described in the Readiness Plan, including a summary table that identifies the various fuel channel degradation mechanisms associated with aging, and mitigation strategies to support operation to 2024. The table will also provide the current status of each of the degradation mechanisms and the acceptance criteria to ensure the effects of aging will be managed to the expected end of commercial life. The summary will also identify the FFS assessments that provide assurance for continued operation, required R&D, and improvements to assessments required to support fuel channel FFS for extended life.

In Reference B.6, the CNSC provided feedback regarding OPG's plan to demonstrate compliance with REGDOC-2.6.3. OPG is confident that compliance with REGDOC-2.6.3 is addressed through the IIP actions and in future updates and through a complementary Readiness Plan which together demonstrate that OPG's aging management program for fuel channel components satisfies the requirements of the REGDOC for effective aging management.

# 8 Summary

This addendum briefly provides an overview of how fitness for service of fuel channels is established and monitored throughout the operational life of a fuel channel.

OPG can confidently state that the fuel channels will remain fit for service up to their intended service life of 295,000 EFPH. This confidence is derived from a mature, well-defined life cycle management program that is based on years of operating experience and supporting research. This program produces fitness-for-service assessments that are aligned with all licensing requirements. Based on the established programmatic controls for managing fuel channel aging, which include an extensive reactor inspection program, sound technical assessments, and the implementation of mitigating measures where required, OPG is confident that Pickering fuel channels will remain fit for service to the end of 2024. OPG is documenting, in a Pickering 2024 Readiness Plan, the key life cycle management actions needed to support safe operation to end of 2024.

OPG is committed to safe and reliable operation of fuel channels at Pickering NGS throughout the planned commercial operating, estimated to be up to 295,000 EFPH.

## References

[B.1] "Periodic Inspection of CANDU Nuclear Power Plant Components", CAN/CSA Standard No. N285.4-05, Update No.1 June 2007.

[B.2] "Technical Requirements for In-Service Evaluation of Zirconium Alloy Pressure Tubes in CANDU Reactors", CAN/CSA Standard No. N285.8-10, Update No.1, June 2011.

[B.3] OPG letter, R. Lockwood to A. Viktorov, "Pickering NGS - Assurance of Fuel Channel Fitness-for-Service for the Assumed Target Service Life of the Pickering Units", April 4, 2017, CD# P-CORR-00531-04953.

[B.4] CNSC letter, A. Viktorov to R. Lockwood, "Pickering NGS - Assurance of Fuel Channel Fitness-for-Service for the Assumed Target Service Life of the Pickering Units", August 25, 2017, e-Doc # 5309704, CD# P-CORR-00531-05127.

[B.5] OPG letter, R. Lockwood to A. Viktorov, "Pickering NGS - Suplementary Submission on Assurance of Fuel Channel Fitness-for-Service for the Assumed Target Service Life of the Pickering Units", November 15, 2017. CD#P-CORR-00531-06201.

[B.6] CNSC letter, A. Viktorov to R. Lockwood, "Pickering NGS: Supplemental Submission on Assurance of Fuel Channel Fitness-for-Service for the Assumed Target Service Life of the Pickering Units", February 8, 2018, e-Doc #5430102, CD# P-CORR-00531-05306.

[B.7] OPG letter, S. Woods to A. Viktorov and N. Riendeau, "Darlington and Pickering NGS: Response to Action Item 2017-OPG-11706 Cohesive-Zone Fracture Toughness Model and Closure of Action Item 2014-OPG-4782, Approach to Fitness-for-Service Assessments for Pressure Tubes", January 29, 2018, N-CORR-00531-18994.

[B.8] CNSC publication, "Aging Management", CNSC Regulatory Document REGDOC-2.6.3, March 2014.

[B.9] IAEA publication, "Aging Management for Nuclear Power Plants", International Atomic Energy Agency (IAEA), Safety Standards Series, Safety Guide NS-G-2.12, 2009.

[B.10] CNSC publication, "Aging Management for Nuclear Power Plants", CNSC Regulatory Document RD-334, 2011.

# Addendum C
# Pickering Whole-Site Risk Assessment

## Introduction

This addendum summarizes the Pickering whole-site risk assessment, which represents a substantial effort that is first-of-a-kind and at the forefront of whole-site probabilistic safety assessment (PSA) development.

OPG understands and deeply appreciates the importance of nuclear safety, and recognizes that assuring the low risk of the site is of great public interest. As such, site risk has always been considered and managed at OPG's nuclear facilities, including at Pickering. In the course of further exploring this topic, the present study has enabled OPG to revisit the topic from a fundamental and holistic perspective, and to better characterize whole-site risk.

## Background

PSA has long served as an important tool for assessing and managing nuclear power plant risk. A major benefit of PSA is the identification of risk insights which can be used to improve plant design and operation. PSAs are conducted separately for internal and external types of hazards, in particular for internal events, internal fires, internal floods, seismic hazards, and high wind hazards. Many other hazards are also considered and dispositioned as part of the PSA hazard screening process.

During the previous relicensing hearings for Pickering, the topic of "whole-site" risk was raised in light of the fact that – for each of the hazard PSAs – results have been expressed on a "per reactor unit" basis. Whole-site risk refers to the characterization of the overall risk of the site due to:

- multiple reactor units;
- internal and external hazards;
- other reactor operating modes (besides full power and outage states); and
- other on-site sources of radioactivity (such as the irradiated fuel bays).

One of the key issues concerns the numerical aggregation of PSA results. For instance, if aggregating across all reactor units, for a given hazard, the multi-unit PSA value is generally not equal to the per-unit PSA value multiplied by the number of units on site.

Moreover, the simple addition of PSA values across all hazards (internal events + fire + flood +...etc.) - might not be appropriate. Caution must be exercised as it is recognized that when risk metrics for external events are conservatively estimated, their summation with risk metrics for other events can lead to misinterpretation, in particular if the aggregated total exceeds the safety goal.

Another key issue is around the lack of international consensus on whole-site PSA methodology. Whole-site PSA remains an area of ongoing development outside of Canada.

Furthermore, not all hazards are quantified in terms of PSA risk metrics (for example, security threats), and hence, they do not lend themselves to aggregation by simple summation of common risk metrics. As such, there are broader considerations in the risk assessment of nuclear facilities (including programmatic, deterministic, and defense-in-depth aspects, in addition to PSA).

It is important to emphasize, given the extensive sharing of safety-related systems including shared containment, that the OPG "per-unit" based PSAs have always addressed multi-unit effects and hence, are "multi-unit" PSAs. This is briefly described in "OPG's PSAs are multi-Unit PSAs" on page 115.

# OPG's PSAs are multi-Unit PSAs

For each type of hazard (internal events, fire, flood, etc.), the detailed PSAs are used to estimate severe core damage frequency (SCDF) and large release frequency (LRF) on a per- hazard, per-unit basis. To facilitate the estimation of a per-unit risk metric, one of the units at the station is chosen as the reference unit and the risk metrics are estimated for that unit. As there are few design differences between the units in a station, the SCDF and the LRF for the reference unit are representative of the SCDF and the LRF for the other units. However, each hazard PSA is broken down into a range of initiating events that also include multi-unit scenarios. The initiating events include those that:

1. Occur on the reference unit and affect only the reference unit, e.g. loss of reactor power control.
2. Occur on an adjacent unit and affect the reference unit as well as the adjacent unit e.g. steam from a large steam line failure on an adjacent unit causing a transient on the reference unit.
3. Affect all units simultaneously, e.g. a loss of off-site power, a main control room fire, or a seismic event.

An event tree is prepared for each initiating event and a fault tree is prepared for each of the safety functions defined in the event tree. While the focus of the PSA is the reference unit, the event trees and the fault trees take into account multi-unit dependencies, for example:

1. A common initiating event can affect the reliability of the safety functions on all units and affect the reliability of inter-unit safety functions. For example, failures associated with a common service water intake can cause an initiating event and affect the reliability of the unitized, shared and inter-unit emergency service water supplies.
2. The PSA takes into account the number of units participating in the sequence. For example, more emergency service water pumps may be required to operate following an initiating event affecting multiple units than for an initiating event affecting a single unit.
3. The range of post-operator actions required to be performed in a sequence affecting multiple units might be greater than the range of actions required to be performed in a single unit sequence. This might increase the probability of failure to perform the required actions either as a result of increased complexity or increased time pressure.

Sequences that result in severe core damage are grouped according to similar characteristics, i.e., plant damage states (PDS). The attributes of a PDS include the number of units participating in the sequence, in addition to other factors such as the type of initiating event, the severity and timing of core damage, and the mitigating system status.

Thus, the OPG PSAs have always been multi-unit PSAs (MUPSA) in that they explicitly account for multi-unit interactions, even though PSA results are expressed on a per-unit, per-hazard basis. Through careful risk aggregation, the per-unit based PSA results may be combined to more fully quantify MUPSA (or whole-site PSA) risk metrics for a given hazard type.

## Efforts Related to Whole-Site Risk Estimation

OPG has fulfilled its commitment to provide the Pickering whole-site PSA. The work is complete and was submitted to CNSC staff in December 2017. Much of this work was performed in collaboration with industry via the CANDU Owners Group (COG). Furthermore, OPG and industry members have met regularly with CNSC staff to provide updates on progress and to present results.

In January 2014, COG hosted an international workshop on topics related to whole-site risk.

COG members have also actively participated in CNSC workshops and other international initiatives, such as by the IAEA. These workshops were well attended by many experts from around the world, and they served to provide valuable exchanges of information and insights for consideration in the Pickering whole-site PSA.

In February 2014, COG issued an initial, concept-level paper on whole-site PSA, COG-13-9034 Development of a Whole-Site PSA Methodology. This paper provided a general methodology that was accepted by CNSC staff. The paper was made publicly available on OPG's external website.

Furthermore, a COG joint project was launched to further develop the initial concepts in support of the Pickering whole-site PSA. The participants who have been involved and funded this joint project include:

- from within Canada: OPG, Bruce Power, New Brunswick Power; and Canadian Nuclear Laboratories; and
- from overseas: SNN, of Romania, and the Korea Hydro and Nuclear Power Company Limited.

The output of this work has been utilized as part of the overall approach for Pickering whole-site risk assessment, as outlined further below.

## Risk and Safety Concepts

The topic of risk is complex and has been studied extensively. In trying to evaluate risk, it is useful to refer to the following excerpts which provide some high-level, qualitative guidance in the form of overarching objectives.

- Nuclear Safety Control Act - prevent unreasonable risk, to the environment and to the health and safety of persons associated with development and use of nuclear energy.
- IAEA Fundamental Safety Principles - The Fundamental Safety Objective is to protect people and the environment from harmful effects of ionizing radiation. Measures for controlling radiation risks must ensure that no individual bears an unacceptable risk of harm.
- US NRC - Individual members of the public should be provided protection from the consequences of nuclear power plant operation such that individuals bear no significant additional risk to life or health. Societal risks to life and health from nuclear power plant operation should be comparable to or less than the risks of generating electricity by viable competing technologies and should not be a significant addition to other societal risks.

In the above, there are some universal themes around protection of the public and the environment, using the terms "risk" and "safety", and notions on the acceptability and relativity of risks - that is, compared to other risks that the public is normally exposed to.

The word "risk" is commonly used in everyday language, in some context or another. Risk can be used to indicate the degree of safety of an activity - recognizing that there are inherent risks in many human activities, such as driving a car. In very general terms, risk is the likelihood of an undesirable event multiplied by the consequence of the event.

As a simple illustration, Figure C.1 shows how risk can be qualitatively characterized in terms of high, medium, and low risks – depending on both the likelihood and consequences of events.

| Likelihood | Potential Consequence | | | | |
|---|---|---|---|---|---|
| | Negligible | Minor | Moderate | Major | Extreme |
| Almost Certain | Medium | High | High | Very high | Very high |
| Likely | Medium | Medium | High | High | Very high |
| Possible | Low | Medium | Medium | High | High |
| Unlikely | Low | Medium | Medium | Medium | High |
| Rare | Low | Low | Low | Medium | Medium |

Key for black & white print:

| | |
|---|---|
| Green | Low |
| Yellow | Medium |
| Amber | High |
| Red | Very high |

**Figure C.1 -** Example of qualitative characterization of risk in terms of likelihood and potential consequences of events

In the assessment of risk for any activity, the criteria that define tolerable versus intolerable risk are often quite challenging to determine. As a case in point, the excerpt below is from a Canadian Federal Court ruling for an incident that occurred outside of the nuclear industry; the excerpt can be found on the CNSC's public website.

*...safety is not measured. It is judged and it is judged according to an assessment of an acceptable risk: ... An acceptable risk is essentially a value-based proposition determined by policy and/or by those authorized by governments to judge safety and/or by those exposed to the risk.*

A key point to highlight is that safety is not measured. Rather, it is a judgement that is based on an assessment of what is deemed to be an acceptable risk associated with the activity. These concepts apply to nuclear safety as well.

## Pickering Whole-Site Risk: Overall Approach and Key Results from the Whole-Site PSA

The overall approach for the Pickering whole-site risk assessment is basically comprised of two elements: a qualitative assessment to describe how nuclear safety is assured and a quantitative set of studies associated with whole-site PSA.

### 1. How nuclear safety is assured at a nuclear power plant site

The first element involves setting the appropriate context and broad perspective for the discussion of whole-site risk and the role of PSA. Site risk has always been considered and managed at OPG's nuclear facilities, including at Pickering.

As explained in a COG white paper (COG-JP-4499-025-R1, Whole-Site Risk Considerations for Nuclear Power Plants), the evaluation of whole-site risk involves the consideration of both qualitative and quantitative information that facilitates a value judgment of the reasonableness of risk and is informed by many factors within a broad perspective that includes various programmatic, deterministic, and defense in depth considerations, as well as PSA. This is consistent with the general principles of risk-informed decision making.

Hence, whole-site PSA is distinguished as a supporting tool and subset of whole-site risk assessment. That is, PSA plays an important complementary role to other factors. Its main benefit is to help identify risk insights for improvement of plant safety. Furthermore, calculated PSA risk metrics provide an indication of the level of plant risk – not an absolute measure of safety.

OPG and other utilities have always considered various sources of risk at their nuclear power plant (NPP) sites when making a determination on the adequacy of safety. OPG demonstrates the reasonableness of site risk by means of various programs that:

a. are in place for all aspects of operation;

b. comply with applicable regulatory requirements;

c. collectively, assure NPP safety; and

d. manage risk to be reasonably low.

Whole-site risk should not be characterized by a single number. Rather, as explained in the COG white paper, whole-site risk evaluation is supported by an integrated assessment using quantitative and qualitative information in 14 Safety and Control Areas (SCAs). At Pickering NGS, the aforementioned programs are in place for each SCA to ensure effective risk management (for example, via the Risk and Reliability Program). These programs are robust and are briefly described the Pickering NGS Licence Application (Reference C.1).

OPG maintains oversight and regularly assesses the performance of these programs, and periodically improves the programs as necessary. Collectively, the programs serve to assure nuclear safety and that the overarching objectives on protection of public health and the environment are met. Furthermore, the annual CNSC Integrated Plant Rating for each station is viewed as an independent indication that the overall risk associated with each site is limited to a reasonable level. Recent Integrated Plant Ratings for Pickering NGS have been Fully Satisfactory, which supports that the Pickering whole-site risk is low.

In the most general sense of the term, risk aggregation (whole-site risk) is addressed holistically as discussed above. Caution must be exercised with any form of numerical risk aggregation. For instance, the simple addition of PSA risk values across all hazards may yield a biased result due to the large uncertainties and conservative assumptions associated with external hazards such as seismic and high winds (i.e., the sum of the means may not equal the mean of the sum). Furthermore, as indicated earlier, for a given hazard type, a multi-unit PSA risk result (such as LRF) is generally not equal to the per-unit risk value multiplied by the number of units on site. Moreover, not all hazards are quantified in terms of PSA risk metrics (for example, malevolent acts) and hence, they do not lend themselves to risk aggregation by arithmetic summation of common risk metrics. The COG white paper also discusses numerical risk aggregation of the different hazard PSA results and the manner in which such risk aggregation results can be meaningfully presented - as part of a whole-site PSA (which is in support of the broader approach to whole-site risk).

With respect to the current OPG per-unit PSA safety goals (SCDF and LRF), it is important to note that their underlying basis was originally rooted in serving as surrogates for meeting health objectives while also providing a reasonable basis to address other potential impacts; in particular, large releases of long-lived radioactivity leading to extensive land contamination of the environment.

The per-unit LRF goal ($1x10^{-5}$/yr) is more directly linked to these aspects. However, these PSA goals are targets, not "hard limits"; the values are somewhat arbitrary and represent a broad consensus for individual reactor units. A LRF value on the order of $10^{-5}$/yr (i.e., somewhat greater than $1x10^{-5}$/yr) can still provide margin to quantitative health objectives, QHOs (such as the US NRC QHOs), and is a reasonable basis for other considerations discussed above.

## 2. Whole-Site PSA

This element of the overall approach focusses on the application of whole-site PSA, as a means of providing a quantitative perspective on the whole-site risk. For the Pickering whole-site PSA, the major tasks involved the following:

- The development of guidance for the assessment of lower power reactor operating states, recognizing that the PSAs have traditionally assessed 100% full-power conditions, and not the intermediate operating states between the Guaranteed Shutdown State and full power;
- The application of this guidance for the Pickering "A" and "B" reactor units;
- The development of a general method to determine which other sources of on-site radioactivity, besides the reactors, need to be addressed within a whole-site PSA;
- The systematic and detailed walkdowns of the Pickering site to identify the non-reactor sources;
- The development and application of risk assessment methodology for the irradiated fuel bays at Pickering;
- A risk assessment of the Pickering used fuel dry storage facility;
- The comprehensive updating of the Pickering 1, 4 and Pickering 5-8 reactor PSAs and risk estimates, to reflect modelling enhancements and physical plant improvements; and
- The numerical aggregation of PSA results, across the site.

### Results for lower power reactor operating modes and other non-reactor sources of radioactivity

With respect to other reactor operating modes, the current PSAs explicitly cover the 100% full-power (FP) operating state and the Guaranteed Shutdown State (GSS). CNSC REGDOC-2.4.2 requires the assessment of other states where the reactor is expected to operate for extended periods of time. As part of the Pickering whole-site PSA, such states have been comprehensively assessed following the COG guideline for selection of the "other states", called plant operating states (POS). The applications of this guideline for Pickering 'A' and Pickering 'B' have been submitted to CNSC staff. All stages of the reactor start-up and shutdown procedures were reviewed, and it was confirmed that the risk is bounded by the 100% Full Power and outage PSAs. Based on this work, the overall conclusion is that the risk associated with these operating states is low.

With respect to other sources of radioactivity on the Pickering site, i.e., besides the reactors, comprehensive work was performed to assess the associated risk. OPG followed the COG general approach for source identification and screening, i.e., to identify sources of radioactive material that potentially fall within the scope of a whole-site PSA and to develop criteria for deciding if a source should be included within the scope of a whole-site PSA. The systematic application of this approach for the Pickering site was documented and submitted to CNSC staff, and included detailed walkdowns at the site. The whole site was checked for sources that could result in a large release of cesium-137 – whether releasable by the sources themselves, or in combination with other sources. Based on this work, various non-reactor sources of radioactivity were screened out as being insignificant risk sources at Pickering, with the exception of two sources identified for further study: the irradiated fuel bays (IFB) and the used fuel dry storage facility.

An IFB risk assessment methodology was developed by COG, and a risk assessment of the Pickering IFBs has been conducted, generally consistent with the COG method. The IFB risk assessment involves both deterministic and probabilistic considerations, and was submitted to CNSC staff. The overall conclusion is that the risk associated with the Pickering IFBs is low.

OPG also submitted its assessment of the Pickering used fuel dry storage facility. The overall conclusion is that the risk associated with this facility is low.

## Results of PSA risk aggregation

The current per-unit, per-hazard based PSAs have provided risk insights that have led to improvements in plant design and operation. It was recognized that further risk insights might be obtained through the calculation of PSA results on a station-wide basis for each hazard type (i.e., a set of all-units, per- hazard results).

The primary figure of merit is the site-based LRF, as it is a more direct indicator of risk to the public than a site-based SCDF. The COG white paper outlines the general methodology for the arithmetic aggregation of per-unit LRF results to express the LRF on a per-station basis for a given hazard type (i.e., how to obtain an all-units, per-hazard LRF value). Essentially, the LRF aggregation across all units is a form of extrapolation of the per-unit based LRF results, leveraging the multi-unit contributions that have already been accounted for in the per-unit based PSA (as described earlier). As such, it represents a pragmatic approach to estimating the site LRF for a given hazard type.

It is noted that the approach requires careful decomposition of the per-unit based PSA results and that some assumptions may be necessary in lieu of more detailed PSA modelling of all units. One needs to very carefully utilize the per-unit based large release frequency information so as to avoid overcounting events in the aggregation. For example, if the per-unit large release frequency calculation already accounts for a seismic event that causes all units to simultaneously undergo severe core damage and result in a large release - then, in the per-site large release frequency aggregation, that same event should only be counted once and not multiple times for each of the non-reference units.

To summarize the key terms, the OPG per-unit based PSA is in fact a multi-unit PSA (MUPSA) in that:

- the *per-unit LRF* represents the likelihood of an off-site large release due to severe accidents that involve the "reference unit", either that unit alone or simultaneously with one or more of the other (non-reference) units.

The LRF aggregation approach enables a more comprehensive MUPSA quantification in that:

- the *per-site LRF* represents the likelihood of an off-site large release due to severe accidents that involve "any" one or more of the units (whether the reference or non-reference units).

The PSA risk aggregation calculations consider all six operating units from the "A" & "B" sides of the station and are based on a number of items, including:

- Pickering "B" PSA results from the 2017 S-294 PBRA updates for internal and external hazards;
- Pickering "A" risk estimates based on the 2014 PARA updates with Fukushima Action Plan items and various elements of the Pickering risk improvement plan;
- Emergency mitigation equipment (EME);
- Plant modifications being pursued in relation to the Periodic Safety Review; and
- Severe Accident Management Guidance (SAMG).

While there is no site LRF safety goal per se, the calculated values of site LRF are conservatively compared against the per-unit LRF safety goal of $1 \times 10^{-5}$/reactor-yr. For each hazard, the corresponding Pickering NGS site LRF is less than $1 \times 10^{-5}$/yr (see Table C.1), i.e., well below the per-unit LRF safety goal.

As discussed above under Element 1, whole-site risk should not be characterized by a single number and risk aggregation across all hazards is not technically appropriate. Notwithstanding, the simple addition of the per-site LRF aggregation results across all hazards is calculated to be 0.82 x $10^{-5}$/yr, as shown in Table C.1, i.e., this is still lower than the per-unit LRF safety goal, which is normally applied on a per-hazard basis. These results serve to indicate that the Pickering whole-site risk is acceptably low.

| Hazard | Large Release Frequency (x $10^{-5}$ per year) |
|---|---|
| | per site |
| Internal Events | 0.18 |
| Internal Floods | 0.07 |
| High Wind | 0.31 |
| Internal Fires | 0.17 |
| Seismic | 0.09 |
| Total | 0.82 |

**Table C.1** - Summary of Pickering NGS LRF Aggregation

## Risk Aggregation Calculation

Detailed calculation of Pickering NGS LRF aggregation

### For each hazard type:

**Pickering NGS LRF = PNGS 'A' LRF + PNGS 'B' LRF**

### For each side of station:

**LRF = LRF from single-unit events + LRF from multi-unit events**

**PNGS 'A' LRF = 2 x single-unit LRF + 1 x two-unit LRF**

**PNGS 'B' LRF = 4 x single-unit LRF + 2 x two-unit LRF + 1 x four-unit LRF**

where, for each side of the station (as applicable):

- the "single-unit" LRF is a subset of the per-unit LRF that includes initiating events for which only a single unit is affected (i.e., reference unit only)
- the "two-unit" LRF is a subset that includes accident sequences where two units are simultaneously affected, i.e., the reference unit + one other unit [note: for a four-unit station, there are 3 such combinations, out of a possible 6 two-unit combinations in total]
- the "four-unit" LRF is a subset that includes initiating events that affect all four units simultaneously
- three-unit sequences are very few; lumped with four-unit cases

**Total Whole-Site LRF = Sum across hazards of Pickering NGS LRF for each hazard**

Note: Need to carefully interpret the result.

## Insights

Detailed breakdowns and graphical displays of the various Pickering LRF values were provided to the CNSC staff in OPG's submission of December 2017. This facilitates the identification of some additional insights from the whole-site PSA.

For instance, with respect to the Pickering B per-unit LRFs reproduced below in Figure C.2:

- The composite (blue and orange portion) shows the "per-unit" LRF as traditionally calculated in the hazard PSA, where multi-unit effects are taken into account; and
- The "single unit only" (blue portion) represents the LRF contributions for which only the reference unit is involved in accidents leading to large off-site releases.

These results are based on the 2017 S-294 PBRA update (which includes EME) and credit of SAMG and PSR modifications. The proximity of the "per-unit" LRF value relative to the "single-unit only" LRF value illustrates the extent to which multi-unit effects factor into the per-unit LRF. In this case for Pickering B, Figure C.2 shows that the "per-unit" LRF is well above the "single-unit only" LRF for internal events and seismic, indicating that additional multi-unit sequences significantly contribute to the per-unit LRF for both of these hazards (i.e., although the per-unit LRF is "per unit" based, it includes more than just events involving the reference unit only). In contrast, for the case of internal floods, Figure C.2 shows that the "per-unit" LRF is very close to the "single-unit only" LRF value, indicating that although some additional multi-unit sequences are captured – they are not major contributors to the per-unit LRF for Pickering B flood hazards (single-unit events dominate for this hazard type).

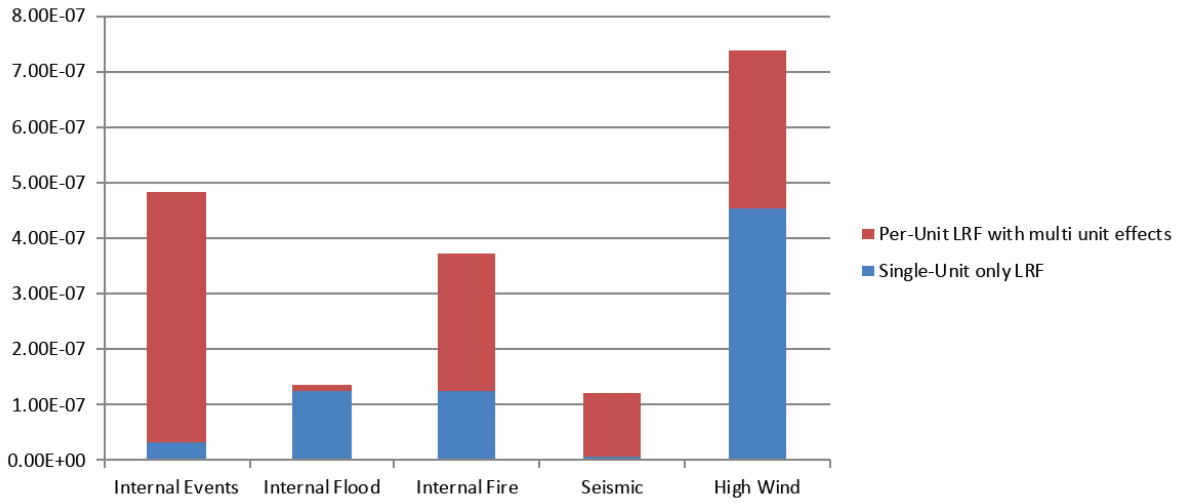


**Figure C.2** - Pickering 5-8 per-unit vs single-unit LRFs

On a per-site (or per-station) basis, the calculated LRF more fully accounts of multi-unit effects, i.e., by consideration of LRF contributions directly from the non-reference units. The proximity of the "per-unit" LRF relative to the "per-site" LRF value represents the extent to which the per-unit LRF covers multi-unit sequences across the station. For example, by inspection of the detailed results from this study, the Pickering B per-unit LRF largely encompasses the LRF aggregated across all units on the Pickering B side of the station, indicating that the Pickering B seismic risk is dominated by sequences where all units are simultaneously affected. Such a comparison of per-unit LRF vs per-station LRF sheds light on the extent of inclusion of multi-unit effects in the per-unit LRF.

As another example, consider the summary of the Pickering NGS per-site LRFs shown below in Figure C.3 Here, the per-site, per-hazard results have also been broken down into the purely “single unit” and “multi unit” contributions. For a given hazard, the ”single units only” (blue portion) represents the site-wide large release frequency associated with events where only a single unit is involved (whether it is the reference unit or one of the non-reference units). The “multi units” (orange portion) represents the additional large release frequency contribution for events which involve more than one unit; and the composite (blue plus orange portions) represents the full value of the site-wide large release frequency, for the given hazard.

Figure C.3 shows that, depending on the hazard, the site risk associated with a hazard may be dominated by multi-unit scenarios (as in the case of internal events) or by single-unit type of events (as in the case of internal fires).

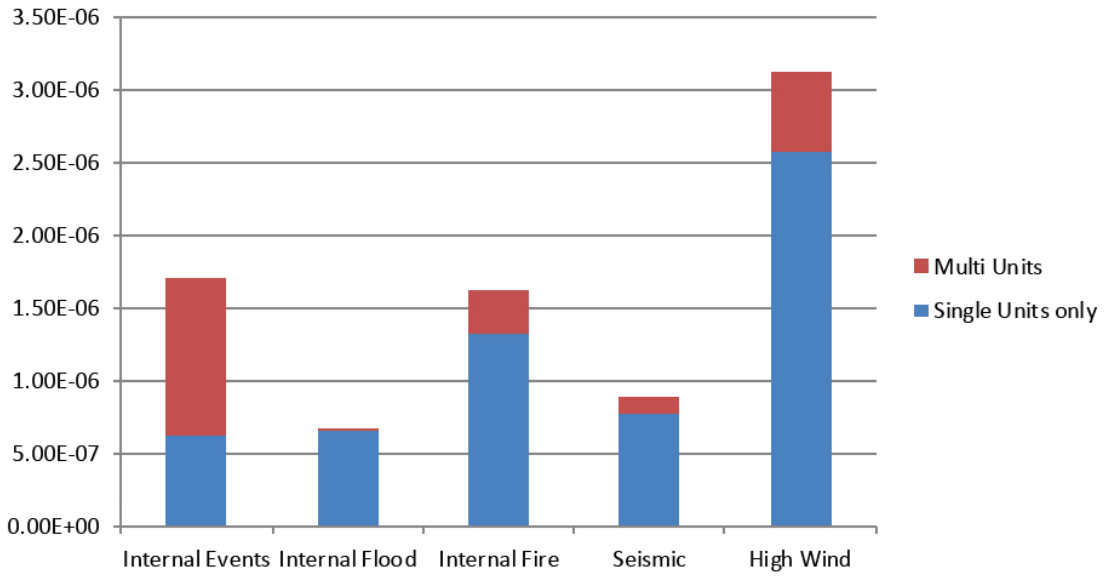


**Figure C.3** - Pickering NGS site-wide LRF summary

Lastly, careful examination of the per-unit vs. per-station LRF results may also shed new light on the relative risk of different hazards. That is, the hazard risk profile may look different when results are viewed from a per-station basis rather than a per-unit basis. For example, based on inspection of the present results:

- for Pickering 5-8, internal flood appears as a comparable LRF risk to internal events and fire when viewed from a Pickering B per-station perspective, and high wind is still dominant; and
- for Pickering 1, 4, high wind appears as a comparable LRF risk to internal events as the dominant risk, when viewed from a Pickering 1, 4 per-station perspective.

## Summary

A substantial amount of work has been conducted in support of Pickering whole-site risk. OPG has worked in collaboration with COG and has kept CNSC informed of progress.

Site risk has always been considered and managed at OPG's nuclear facilities, including at Pickering. Nonetheless, the present study has enabled a new perspective on the characterization of whole-site risk. The overall evaluation of whole-site risk involves the consideration of both qualitative and quantitative information that informs the judgement of risk, and this includes many factors within a broad perspective that encompasses various programmatic, deterministic, and defense-in-depth considerations, as well as PSA.

The traditional OPG PSAs have always been multi-unit PSAs in that they explicitly account for multi-unit interactions, even though the PSA results are expressed on a per-unit basis. Whole-site PSA is an important tool that supports whole-site risk assessment. Through careful risk aggregation, the per-unit based PSA results have been combined to more fully quantify multi-unit PSA risk metrics separately for each hazard type.

Further to the detailed technical insights that were previously gleaned from the per-unit PSAs on a hazard by hazard basis, the Pickering whole-site PSA has identified some additional insights, particularly around the understanding of the relative contributions of purely single vs. multi-unit risks and of the relative risk of different hazards from a site perspective.

The risks associated with other on-site sources of radioactivity, such as the IFBs, as well other (low power) modes of reactor operation, have also been systematically assessed.

The overall conclusion, based on the information provided in this submission, is that the Pickering whole-site risk is low.

OPG will continue to share its learnings with the international community, for example, through IAEA initiatives on multi-unit PSA, and will monitor the best industry practices in this subject area.

## References

[C.1] OPG letter, R. Lockwood to Mr. M. A. Leblanc, "Application for Renewal of Pickering Nuclear Generating Station Power Reactor Operating Licence", August 28, 2017, CD# P-CORR-00531-05055.

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