

# 2024 Nuclear Benchmarking Report



**Safety • Reliability • Value for Money • Human Performance**



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Controllershship – Business Planning & Benchmarking

**ONTARIOPOWER**  
GENERATION

*Electrifying  
life*

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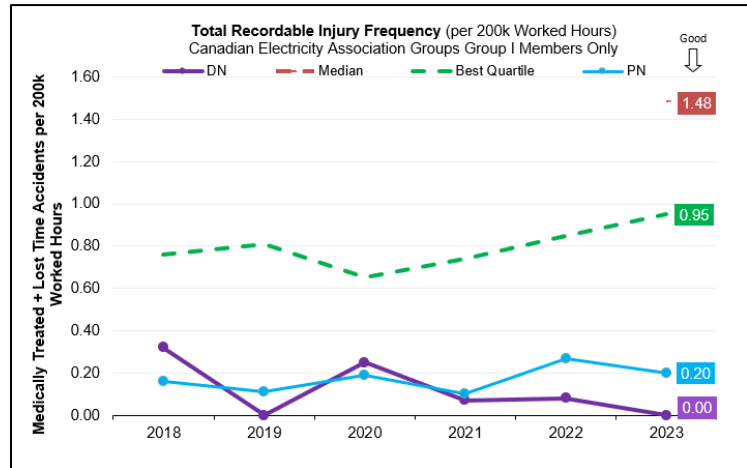
In 2023, Ontario Power Generation (OPG) demonstrated favorable results compared to its peer in number of key areas.

### Safety

#### Total Recordable Injury Rate (TRIF)

Both Darlington Nuclear Generating Station (DN) and Pickering Nuclear Generating Station (PNGS) improved performance in 2023, contributing to OPG's best ever TRIF performance, and exceeding industry top quartile.

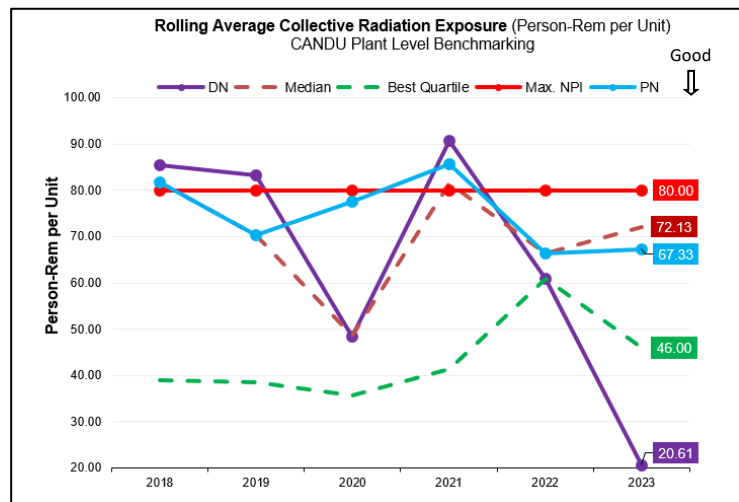
To further strengthen safety performance, OPG continues to build on its Fail-Safe strategy by building capacity & strengthening safety defences, implementing the Edison Electrical Institute Safety Classification & Learning (SCL) model to recognize and mitigate Serious Injuries & Fatalities (SIF) precursor conditions, as well as the integration of the Electronic Safe work Planning & Pre-Job Briefing (eSWP) platform to enhance sharing of safe work planning knowledge including the Energy Wheel to identify energy hazards.



#### Collective Radiation Exposure (CRE)

DN and PNGS continued to achieve maximum Nuclear Performance Index (NPI) in 2023. DN improved performance is due to the planned outage schedule in 2023 of zero outages. PNGS CRE slightly increased as a result of planned and unplanned outage scope.

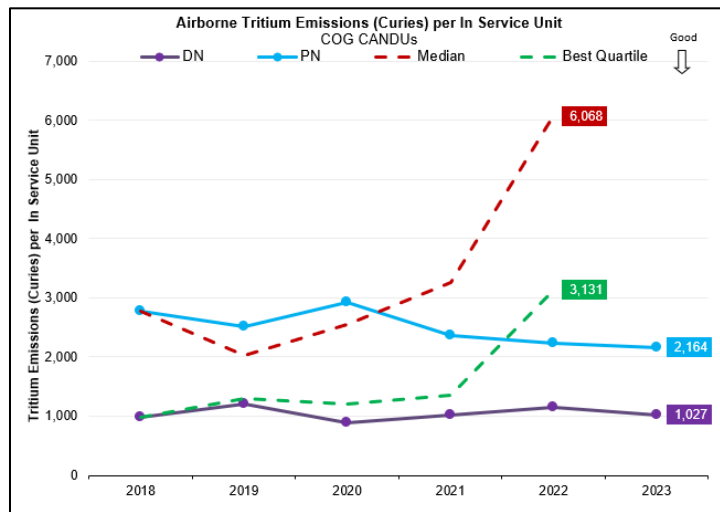
DN and PNGS have implemented source term controls including utilizing dose reducing Lanxess resin and improved shielding to reduce dose rates. PNGS is also continuing to focus on foreign material and chemistry heat transport purification management.



### Airborne Tritium Emissions

PNGS and DNGS Airborne Tritium Emissions remain at a very small fraction of regulatory limits.

DNGS and PNGS achieved top quartile in 2023, largely driven by the increase of industry quartiles. This factor led to PNGS achieving top quartile in 2023 for the first time since 2005. DNGS continued best quartile performance is also attributable to tritium identification and reduction activities.

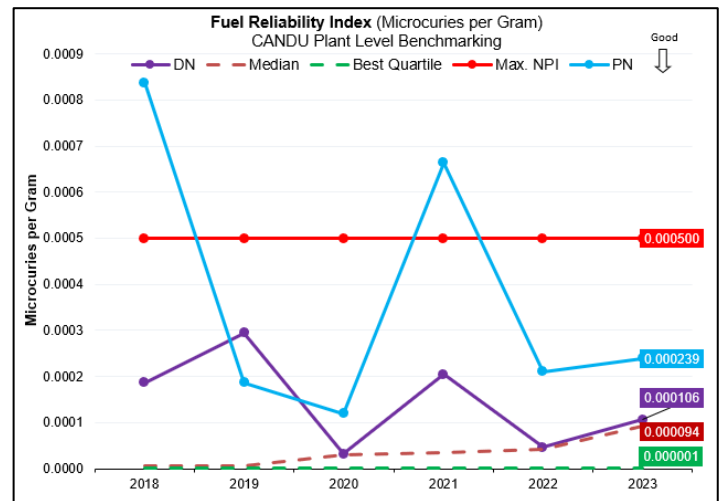


Both sites have continued tritium reduction activities driven by a High Impact Team (HIT), enhancing focus on tritium sources identification and enhanced management oversight. In addition, collaboration between both sites to exchange operating experience, innovation activities on tritium mitigation, and benchmark performance.

### Fuel Reliability Index (FRI)

DNGS and PNGS continued to achieve maximum NPI points in 2023.

One fuel defect was observed for DNGS in 2023 in comparison to zero in 2022. Two fuel defects for PNGS were confirmed in 2023, similar to 2022.



Continual efforts to enhance performance at both sites includes completing the fuel design manual and drawing update which strictly controls the manufacturing process as well as the fuel operating, fuel handling and fuel performance limits. PNGS is also improving surveillance methods and eliminating foreign materials from entering the Heat Transport System through improved Fuel Handling and Outage practices. DNGS continues to mitigate fuel debris failures by utilization of Foreign Material Exclusion practices.

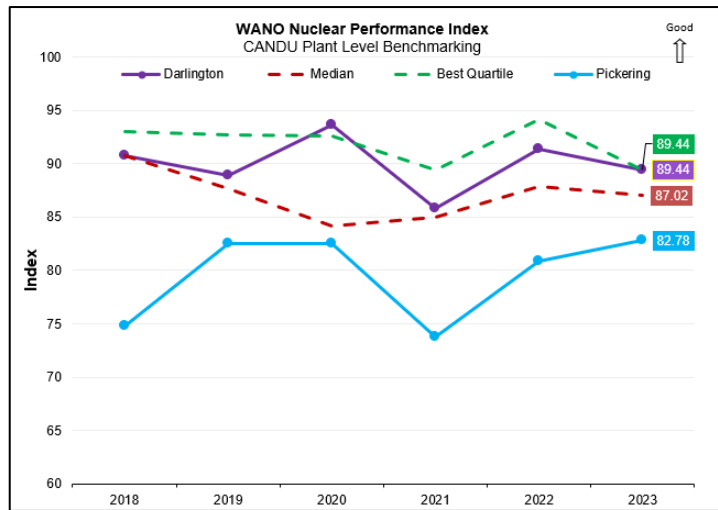
The five other safety-related metrics at DNGS and PNGS were favourable and achieved green ratings in 2023. Both DNGS and PNGS achieved maximum World Association of Nuclear Operators (WANO) NPI results and best quartile performance for all NPI Safety sub-metrics.

## Reliability

### Nuclear Performance Index (NPI)

In 2023, DNGS performance continues to achieve best quartile due to excellent performance for all seven of the safety metrics.

PNGS performance improved in 2023 due to Unit Capability Factor (UCF) and Forced Loss Rate (FLR) improving performance. PNGS’ third quartile performance also reflects the need for extended outages to accommodate fuel channel inspection programs, unbudgeted planned outages for non-routine maintenance work and unplanned outages due to external causes which impact UCF, Collective Radiation Exposure (CRE) and Chemistry Performance Index (CPI) Metrics.

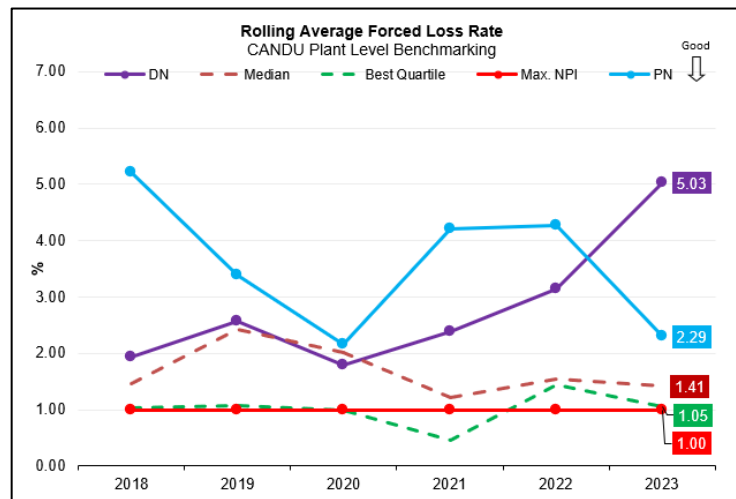


### Forced Loss Rate (FLR)

In 2023, FLR performance declined at DNGS and improved at PNGS.

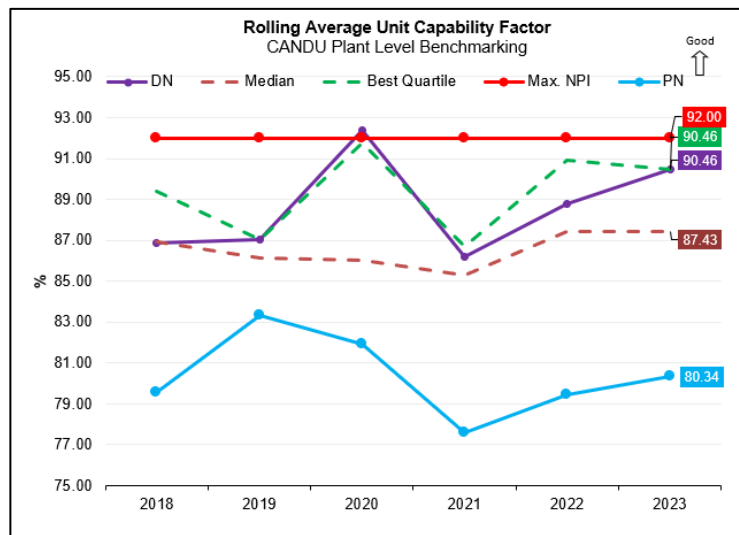
PNGS experienced six forced outages in 2023 compared to elevated FLR in 2021 which is no longer included in the rolling window. DNGS experienced one forced outage and was attributable to post refurbishment outage events on Unit 2.

Fuel handling contribution reduced in 2023 and remains a focus area to build sustainability. Focused initiatives including vulnerability identification and elimination, proficiency building and project execution at both stations to increase Turbine Generator Reliability, the highest fleet contributor. Fuel handling remains a fleet focus area to build sustainability.



### Unit Capability Factor (UCF)

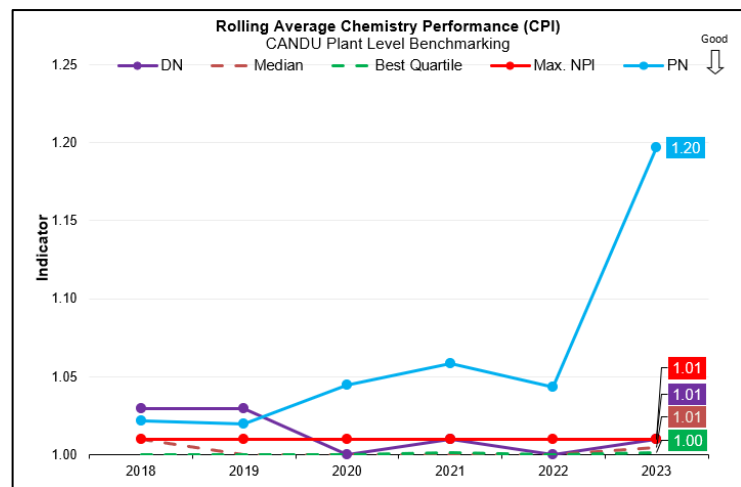
In 2023, DNGS improved to achieve best quartile and PNGS remained in fourth quartile. PNGS improved performance is attributable to improved FLR performance in 2023 compared to elevated FLR in 2021 which is no longer included in the rolling average. This was partially offset by increased planned outage days in 2023 in comparison to 2021. DNGS best quartile performance in 2023 is attributable to reduced planned outage days in 2023 compared to 2021, partially offset by forced outage events impacting post refurbishment for Unit 2.



Focused initiatives including vulnerability identification and elimination, proficiency building and project execution at both stations to increase Turbine Generator Reliability, the highest fleet contributor. Fuel handling contribution reduced in 2023 and remains a focus area to build sustainability.

### Chemistry Performance Index (CPI)

PNGS decline in 2023 performance is attributed to condenser tube leaks and boiler level transient. Declined performance in 2019-2022 was primarily caused by start-up boiler sulfates due to turbine maintenance activities during outage, and condenser tube leak resulted in elevated boiler ions.



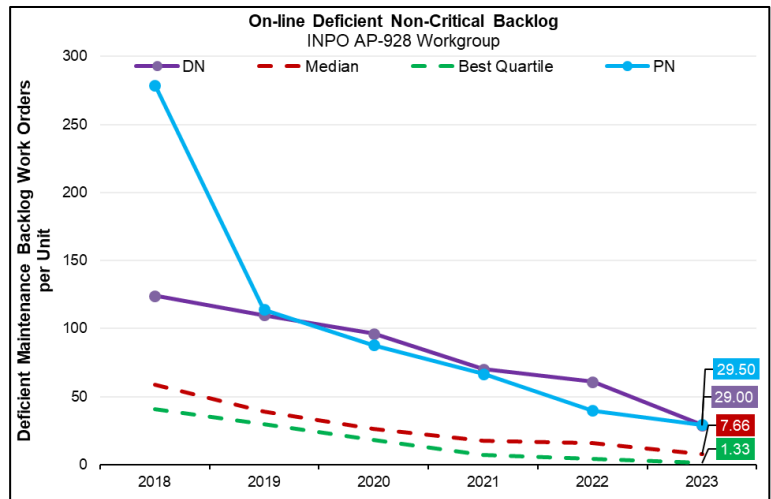
DNGS continues to achieve maximum Nuclear Performance Index (NPI). The slight decline in performance in 2023 compared to 2022 can be attributed to condenser tube leaks on Unit 2.

DNGS and PNGS continue to have a Chemistry Outage Single Point of Contact (SPOC) to provide improved coordination/planning such that system chemistry control is improved during outages/start-ups.

**On-Line Deficient Non-Critical Backlog and Deficient Critical Backlog**

The favourable trend for Backlog performance at PNGS continued into 2023, with significant improvements for On-line Deficient Non-Critical Backlogs (26% improvement) compared to 2022 results.

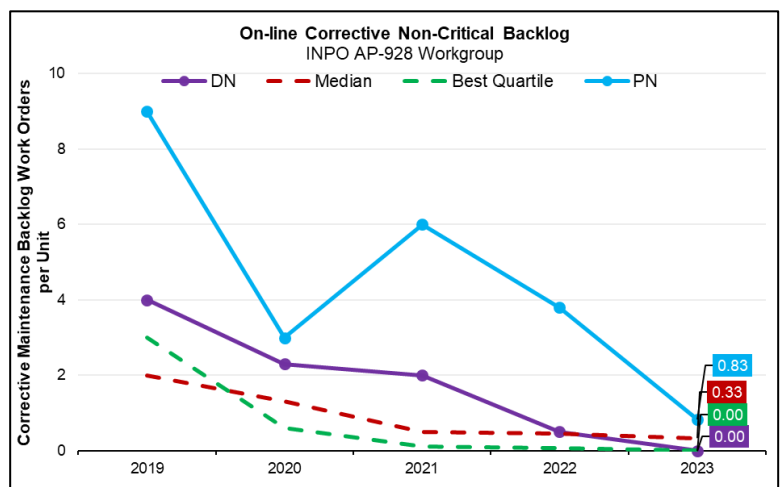
DNGS improved their On-line Deficient Non-Critical Backlog by 52% and Deficient Critical Backlog sustained a best quartile score of zero as a result of continued station focus, overall maintenance efficiency and improved schedule quality.



**On-Line Corrective Non-Critical Backlog and Corrective Critical Backlog**

PNGS On-line Corrective Non-Critical Backlog performance improved in 2023 due to decreases in the Corrective Non-Critical Backlogs.

DNGS remained in the best quartile for the Corrective Critical Backlogs and improved to best quartile for On-line Corrective Non-Critical Backlog performance.

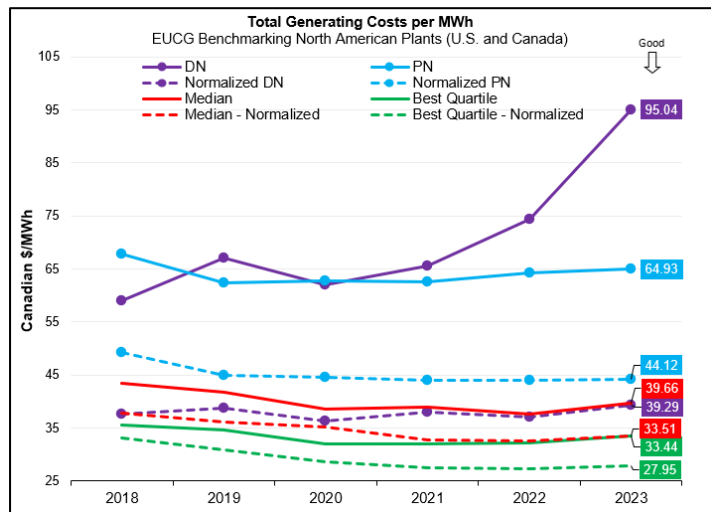


## Value for Money

### TGC/MWh

In 2023, normalized Total Generating Cost per Megawatt-hour (TGC/MWh) performance remained in the third quartile for DNGS and the fourth quartile for PNGS after normalizing<sup>1</sup> for refurbishment, technology including outage duration and age-related impacts.

DNGS normalized performance was impacted by capital investment requirements for life post-refurbishment and reduced 3-year generation related to the refurbishment schedule while PNGS normalized performance reflects continued reduction in capital investment as the station approaches the end of commercial operations in 2026.



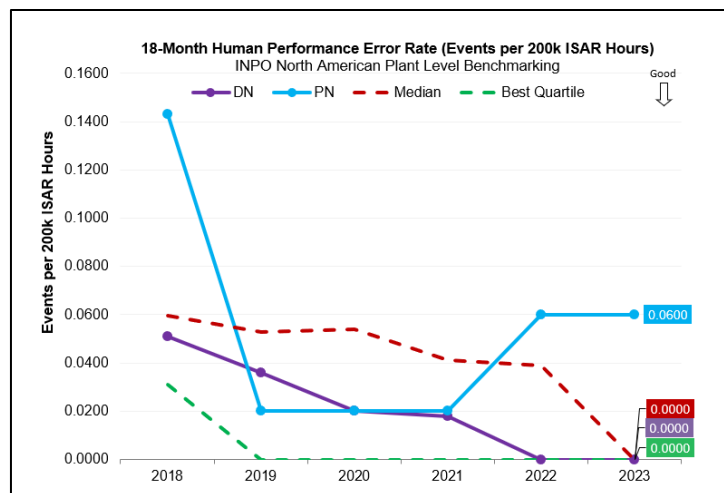
## Human Performance

### Human Performance Error Rate

DNGS maintained best quartile performance and did not experience any Site Event Free Day Reset (S-EFDR)'s in 2023.

PNGS experienced one S-EFDR which contributed to fourth quartile performance. The event causes were identified, and corrective actions implemented to address the gaps.

Human performance continues to be a focus across the fleet with actions taken to further improve performance by continuously improving the Observation & Coaching program as well as integration of Fail Safe strategies and trending processes to strengthen values and behaviours of Nuclear Professionals.



<sup>1</sup> See section 4.0 for more information about the TGC/MWh normalization methodology.

**Benchmarking Results – Plant Level Summary**

Table 1 provides a complete summary of 2023 performance compared to benchmark results.

**Table 1: Plant Level Performance Summary**

Metric	2023 Actuals					
	NPI Max	Best Quartile	Median	Third Quartile	Pickering	Darlington
<b>Safety</b>						
Total Recordable Injury Frequency (#/200k hours worked)		0.95	1.48	2.21	0.20	0.00
Rolling Average <sup>2</sup> Industrial Safety Accident Rate (#/200k hours worked) <sup>1</sup>	0.20	0.00	0.00	0.05	0.00	0.00
Rolling Average <sup>2</sup> Collective Radiation Exposure (Person-rem per unit) <sup>1</sup>	80.00	46.00	72.13	94.67	67.33	20.61
Airborne Tritium Emissions (Curies) per Unit <sup>3</sup>		3,131	6,068	6,845	2,164	1,027
Fuel Reliability (microcuries per gram) <sup>1</sup>	0.000500	0.000001	0.000094	0.000239	0.000239	0.000106
2-Year Reactor Trip Rate (# per 7,000 hours) <sup>1</sup>	0.500	0.000	0.215	0.430	0.247	0.430
3-Year Auxiliary Feedwater System Unavailability (#) <sup>1</sup>	0.0200	0.0000	0.0006	0.0021	0.0019	0.0000
3-Year Emergency AC Power Unavailability (#) <sup>1</sup>	0.0250	0.0002	0.0004	0.0030	0.0000	0.0000
3-Year High Pressure Safety Injection Unavailability (#) <sup>1</sup>	0.0200	0.00000	0.00000	0.00000	0.0000	0.0002
<b>Reliability</b>						
Rolling Average <sup>2</sup> WANO NPI (Index) <sup>1</sup>		89.44	87.02	82.78	82.78	89.44
Rolling Average <sup>2</sup> Forced Loss Rate (%) <sup>1</sup>	1.00	1.05	1.41	2.29	2.29	5.03
Rolling Average <sup>2</sup> Unit Capability Factor (%) <sup>1</sup>	92.00	90.46	87.43	86.59	80.34	90.46
Rolling Average <sup>2</sup> Chemistry Performance Indicator (Index) <sup>1</sup>	1.01	1.00	1.01	1.01	1.20	1.01
1-Year Online Deficient Critical Backlog (work orders per unit) <sup>1</sup>		0.00	0.00	0.50	0.67	0.00
1-Year Online Deficient Non-Critical Backlog (work orders per unit) <sup>3</sup>		1.33	7.66	22.00	29.50	29.00
1-Year Online Corrective Critical Backlog (work orders per unit) <sup>1</sup>		0.00	0.00	0.00	0.00	0.00
1-Year Online Corrective Non-Critical Backlog (work orders per unit) <sup>3</sup>		0.00	0.33	1.00	0.83	0.00
<b>Value for Money</b>						
3-Year Total Generating Costs per MWh (\$ per Net MWh) <sup>1</sup>		33.44	39.66	49.23	64.93	95.04
Normalized 3-Year Total Generating Cost per MWh (\$ per Net MWh)		27.95	33.51	42.57	44.12	39.29
3-Year Total Generating Cost per Unit (M \$ per Unit)		283.01	313.31	358.44	230.73	627.40
Normalized 3-Year Total Generating Cost per Unit (M \$ per Unit)		236.12	276.78	320.69	168.77	277.51
3-Year Non-Fuel Operating Costs per MWh (\$ per Net MWh) <sup>1</sup>		19.64	24.64	32.22	58.31	62.76
3-Year Normalized Non-Fuel Operating Cost per Net MWh (\$/MWh)		19.64	24.64	32.22	--	43.89
3-Year Fuel Costs per MWh (\$ per Net MWh) <sup>1</sup>		6.11	6.68	7.44	3.79	4.05
3-Year Capital Costs per MW DER (k\$ per MW) <sup>1</sup>		33.87	60.01	107.30	19.54	212.29
Normalized 3-Year Capital Cost per MW DER (k\$ per MW)		33.87	60.01	107.30	--	106.57
<b>Human Performance</b>						
18-Month Human Performance Error Rate (# per 200k ISAR and contractor hours) <sup>1</sup>		0.0000	0.0000	0.0410	0.0600	0.0000

1. Best Quartile, Median and Third Quartile are from Q4 2023 best available information.
2. Indicates a 2-Year Rolling Average for Pickering and a 3-Year Rolling Average for Darlington.
3. Best Quartile, Median, Third Quartile are from the Q4 2022 which is the most current available benchmark for these metrics.

**Legend**

4th Quartile Performance	3rd Quartile Performance	2nd Quartile Performance	Maximum NPI points achieved or Best Quartile
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## Background

This report presents a comparison of OPG Nuclear’s performance to that of nuclear industry peer groups. Benchmarking results are used during business planning to drive top-down target setting with business improvement as the objective.

### Performance Indicators

Good performance indicators used for benchmarking are metrics with standard definitions, reliable data sources, and utilization across a representative portion of the industry. Good indicators allow for benchmarking to be repeated year after year in order to track performance and improvement. Additionally, when selecting an appropriate and relevant set of metrics, a balanced approach covering all key areas of the business is essential. In accordance with these criteria, key performance indicators have been selected for comparison to provide a balanced view of performance and for which consistent, comparable data is available. These indicators are defined in Section 6.0.

Each indicator reflects a particular duration of historical performance in accordance with peer group expectations. For example, Electric Utility Cost Group (EUCG) data for Value for Money metrics are based on three-year average performance, whereas WANO NPI safety and reliability metrics reflect multi-year rolling averages based on each station’s outage cycle. For NPI metrics, Darlington and Pickering’s results reflect a three-year and two-year outage cycle, respectively.<sup>2</sup>

### Industry Peer Groups

Peer groups were selected based on performance indicators widely utilized within the nuclear industry. Overall, six different peer groups were used as illustrated in Table 2 of Section 6.0 and panel members are detailed in Tables 3 to 8 of Section 6.0.

### Report Structure

Sections 2.0 to 5.0 of the report focus on safety, reliability, value for money and human performance areas.

The Major Operator Section (historically Section 6.0) was removed from this report, consistent with ScottMadden’s recommendations with respect to streamlining the report and ensuring consistency with leading practices and value for stakeholders. The Major Operator section provided a fleet operator level summary across a few key metrics, primarily across North America, utilizing a simple average of the results (mean) from each of their units/plants. While the operator level summary can be informative, it is more appropriate to look at OPG’s two nuclear facilities individually given that they are at different stages of their lifecycle, have different sized units and reflect different generations of CANDU technology. This view is aligned with ScottMadden’s most recent evaluation OPG Nuclear Benchmarking. The detailed data in sections 2.0 to 5.0 of the report provides a more complete picture of OPG’s performance.

Section 6.0 provides an appendix of supporting information, including common acronyms, definitions, peer group and panel composition details.

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<sup>2</sup> The planned outage cycle for each unit at Pickering is transitioning from a 24-month to a 30-month outage cycle. Pickering continues to assume a 24-month rolling average for benchmarking to be consistent with WANO reporting expectations.

## Methodology and Sources of Data

The majority of safety metrics were calculated using data from WANO. Data labelled as invalid by WANO were excluded from all calculations. Indicator values of zero are not plotted or included in calculations except in cases where zero is a valid result. Current data was obtained and consolidated with previous benchmarking data.

The WANO Nuclear Performance Index (NPI), a maximum score of 100 is possible. The WANO NPI is an operational performance indicator comprised of 10 metrics, 7 of which are analyzed in this section:

- Industrial Safety Accident Rate (ISAR) [Rolling Average]
- Collective Radiation Exposure (CRE) [Rolling Average]
- Fuel Reliability Index (FRI) [Annual]
- 2-Year Unplanned Automatic Reactor Trips
- 3-Year Auxiliary Feedwater Safety System Performance Unavailability
- 3-Year Emergency AC Power Safety System Performance Unavailability
- 3-Year High Pressure Safety Injection Unavailability

The remaining three WANO NPI metrics are included in the Reliability Section (Section 3.0).

Note: To benchmark performance, Max NPI is used to indicate best quartile performance for metrics that perform better than the Max NPI benchmark. If metric performance is not better than Max NPI, quartile benchmarks are used to benchmark performance.

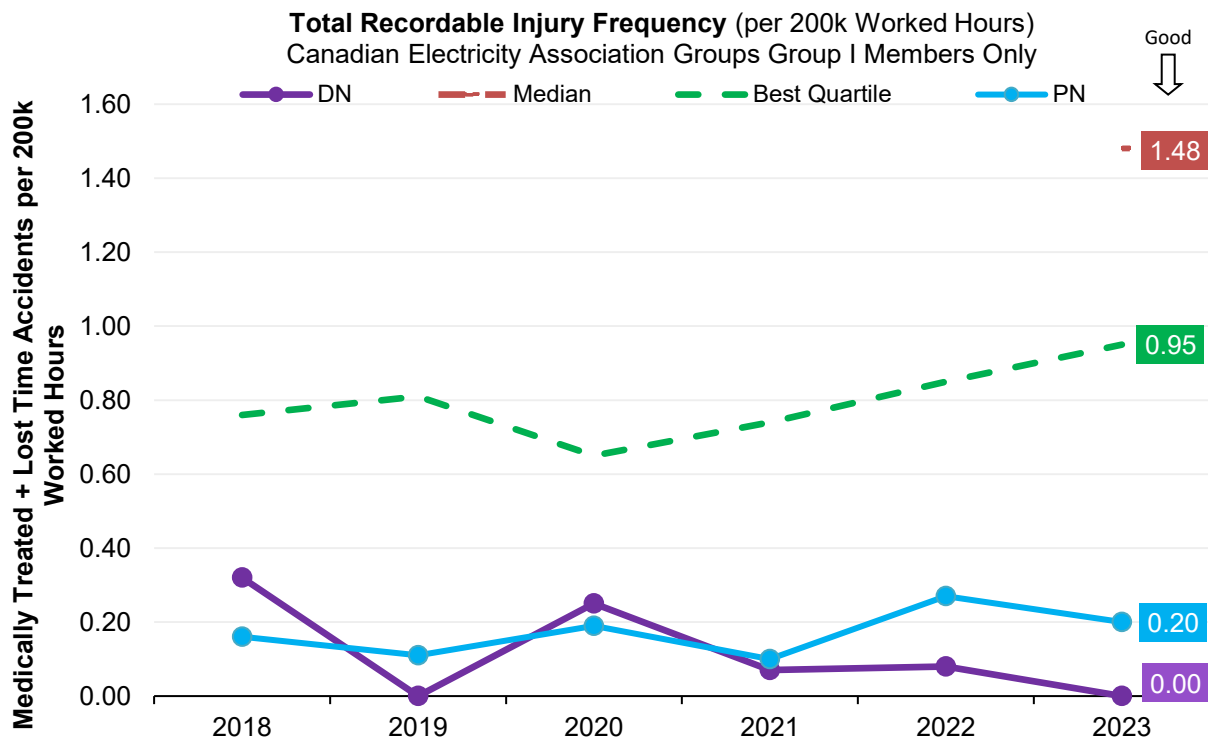
In addition to the WANO NPI safety sub-indicators listed above, Total Recordable Injury Frequency and Airborne Tritium Emissions per In Service Unit are included in this section of the report.

Total Recordable Injury Frequency (TRIF) was calculated using data from the Electricity Canada (EC). The peer group are members of Electricity Canada (EC) (Section 6.0, Table 6).

- OPG benchmarks against EC Group 1 peers (a subset of all EC members), which incorporates organizations with more than 1,500 employees, including most provincial utilities, leveraging EC's Occupational Health & Safety Statistics 2023 Report.

Airborne Tritium Emissions per In Service Unit data was collected from the CANDU Owners Group (COG). The peer group for this metric is all CANDUs who are a member of COG. There is a one-year lag for the industry values associated with this metric.

**Total Recordable Injury Frequency (TRIF)**



Note: Annual Value; median unavailable 2018-2022.

	2023 Value
DN	0.00
PN	0.20
Best Quartile	0.95
Median	1.48

**Factors Contributing to Performance**

- DNGS and PNGS improved performance in 2023 continued a long-standing pattern of excellent TRIF performance by exceeding the industry top quartile (top 25%) mark of 0.95 and top decile (top 10%) mark of 0.56, where DNGS reached 0.00 and PNGS achieved 0.20.
- Both DNGS and PNGS combined TRIF performance of 0.13 contributed to OPG’s best TRIF performance of 0.16 in 2023 since the company’s inception in 1999 and was the best performance in 2023 when compared to Electricity Canada’s Group 1 companies with over 1,500 employees.

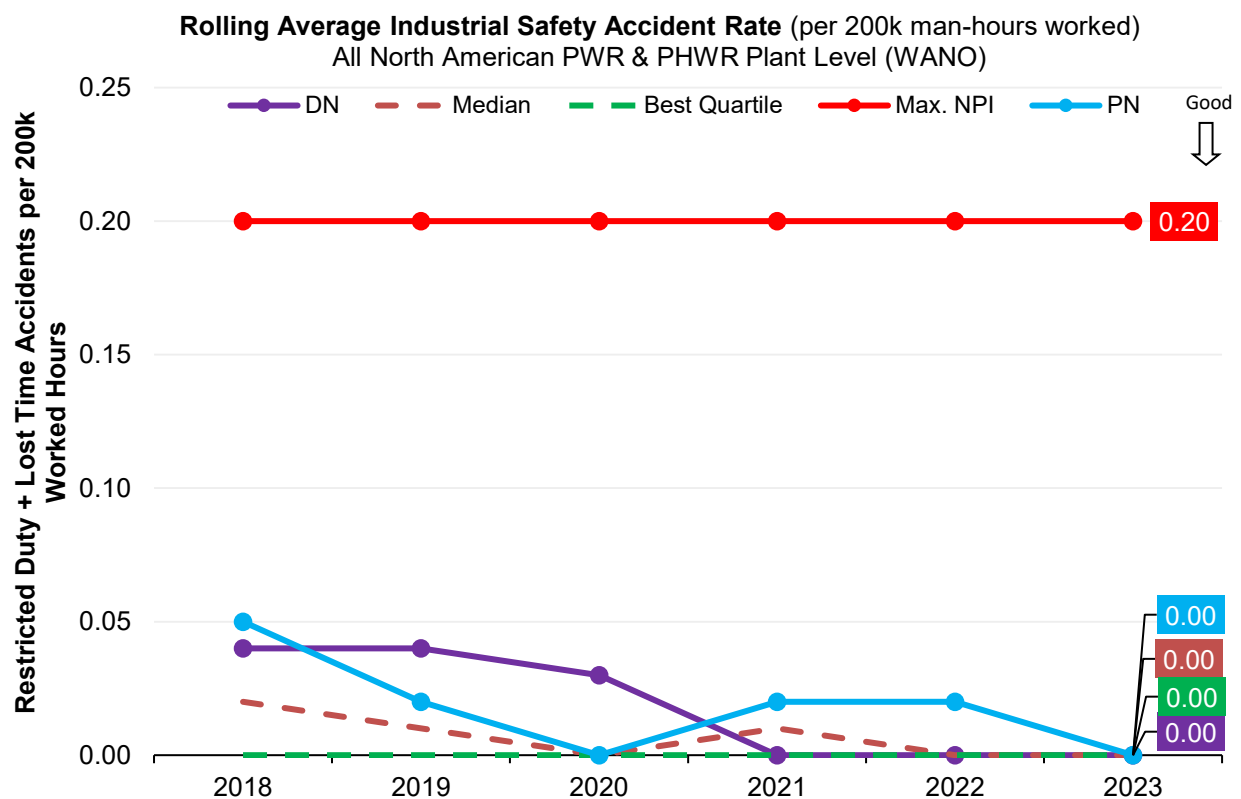
**Initiatives to Improve and Sustain Favorable Performance Include:**

Implementation of the following initiatives are aimed at leading OPG to world-class safety performance:

- OPG continues to build upon its Fail-Safe Strategy to reduce the frequency of employee injuries by building capacity and strengthening safety defences.

- As part of the Fail-Safe Strategy, OPG is modernizing how it classifies safety events - through the implementation of the Edison Electrical Institute Safety Classification and Learning (SCL) model. The SCL model helps enable early recognition and mitigation of Significant Injuries & Fatalities (SIF) precursor conditions to learn from safety events and prevent recurrences. In addition, the SCL model identifies if barriers/controls were in place when the event occurred, providing learnings and insights on where OPG can make improvements.
- OPG has an ongoing initiative to modernize Pre Job-Briefs (PJBs) and Safe Work Plannings (SWPs) into a single integrated digital platform, the Electronic Safe Work Planning & Pre-Job Briefing (eSWP) platform. The eSWP will strengthen Fail-Safe defences and enhance the sharing of safe work planning knowledge. The eSWP platform will also feature The "Energy Wheel" tool, to aid in the identification of energy hazards that are often overlooked, and to support workers in implementing additional safety precautions for high-energy tasks that pose significant risks in the event of human error or equipment failure.
- Updates have been made to data systems to integrate and facilitate trending of safety events as well as the early identification of emerging safety risks.
- OPG continues to incorporate and implement external benchmarking learnings to achieve industry best practice.

**Rolling Average Industrial Safety Accident Rate (ISAR) \* †**



\* Sub-indicator for WANO NPI

† 2 Year Avg PNGS, 3 Year Avg DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	0.00
PN	0.00
Best Quartile	0.00
Median	0.00

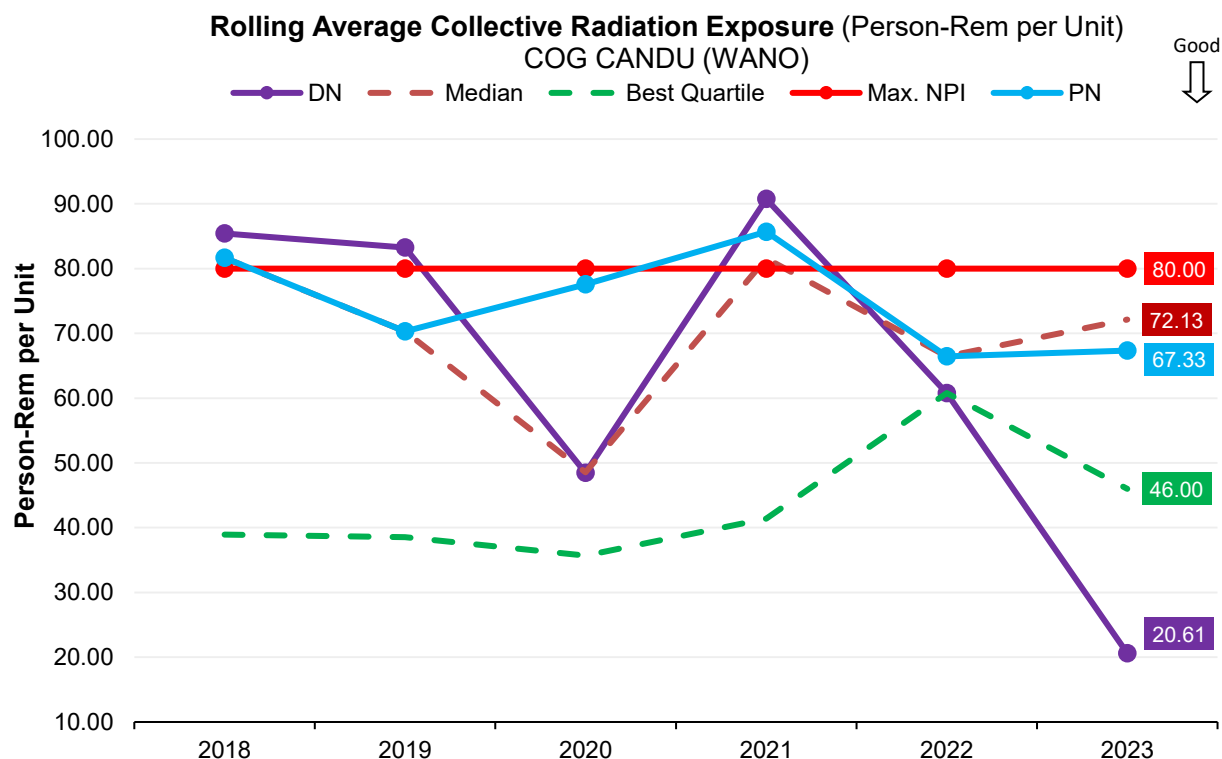
### Factors Contributing to Performance

- DNGS and PNGS continued to achieve maximum Nuclear Performance Index (NPI) points.
- DNGS achieved best quartile performance with zero ISAR events during the last 3-year rolling average reporting period.
- PNGS achieved best quartile performance with zero ISAR events during the last 2-year rolling average reporting period.

### Initiatives to Improve and Sustain Favourable Performance Include:

- OPG continues to prioritize the implementation of the Fail-Safe health and safety program, which focuses on high-energy work, sequential control measures, event learning, and various strategies:
  - Modernization of safety metrics to incorporate leading indicators for early intervention includes the use of Quality of Safety Practices (QSP) which monitors high and low energy conventional safety risks to identify vulnerability and opportunities to increase capacity by implementing controls.
  - Implementation of Electronic Safe Work Planning (eSWP) which aims to assess the quality of direct controls addressing high-energy hazards within safe work plans.
  - Adoption of the Edison Electrical Institute Safety Classification and Learning (SCL) model to better identify more learning opportunities through safety classifications which will allow for better benchmarking within the industry.
  - Enhancing the oversight program with a graded approach that monitors performance for prevention and early intervention by increasing oversight to address behaviors and/or program deficiencies through Observation and Coaching (O&C's), metrics, audits/assessments, benchmarking, and events.

**Rolling Average Collective Radiation Exposure (CRE) \* †**



\* Sub-indicator for WANO NPI

† 2 Year Avg PNGS, 3 Year Avg DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	20.61
PN	67.33
Best Quartile	46.00
Median	72.13

**Factors Contributing to Performance**

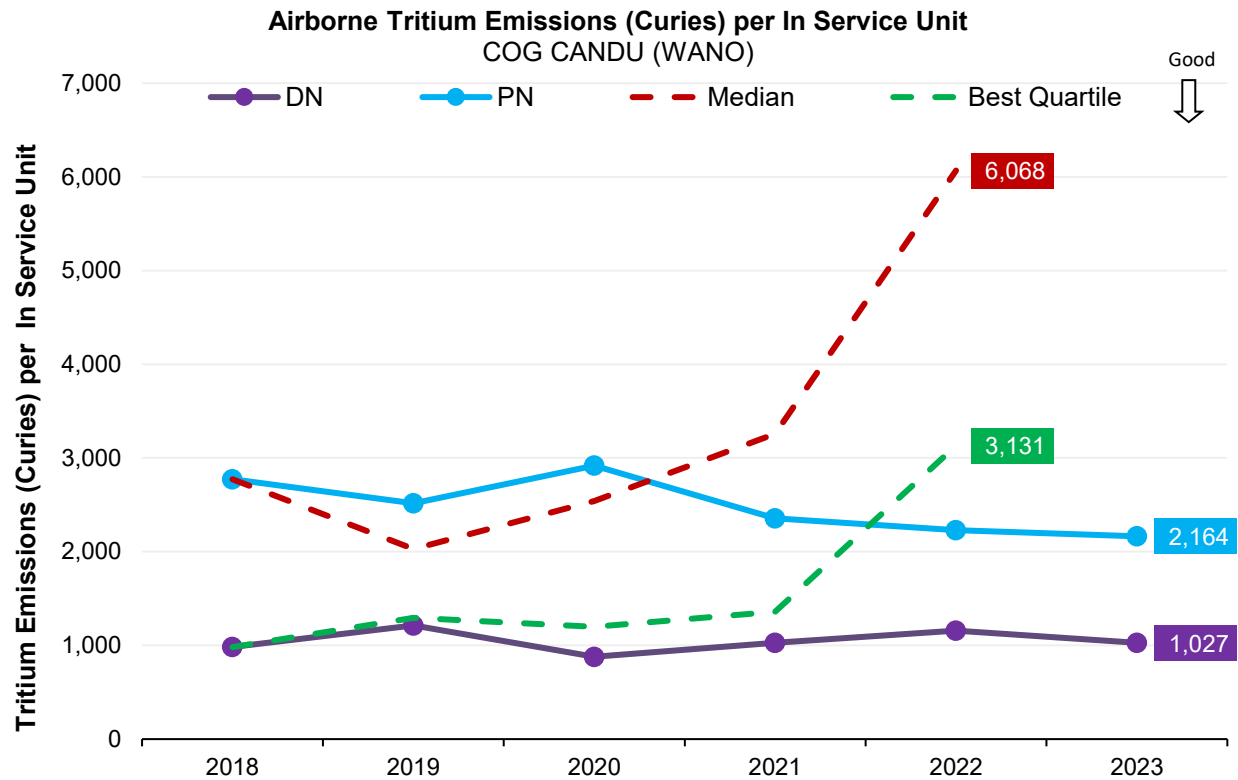
- DNGS and PNGS continued to achieve maximum Nuclear Performance Index (NPI) points.
- DNGS performance improved in 2023, as a result of:
  - Zero planned outages scheduled in 2023.
  - 2022 CRE calculated for Unit 4 prior to refurbishment (Unit 1 & 3 were in refurbishment and Unit 2 was only online for 2 years) and 2023 CRE calculated for Unit 2 post-refurbishment (Units 1, 3 and 4 were in refurbishment) as this metric is a rolling average.
  - Two forced unit outages occurred but did not have significant impact to collective dose. Outage scope involved repairs on a primary heat transport pressurizer valve, moderator cover gas system repairs, tritium immobilization system glovebox repair, and a rupture disk repair.
  - Online and major project dose remained consistent compared to previous years.

- PNGS performance in 2023 was slightly higher compared to 2022. This was a result of additional planned unbudgeted and forced outages.
  - In 2023 there were three planned outages, two planned unbudgeted outages and six forced outages compared to three planned outages, one planned unbudgeted outage and five forced outages in 2022.
  - Work programs for the planned maintenance outages which contributed to dose included fuel channel components periodic inspection program, boiler inspection programs and a first in a while evolution of Boiler Secondary Side Chemical Clean which was performed on Unit 8.
  - The two planned unbudgeted outages were taken to address fueling machine vault air conditioner unit repairs and the six forced outages were taken to address emergent conditions.

### **Initiatives to Improve and Sustain Favourable Performance Include:**

- DNGS has placed emphasis on these initiatives and practices to reduce exposures:
  - Implementation of source term controls such as post-refurbishment source term monitoring and characterization program, dose reducing Lanxess resin in purification systems, permanent isolation of containment equipment D<sub>2</sub>O circulation supply lines, development and testing of ultrasonic technology for hot spot and crud removals.
  - Upcoming deployment of the Rapid Delivery Machine (RDM) for automated fuel channel inspections during unit outages to eliminate personnel on the reactor maintenance platform and minimize collective dose.
  - Modification of piping and lines containing build up of crud and hot spots to facilitate installation of magnetic shielding to reduce ambient dose rates inside containment during outages.
- PNGS continues to place concerted effort on improving performance by utilizing the following practices:
  - Reactor face dose rate surveys performed during 2023 Planned Outages showed that dose rates were slightly lower than the previous outages with between a 5 – 10% reduction.
  - Implementation of specialized source term reduction agents (i.e., Lanxess resin, fueling machine filter pore size reduction)
  - Continued focus on foreign material management and chemistry heat transport purification management.
  - ALARA (as low as reasonably achievable) initiatives, such as improved shielding, source term reduction initiatives and work methods improvements and efficiencies, contribute to improvements in dose performance.

**Airborne Tritium Emissions**



**Notes:**

- Annual Value
- Median and Best Quartiles are plotted until 2022 as the 2023 results were unavailable at the time of benchmarking (one-year lag).
- Darlington values exclude Tritium Removal Facility (TRF) and associated West Annex emissions (consistent with COG benchmark results).
- Unit 1, Unit 3 and Unit 4 refurbishment periods, and the Retube Waste Processing Building (RWPB).

	2023 Value
DN	1,027
PN	2,164
Best Quartile	3,131
Median	6,068

**Factors Contributing to Performance**

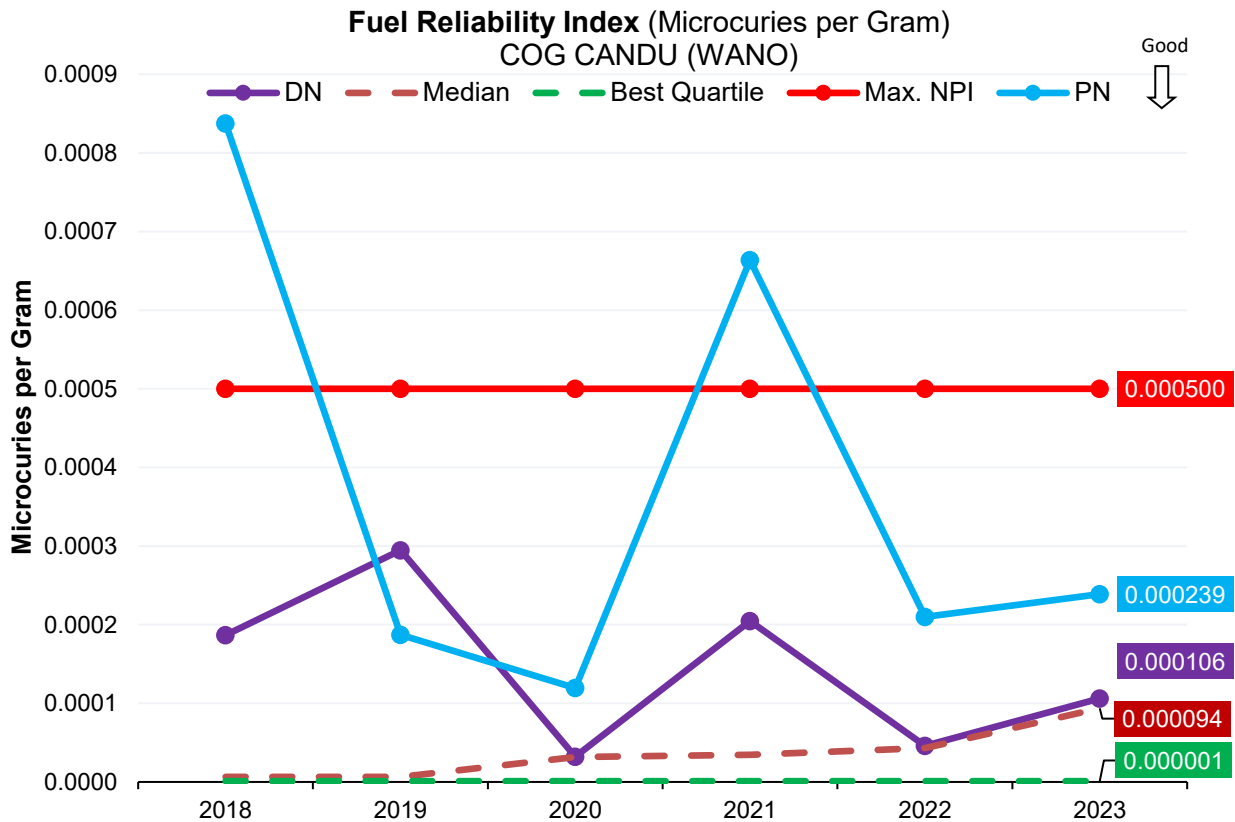
- DNGS and PNGS Airborne Tritium Emissions remain at a very small fraction of regulatory limits
- DNGS and PNGS achieved top quartile in 2023, largely driven by the increase of industry quartile which reflects an additional plant being included in the peer group.
- Both sites have continued tritium reduction activities driven by a High Impact Team (HIT) which focuses on day-to-day tritium reduction activities such as heavy water leaks and repairs, drier performance, continued management oversight and communication of priorities, utilized enhanced monitoring system station wide to provide real-time tritium monitoring capability.

- DNGS continues to achieve best quartile performance. This was mainly attributed to efforts by the station to focus on tritium identification and reduction activities such as prioritized repairs to leaking equipment and driers, utilized enhanced monitoring system station wide to provide real-time tritium monitoring capability and continued management oversight and communication of priorities.
- PNGS achieved industry top quartile performance in 2023 for the first time since 2005. This was mainly attributable to the declining industry performance in 2022. Improved performance can also be attributed to efforts by a High Impact Team in place to drive station tritium reduction activities such as a focused effort on reducing drier downtime, and prioritizing repairs and equipment leaks clean up, thus minimizing airborne impact.

**Initiatives to Improve and Sustain Favourable Performance Include:**

- Ongoing dedicated teams at both sites to enhance focus on tritium sources identification and elimination, including drier performance, heavy water leaks and repair.
- Enhanced management oversight and communication of priorities to focus tritium reduction activities daily at the Integrated Station Brief (ISB) meetings.
- Collaboration to exchange operating experience and innovation activities on tritium mitigation, and benchmark performance.
- Source term reduction on heat transport and moderator water.
- Tritium Oversight Committee in place at DNGS to develop longer term actions, provide oversight, and proactively schedule preventive maintenance activities.
- Tritium Prevention Procedure training for Operators to increase awareness on tritium reduction.
- Ongoing participation in COG environmental benchmarking of participating CANDU stations to determine best environmental practices.

**Fuel Reliability Index (FRI) \***



\* Sub-indicator for WANO NPI

Note: 2023 Most Recent Operating Quarter

Note: DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	0.000106
PN	0.000239
Best Quartile	0.000001
Median	0.000094

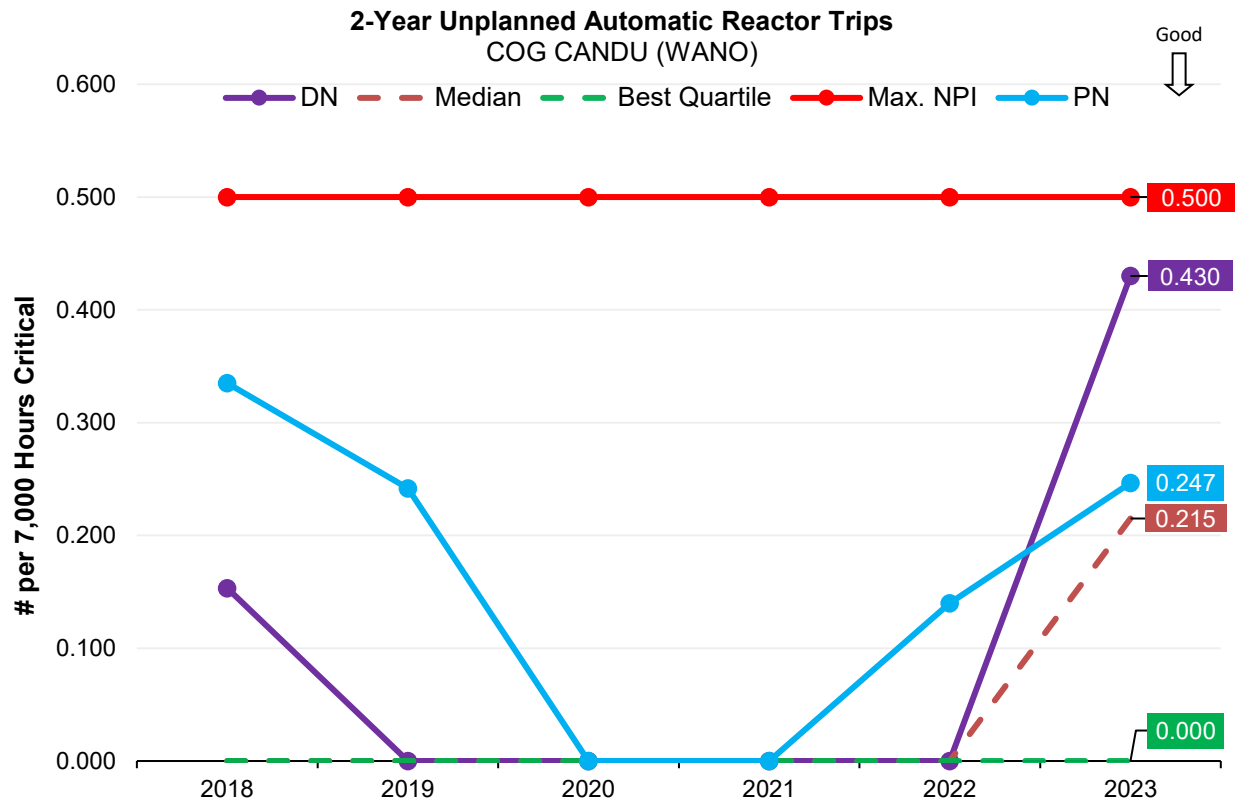
**Factors Contributing to Performance**

- DNGS and PNGS continued to achieve maximum Nuclear Performance Index (NPI) points.
- One fuel defect was observed and discharged at DNGS in 2023, compared to zero in 2022.
- Two fuel defects were observed at PNGS in 2023, similar to 2022. One was discharged and the second remained in-core at the end of 2023. OPG is working to remove the remaining defect at the earliest possibility.

**Initiatives to Improve and Sustain Favourable Performance Include:**

- Both sites completed the fuel design manual and drawing update process. These documents strictly control the manufacturing process, fuel operating limits, fuel handling limits and the fuel performance limits. OPG continues to source fuel with tighter manufacturing tolerances at both sites, thereby eliminating certain modes of fuel defecting following fuelling runs.
- DNGS improvement initiatives include:
  - Foreign Material Exclusion practices continue to mitigate fuel debris fretting failures as shown by the low number of fuel defects following the DNGS reactor refurbishment activities.
- PNGS improvement initiatives include:
  - Increasing scope of Primary Heat Transport System (PHTS) grab sampling and analysis when defects are in-core, continues to assist in earlier detection.
  - Improving the methods of surveillance and elimination of the possibility of foreign materials entrance into the HTS due to Fuel Handling and Outage practices continues to mitigate entrance of micro-debris.
  - Improving and sustaining awareness of impact of foreign material in the PHTS on fuel performance.
  - Improving capability in Units 5 to 8 of detecting the defected fuel bundles during the discharge from the fuelling machines continues to assist in re-directing failed fuel to the inspection area.

**2-Year Unplanned Automatic Reactor Trips \***



\* Sub-indicator for WANO NPI

Note: DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	0.430
PN	0.247
Best Quartile	0.000
Median	0.215

**Factors Contributing to Performance**

- DNGS and PNGS continue to achieve maximum Nuclear Performance Index (NPI) points.
- DNGS performance was impacted by the following unplanned automatic reactor trip:
  - Unit 2: Shutdown System (SDS) 1 trip occurred due to failure of a hand controller causing a control valve to open and resulting in pressurizer steam loss. The cause of failure of the hand controller was a lack of maintenance, and less than adequate risk perception of the potential failure.
- PNGS performance was impacted by the following unplanned automatic reactor trip:
  - Unit 8: An automatic reactor trip on SDS1 and SDS2 occurred. SDS1 tripped on Heat Transport High Temperature (HTHT) trip parameter, while SDS2 tripped on the same trip parameter on channel G, followed by O (LBL) trip parameter on channel J. The direct cause of this event is high output failure of a boiler level transmitter, although the internal mechanism that caused the level transmitter to fail is unknown.

**Initiatives to Improve and Sustain Favourable Performance Include:**

The following are being implemented in both PNGS and DNGS:

- On-going performance monitoring and improvement activities by Station Operations, Engineering, and Maintenance organizations.
- Operating Experience (OPEX) from each event has been shared at PNGS, DNGS and at external summits. To improve human performance, technical procedures have been revised. To improve equipment reliability, where possible, like-for-like parts replacement has taken place. System health teams are involved in obsolescence issues.
- OPEX and lessons learned from the continuous exchange of information among Canadian utilities are incorporated into the OPG governance and governance support documents.
- OPG methods and approaches in Operations, Engineering, and Maintenance are compared with other utility and the latest international standards through CANDU Owners Group (COG) projects. Under the COG sponsorship, OPG participates in the COG task teams for alignment of practices and staying current with best industry practices.
- Internal and external audits as well as inspections and self-assessments are performed to verify compliance and recommend future improvement opportunities.
- Training and qualification requirements are established and reviewed to be up-to-date to execute the job tasks at all levels of Operations, Maintenance and Engineering.

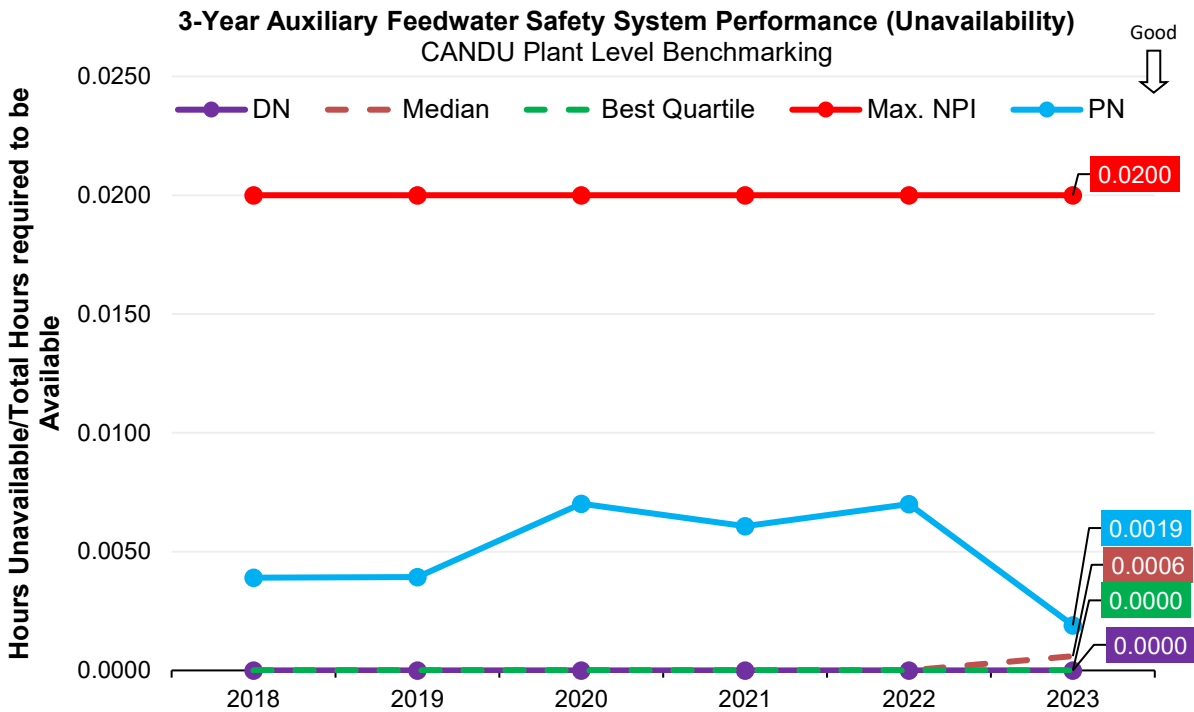
DNGS planned actions:

- Significant Issue Response (SIR) team was initiated with a mandate of determining the cause of control valve drifting fully open over a period of 6 minutes. Systematic Approach to Technical Problem Solving (SATPS) was initiated and a Troubleshooting plan was developed in attempts to replicate the scenario which caused the event. The cause was determined and the hand controller was replaced with new model.
- Continuous actions, such as, Engineering Technical Surveillance Program, are being implemented at DNGS to ensure the best performance through Safety Related System Tests.

The following actions were identified at PNGS:

- Track extent of condition review of this type of Rosemount transmitters and confirm maintenance strategy aligns with the consequence of failure.
- Review forensic analysis results and address any failure modes not already covered.
- Add risk associated with aged boiler level control (BLC) level and flow transmitters to the risk register.
- Propose BLC upgrade Engineering Change Request (ECR) to Site Screening committee.
- Revise BLC level transmitter criticality.
- Implement regular replacement Preventive Maintenance (PM) for BLC level and flow transmitters.

**3-Year Auxiliary Feedwater Safety System Performance (Unavailability)\***



\* Sub-indicator for WANO NPI

Note: DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	0.0000
PN	0.0019
Best Quartile	0.0000
Median	0.0006

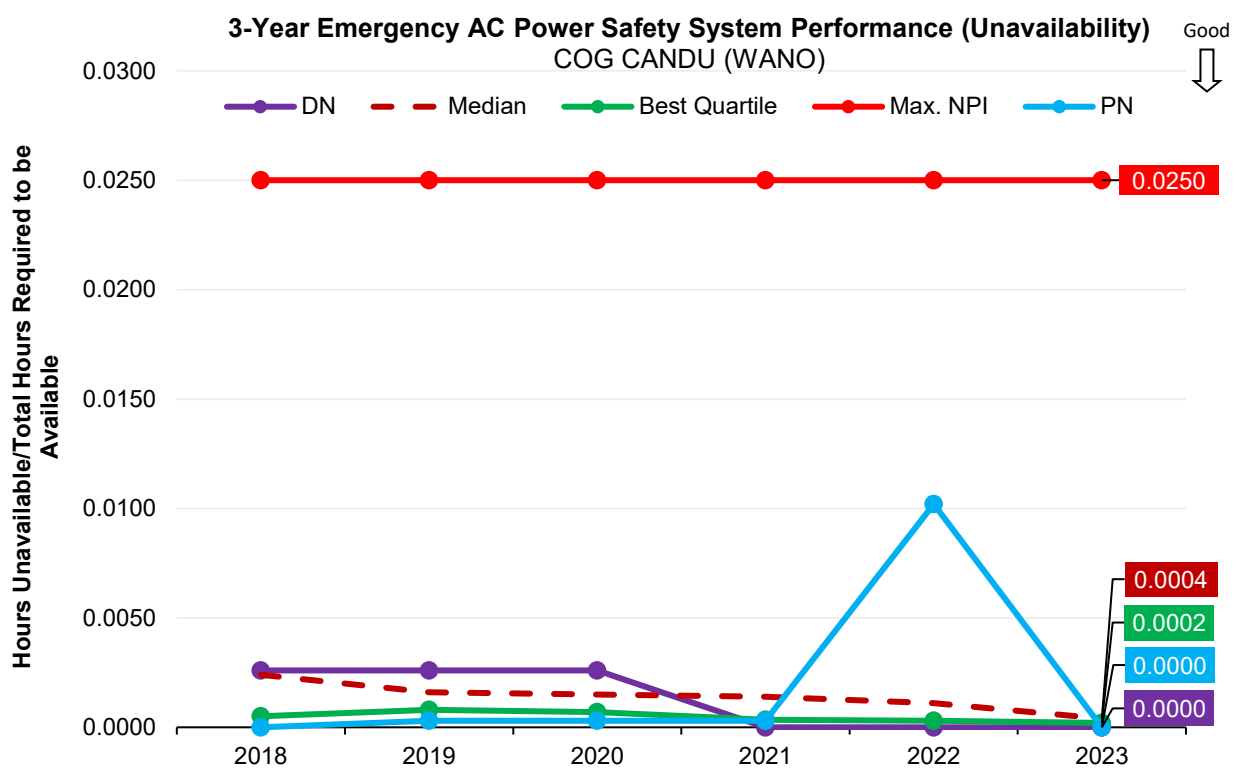
**Factors Contributing to Performance**

- DNGS and PNGS continue to achieve maximum Nuclear Performance Index (NPI) points.
- Factors contributing to performance for DNGS include:
  - Identifying critical work on the plant reliability list.
  - Scheduling work using Integrated Planning Group and Cycle Plan processes.
  - Adhering to the cycle planning.
  - Following the System Performance Monitoring Plan.
  - Adhering to the Health Report 10-Year Improvement Plan.
- Factors contributing to performance for PNGS include:
  - System performance improvement due to preventative maintenance and test procedures
  - Unit 4: During execution of the safety related system, the Auxiliary Boiler Feedwater Pump (ABFP) control valve fails to maintain pump discharge pressure between 5.2 - 5.8 MPag, which leads to system impairment (System Does Not Meet Design Intent (SDNMDI)). Adjusted ABFP controller found setpoint to be higher to allow the control valve to control the pressure at 5.5 MPag.

**Initiatives to Improve and Sustain Favourable Performance Include:**

- DNGS design changes to the Auxiliary Boiler Feed (ABF) system include:
  - Installing gland injection cooling on pump seals to resolve mechanical seal O-ring failure.
  - Replacement of reverse rotation device for main and ABF pumps.
- The following was implemented at PNGS to improve the ABF system performance:
  - Performing an evaluation of repeat failures of Units 1 and 4 ABFP discharge pressure control valves.

**3-Year Emergency AC Power Safety System Performance (Unavailability) \***



\* Sub-indicator for WANO NPI

Note: DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	0.0000
PN	0.0000
Best Quartile	0.0002
Median	0.0004

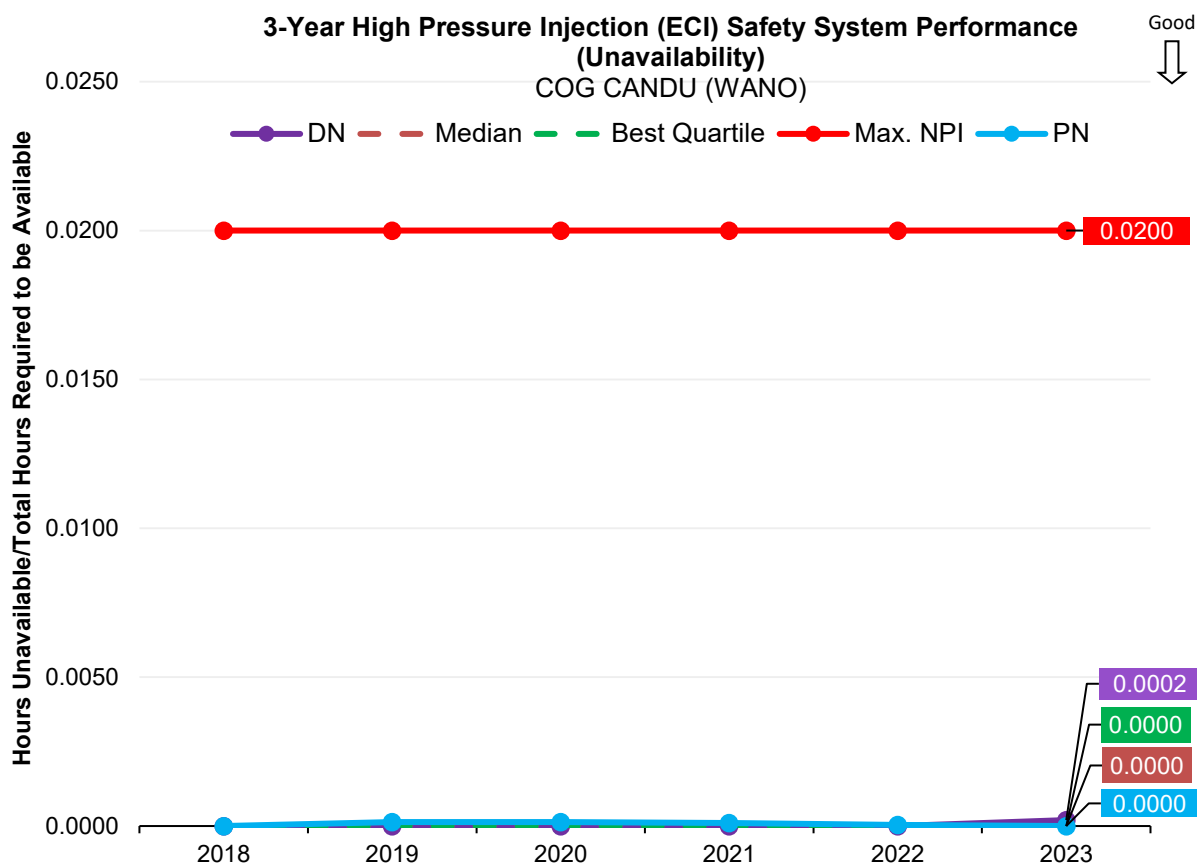
**Factors Contributing to Performance:**

- DNGS and PNGS continue to achieve maximum Nuclear Performance Index (NPI) points.
- DNGS Emergency AC Power system achieved the best quartile performance of zero unavailability by performing the following:
  - Identifying critical work on the plant reliability list.
  - Scheduling work using Integrated Planning Group and Cycle Plan processes.
  - Adhering to the 10-year Outage Maintenance Strategy for the Standby Generators (SG) and Health Report Improvement Plan.
  - Following the System Performance Monitoring Plan.
  - Adhering to the Health Report 10-Year Improvement Plan.
- PNGS Emergency AC Power system achieved best quartile performance of by performing the following:
  - In Q1-2023, there was an overlapping of the failure of Gas Producer Lube Oil Low Pressure of one standby generator (SG), test performed on the second SG, and planned maintenance outage of the third SG. This resulted in unavailability of all three redundant standby generators (SGs) as it impacted quarterly and year-to-date performance despite overall SGs performance unavailability of zero.
  - Corrective and routine outage maintenance.

**Initiatives to Improve and Sustain Favourable Performance Include:**

- DNGS planned actions:
  - SGs Control System upgrades includes small updates to software and hardware to resolve aging/part obsolescence issue on the controls circuits.
  - A 10-year project is in progress on the SG protective relays to replace all the old electro-mechanical relays with modern digital versions.
- PNGS planned actions:
  - Performance Engineering will take actions to ensure timely review/implementation of the corrective and routine maintenance.
  - Cracked power turbine casings will be repaired or replaced.

**3-Year High Pressure Injection (ECI) Safety System Performance (Unavailability) \***



\* Sub-indicator for WANO NPI

Note: DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	0.0002
PN	0.0000
Best Quartile	0.0000
Median	0.0000

**Factors Contributing to Performance:**

- DNGS and PNGS continue to achieve maximum Nuclear Performance Index (NPI) points.
- DNGS High Pressure Safety Injection (HPSI) unavailability was 0.0002. The factor contributing to performance includes:
  - Unit 0: The loss of 4.16 kV Emergency Power Supply (EPS) buses leads to Level 2 impairment of Emergency Cooling Injection (ECI) system, which affected all units due to both Post-Accident Water Cooling System (PAWCS) heat exchanger flow paths being unavailable.
- PNGS continued with the best High Pressure Safety Injection (HPSI) quartile performance of zero unavailability.

**Initiatives to Improve and Sustain Favourable Performance Include:**

- DNGS HPSI related activities include the following:
  - Review the relay logic and determine if closing circuit breaker 0-53290-101CB3 in the TEST mode with a ground fault trip signal present trip of EPS E0-53290-BU101 and BU103 buses supply breakers.
  - Units 1-4 injection valve internals were overhauled.
  - Completion of equipment reliability improvement work is driven via the 52-week cycle plan and Plant Reliability List (PRL) initiatives.
  - Performing preventive maintenance on schedule to reduce component failures and unplanned unavailability hours.
  - Scheduling maintenance work which could cause equipment unavailability as such that it maximizes system availability.
  - Overhaul or replacement of critical components increases the equipment reliability (i.e., ECI Hydraulic Power Unit (HPU)/ECI Accumulator Control Module (AMCA)).
  
- PNGS HPSI related activities include the following:
  - Placing an additional Calandria face cooling fan which returns ECI moderator level indications back in line with SDS2/process indications.
  - H<sub>2</sub>O injection valve diagnostic test.
  - Ultrasonic flow measurements performed on the cooling water supply to the moderator room air conditioning units (ACUs).
  - Ongoing voltage check and routine calibration of logic instrumentation.

## Methodology and Sources of Data

The majority of reliability metrics were calculated using data from WANO. Any data labelled as invalid by WANO was excluded from all calculations. Indicator values of zero are not plotted or included in calculations except in cases where zero is a valid result. Complete data for the review period was obtained and averages are as provided by WANO.

For the WANO Nuclear Performance Index (NPI), a maximum score of 100 is possible. The WANO NPI is an operational performance indicator comprised of 10 metrics, three of which are analyzed in this section:

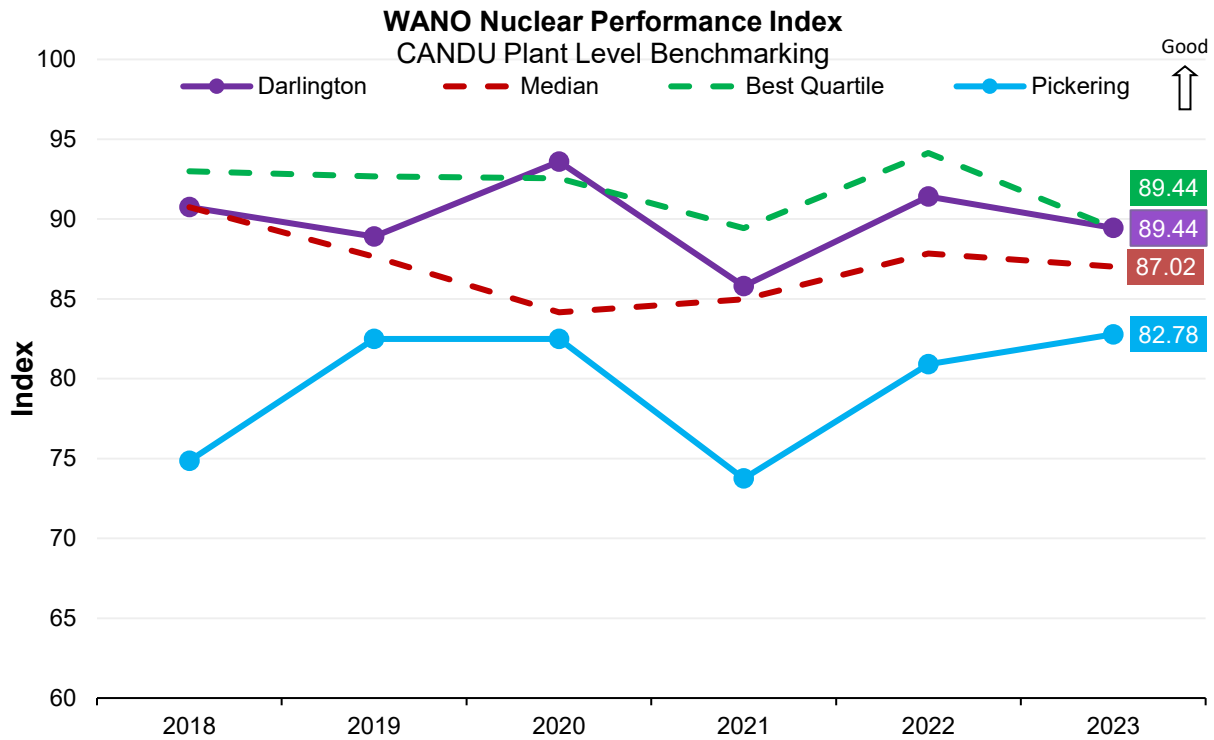
- Forced Loss Rate (FLR) [Rolling Average]
- Unit Capability Factor (UCF) [Rolling Average]
- Chemistry Performance Indicator (CPI) [Rolling Average]

The other seven WANO NPI components are shown in the Safety Section (Section 2.0).

Note: To benchmark performance, Max NPI is used to indicate best quartile performance for metrics that perform better than the Max NPI benchmark. If metric performance is not better than Max NPI, benchmark quartiles are utilized to indicate quartile performance.

Backlog metrics for On-line Deficient and Corrective Maintenance are also included within this section and the data comes from an industry sponsored Institute of Nuclear Power Operators (INPO) AP-928 subcommittee. Data points benchmarked on backlogs are annual, not a rolling average. All data is self-reported.

**WANO Nuclear Performance Index (NPI) <sup>+</sup>**



<sup>+</sup> 2 Year Avg PNGS, 3 Year Avg DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
<b>DN</b>	89.44
<b>PN</b>	82.78
<b>Best Quartile</b>	89.44
<b>Median</b>	87.02

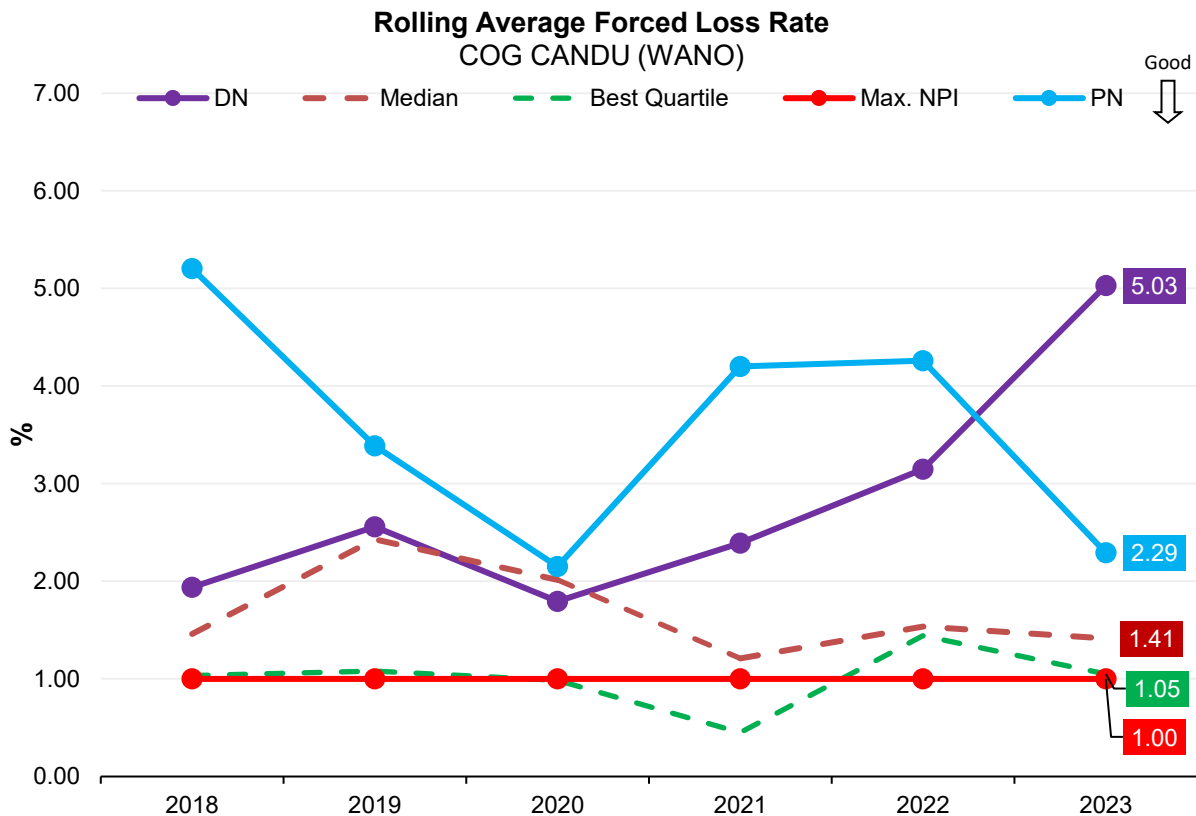
**Factors Contributing to Performance:**

- PNGS performance has improved by approximately two points primarily due to improved Unit Capability Factor (UCF) and Forced Loss Rate (FLR) performance with only brief forced outages in 2023, resulting in a sustained third quartile position from 2022.
  - UCF and FLR have the most significant weighting within NPI calculation.
  - Excellent performance for Reactor Trip Rate (RTR), High Pressure Safety Injection Unavailability (HPSI), Emergency AC Power Unavailability (EACP), Auxiliary Boiler Feedwater Unavailability (ABF), and Industrial Safety Accident Rate (ISAR) combined with good performance on Fuel Reliability Index (FRI), Collective Radiation Exposure (CRE), Chemistry Performance Indicator (CPI) was partially offset by the Unit Capability Factor (UCF) fourth quartile performance. Unit Capability Factor, Collective Radiation Exposure and Chemistry Performance Index metrics were impacted by the need for extended outages to accommodate fuel channel inspection programs, unbudgeted planned outages for non-routine maintenance work and unplanned outages due to external causes, which impacts Unit Capability Factor, Collective Radiation Exposure and Chemistry Performance Index metrics.

- DNGS achieved best quartile performance.
  - NPI slightly lower performance compared to previous years was attributed to continued excellent performance for all seven of the safety metrics offset by decline in FLR performance attributed to Unit 2 forced outage events compared to elevated FLR in 2021 which is no longer included in the rolling window.

Further details on factors contributing to performance and initiatives to improve and sustain favourable performance are discussed within each respective NPI sub-metric in this report.

**Rolling Average Forced Loss Rate (FLR) \* †**



\* Sub-indicator for WANO NPI

† 2 Year Avg PNGS, 3 Year Avg DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	5.03
PN	2.29
Best Quartile	1.05
Median	1.41

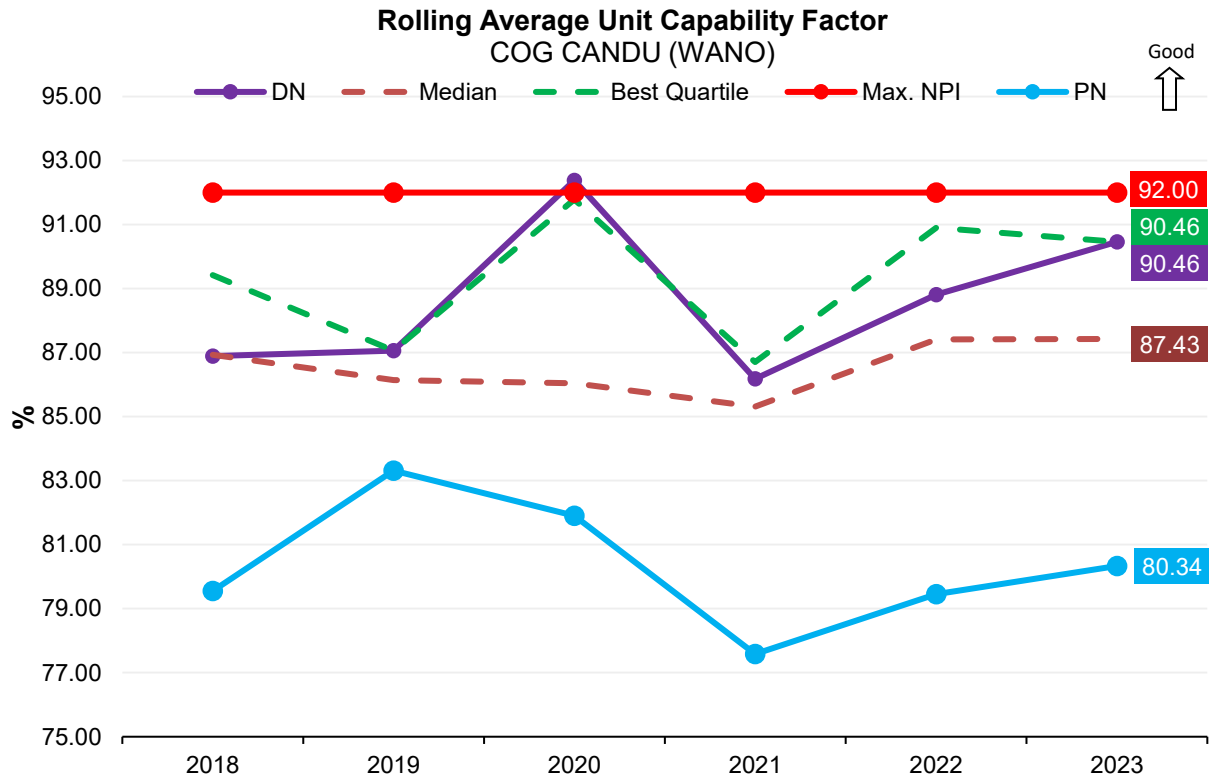
## Factors Contributing to Performance

- PNGS improved performance is attributable to improved FLR in 2023 compared to elevated FLR in 2021 which is no longer included in the rolling window. In 2023, there were six forced outages related to Turbine, Boiler Feedwater, Main Output, and Human Performance, and three forced outages related to Generator, Shutdown Systems and Human Performance in 2022.
- DNGS decline in performance is attributable to forced outage events impacting post-refurbishment Unit 2 on Turbines and Main Power Output (2022) and Primary Heat Transport (2023). As the metric is a rolling average, in 2023 only Unit 2 results are included (Units 1, 3 and 4 were in refurbishment). Similarly in 2022, only Unit 4 results were included (Unit 1 & 3 were in refurbishment and Unit 2 was only online for 2 years) Unit 2 FLR decreased in 2023 compared to 2022.

## Initiatives to Improve and Sustain Favourable Performance Include:

- Focused actions, including vulnerability identification and elimination, project execution, and building proficiency at both the fleet and site level have been implemented for Turbine Generator Reliability, the highest fleet contributor.
- Fuel Handling contribution reduced in 2023 and remains a fleet focus area to build sustainability. Focused actions on proactive risk identification and elimination as well as work management are in place at both the fleet and site level.
- Internal peer teams, industry benchmarking, fleet assessments against industry best practice, enhanced participation in industry working groups are in place to manage this risk going forward.

**Rolling Average Unit Capability Factor (UCF) \* †**



\* Sub-indicator for WANO NPI

† 2 Year Avg PNGS, 3 Year Avg DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	90.46
PN	80.34
Best Quartile	90.46
Median	87.43

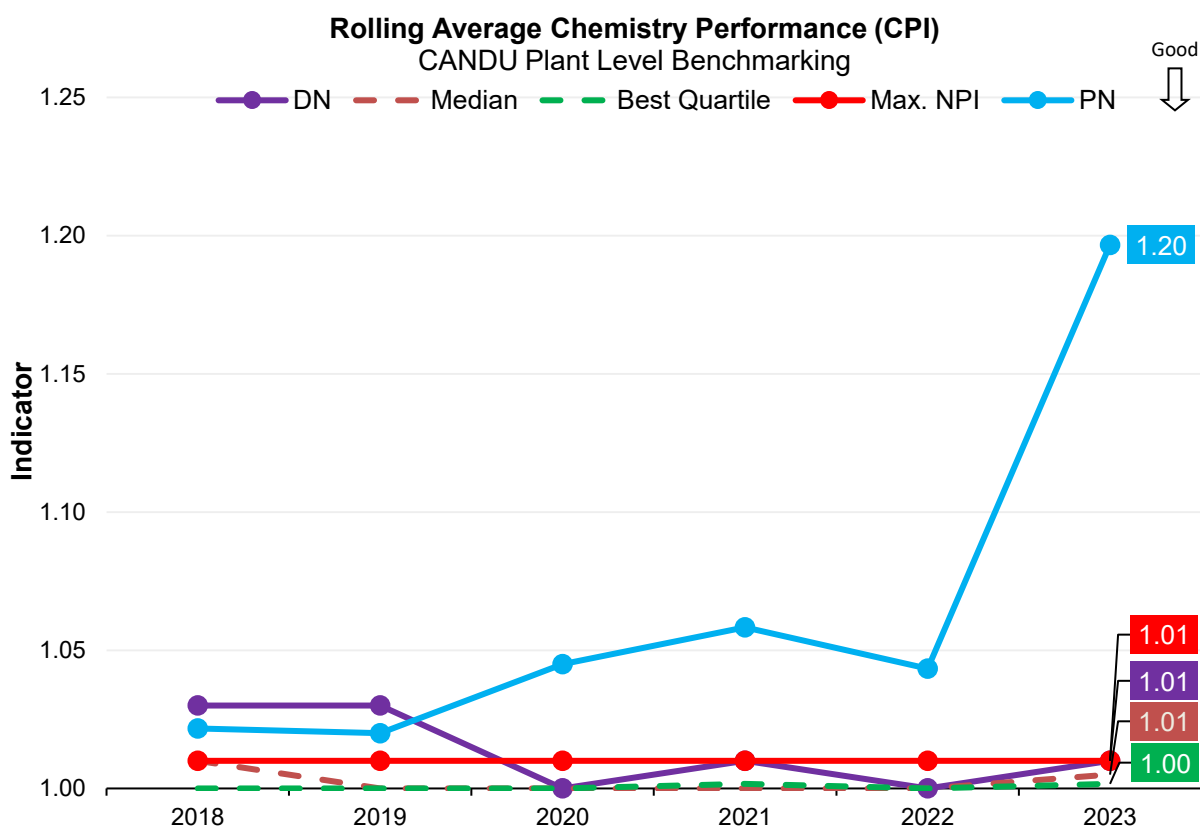
**Factors Contributing to Performance:**

- PNGS improved performance is attributable to improved FLR in 2023 compared to elevated FLR in 2021 which is no longer included in the rolling window, partially offset by increased planned outage days in 2023 compared to 2021 and by increased FLR in 2023 compared to 2022. Unit 7 achieved Industry Best Quartile in 2023. Unit 4 and Unit 6 achieved Industry Best Quartile in 2022.
- DNGS improved and achieved Industry Best Quartile. As the metric is a rolling average, only Unit 2 results are included (Units 1, 3 and 4 were in refurbishment). DNGS improved performance is attributable to reduced planned outage days in 2023 partially offset by forced outage events impacting post-refurbishment Unit 2. 2022 results were measured against Unit 4 performance prior to entering refurbishment (Unit 1 & 3 were in refurbishment and Unit 2 was only online for 2 years).

**Initiatives to Improve and Sustain Favourable Performance Include:**

- Focused actions, including vulnerability identification and elimination, project execution, and building proficiency at both the fleet and site level have been implemented for Turbine Generator Reliability, the highest fleet contributor.
- Fuel Handling contribution reduced in 2023 and remains a fleet focus area to build sustainability. Focused actions proactive risk identification and elimination and work management implementations are in place at both the fleet and site level.
- Internal peer teams, industry benchmarking, fleet assessments against industry best practice, enhanced participation in industry working groups are in place to manage this risk going forward.

**Rolling Average Chemistry Performance Indicator (CPI) \*<sup>+</sup>**



\* Sub-indicator for WANO NPI

<sup>+</sup> 2 Year Avg PNGS, 3 Year Avg DNGS – Unit 2 (U1 & U4 in Refurbishment. Unit 3 in-service Q2, not online for 3 years)

	2023 Value
DN	1.01
PN	1.20
Best Quartile	1.00
Median	1.01

## Factors Contributing to Performance

The decline in performance at PNGS from 2019 to 2023 can be attributed to the following:

- Post Unit 5 (2019) and Unit 7 (2021) start-up boiler sulfates due to turbine maintenance activities during their respective outages.
- Unit 4 condenser tube leak resulted in chronic elevated boiler ions for ~9 months (2021).
- Unit 8 condenser tube leak resulted in elevated boiler ions for ~2 weeks (2021).
- Unit 8 multiple condenser tube leaks resulted in elevated boiler ions (2023).
- Forced outage on Unit 8 resulting from condenser tube leak (2023).
- Forced outage on Unit 8 resulting from boiler level transient (2023).

DNGS continues to receive maximum Nuclear Performance Index (NPI) points. The decline in performance in 2023 from 2022 can be attributed to the following:

- Condenser tube leak on Unit 2 (2023).

## Initiatives to Improve and Sustain Favourable Performance Include:

Both sites have an ongoing Chemistry Outage SPOC to provide improved coordination/planning such that system chemistry control has improved during outages/start-ups.

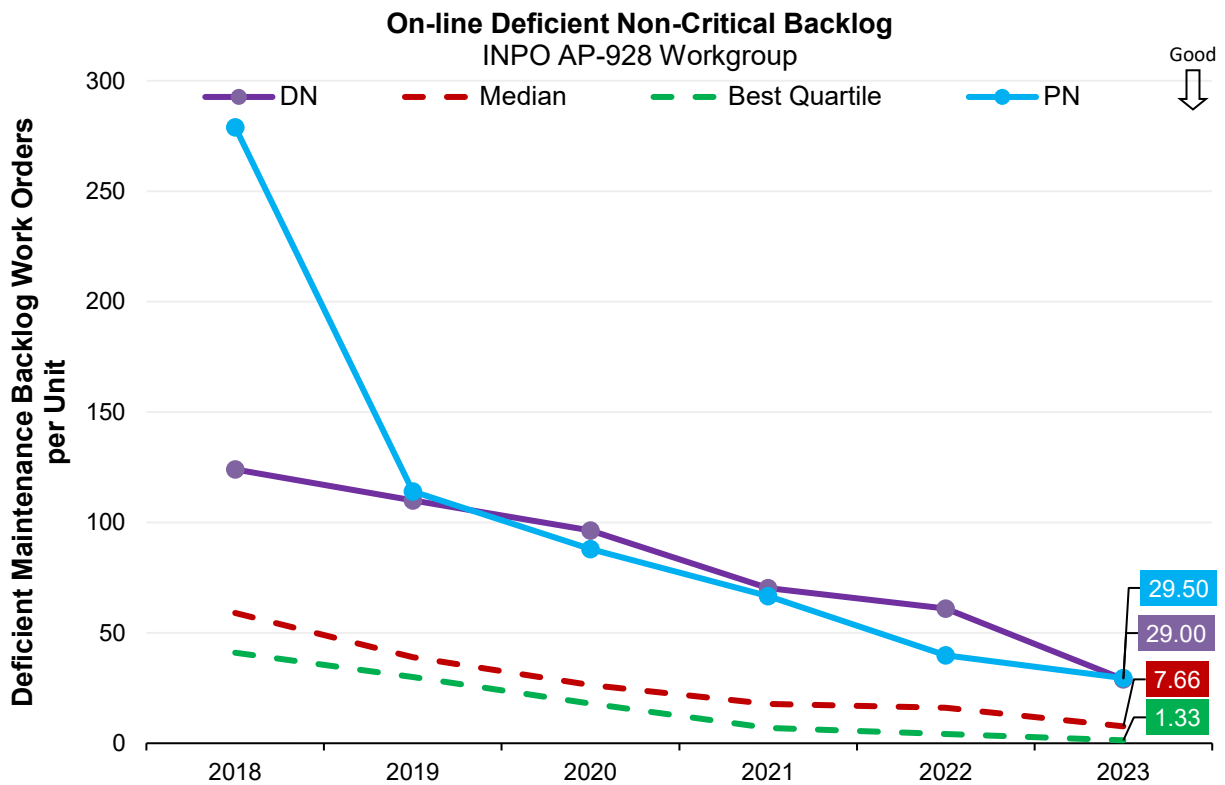
PNGS:

- Assess retubing plugged and stake tubes to regain thermal efficiency.
- Improve turbine vendor quality management program and oversight.
- Improve planning and execution of chemistry start-up activities through integration of Chemistry, Outage, and Operations.

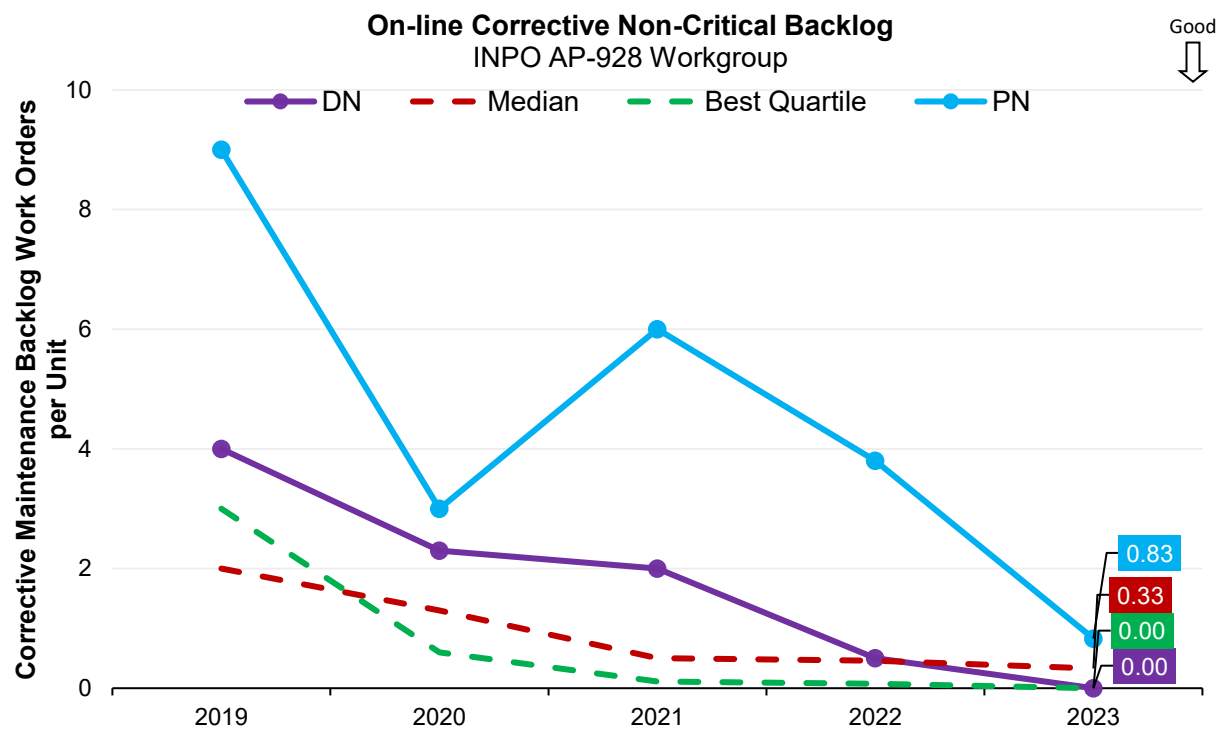
DNGS:

- Improve integration into Outage meetings to optimize boiler chemistry (i.e. minimize duration where boilers are drained, improvements in Boiler Water Lancing activities etc.).
- Implemented a revised chemistry control strategy using continuous boiler blowdowns to manage secondary side chemistry control leading until Unit start-up to remove boiler ions.
- Revise the condenser tube leak response procedure and guidance to include previous operating experience and pre-decision-making logic during leak searching activities.
- Install permanent sodium hotwell analyzers for early detection of condenser tube leaks, to assist in isolating the correct Waterbox and minimize time out of specification.
- Improve reliability of condenser equipment including Condenser Tube Cleaning System (CTCS) through piping and valve replacements and increase inspections to assess condenser tube health to prevent and mitigation condenser tube leaks.

**On-Line Deficient & Corrective Non-Critical Backlog**  
**On-Line Deficient & Corrective Critical Backlog**



Note: Annual



Note: Annual

	2023 On-Line Deficient Non-Critical Backlog	2023 On-Line Deficient Critical Backlog	2023 On-Line Corrective Non-Critical Backlog	2023 On-Line Corrective Critical Backlog
DN	29.00	0.00	0.00	0.00
PN	29.50	0.67	0.83	0.00
Best Quartile	1.33	0.00	0.00	0.00
Median	7.66	0.00	0.33	0.00

**Factors Contributing to Performance**

- PNGS and DNGS continue to meet industry best quartile for Corrective Critical Backlog.
- Both sites experienced performance improvement On-line Deficient Non-Critical Backlog, PNGS 26%, and DNGS 52%.
- PNGS performance improved for On-line Deficient Critical Backlog and On-line Corrective Non-Critical Backlog.
- Factors contributing to performance:
  - Continuing to work down the backlog priorities through Fix It Now (FIN) and Work Management (WM) process.
  - Action to implement sustainable FIN process for Live Zero backlog, long lead part and grace period enhancements.
  - Provide oversight/support on DNGS Refurb Backlog to ensure targets are met.
  - Frequently performed cross functional backlog review of all current Online Backlog work orders for quality of coding.
- Not all station backlog targets were set to industry best quartile for 2023.
- DNGS continues to leverage the Minor Maintenance Tool.
- PNGS initiated Cross Functional Backlog Recovery Team

**Initiatives to Improve and Sustain Favourable Performance Include:**

- Continued review of opportunities to execute online work during unit shutdowns and specific unit configurations.
- Continued scrutiny over work orders that are introduced into the backlog.
- Monitor and track actions as well as metrics via weekly Integrated Station Briefing meetings, bi-weekly Senior Work Management meetings, and monthly Station Excellence meetings.

Note: Factors Contributing to Performance and Initiatives to Improve and Sustain Favorable Performance are relevant to all backlogs-

## Methodology and Sources of Data

The Electric Utility Cost Group (EUCG) database is the source for cost benchmarking data. Data was collected for three-year rolling averages for all financial metrics. All data submitted to and subsequently extracted from EUCG by OPG is presented in Canadian dollars.

EUCG automatically applies a purchasing power parity (PPP) factor to adjust all values across national borders. The primary function of the PPP value is to adjust for currency exchange rate fluctuations, but it also adjusts for additional cross-border factors, which may impact purchasing power of companies in different jurisdictions. As a result, cost variations between plants are limited, as much as possible, to real differences and not due to advantages of utilizing one currency over another.

The benchmarking panel utilized for value for money metrics is made up of all North American (U.S. & Canada) plants reporting to EUCG. Bruce Power is the only other CANDU technology plant reporting within that panel. The remaining plants are Boiling Water Reactors or Pressurized Water Reactors making it challenging to compare performance across plants with technology differences. As a result, beginning with 2017 results, both PNGS and DNGS TGC/MWh and TGC/Unit performance has been normalized for CANDU technology (including outage duration) and age-related impacts.

Darlington's TGC/MWh, TGC/Unit, Non-Fuel Operating Costs (NFOC)/MWh and Capital Cost/MW DER performance have also been normalized for refurbishment. The refurbishment normalization methodology allows OPG to adjust the distribution of actual operating and capital costs to reflect Darlington's number of operating units rather than a four-unit site. OPG is performing a mid-life refurbishment at Darlington, which involves bringing units offline for the replacement of certain life-limiting components. It is necessary to normalize these metrics during refurbishment to allow for comparisons to prior site performance and industry peers, given reduced generation and no corresponding decline in fixed costs.

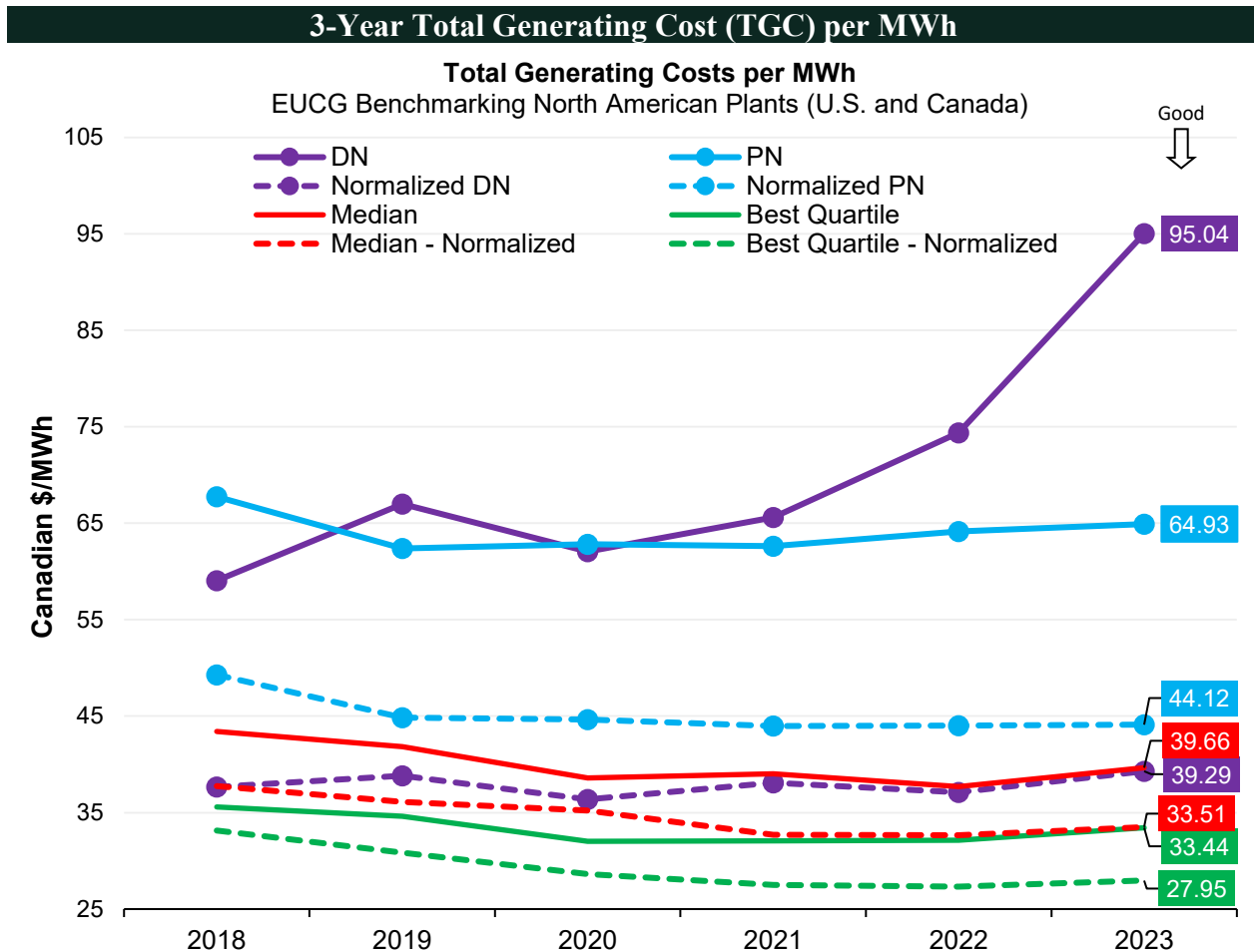
OPG engaged ScottMadden Management Consultants (ScottMadden) to develop the normalization methodologies<sup>3</sup>. The combined normalization allows for a more comparable assessment of performance between peers.

Total Generating Cost per MWh is the sum of Non-Fuel Operating Cost (NFOC), Fuel Cost and Capital Cost measured on a per MWh basis for benchmarking purposes.

Given the differences between OPG's nuclear generating stations and most North American plants with respect to non-fuel operating costs, fuel and capital costs, it is difficult to compare plants using non-fuel operating cost, fuel cost or capital cost metrics separately.

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<sup>3</sup> Two ScottMadden normalization reports provide details on the normalization methodologies: 1) *OPG Nuclear Cost Performance Benchmarking A Study of Factors Impacting TGC/MWh Performance with Normalizing Adjustments to Facilitate Closer Comparison* and 2) *OPG Nuclear Cost Performance Benchmarking Methodology to Adjust for Refurbishment and Validation of Implementation*



\* DNGS – Unit 2, Unit 4 in Refurbishment until Q3 2024, Unit 3 in-service Q2 2024 (U1 in Refurbishment)

	2023 Non-Normalized Value	2023 Normalized Value
DN	95.04	39.29
PN	64.93	44.12
Best Quartile	33.44	27.95
Median	39.66	33.51

### Factors Contributing to Performance

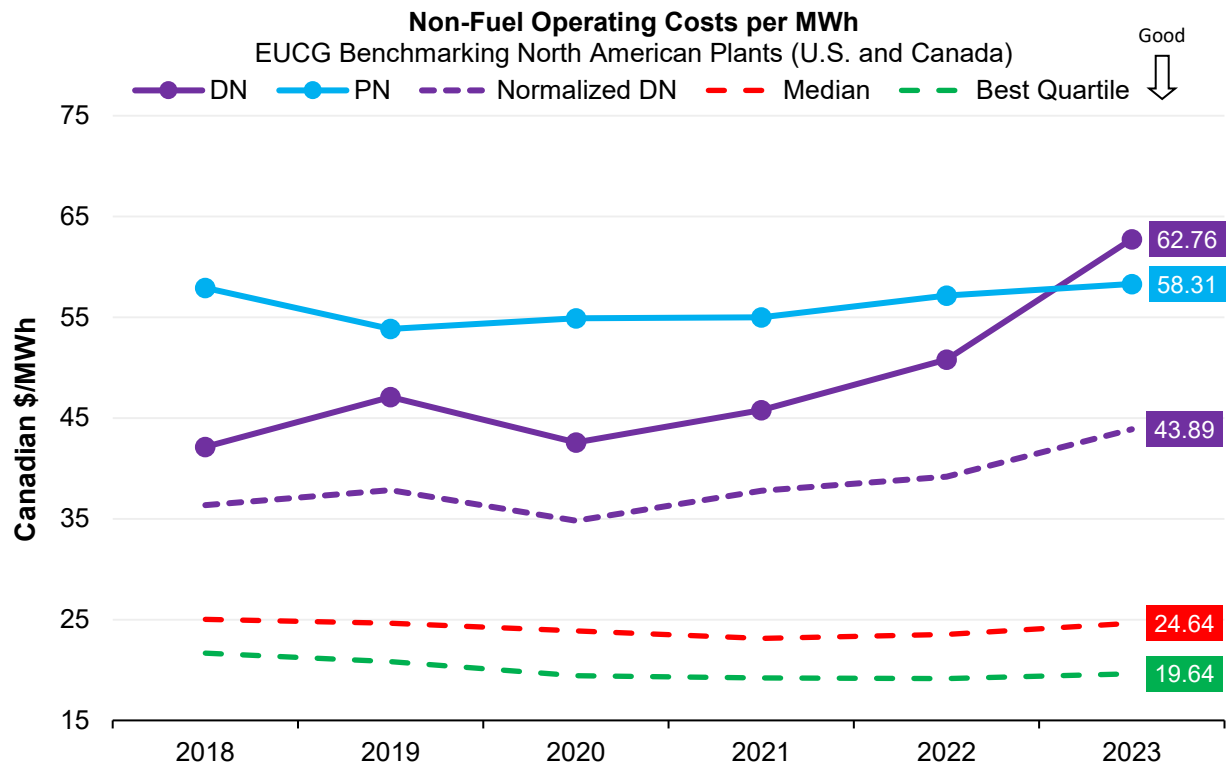
- DNGS normalized performance declined in 2023 compared to 2022 due to reduced 3-year generation related to the Refurbishment outage schedule with the equivalent of two units being in refurbishment outages the full year in 2023 (Unit 1 full year, Unit 4 offline in Q3 and Unit 3 in-service Q2) compared to one unit for 9 months in 2020 (Unit 2 in-service Q2 and Unit 3 offline in Q3) increasing spending on sustaining investments to ensure long term reliability, and higher OM&A costs in 2023 from increased unionized compensation as a result of the Ontario Superior court decision finding Bill 124 of limiting annual wage increases to one percent for a 3-year period unconstitutional, partially offset by lower fuel & OM&A costs due to refurbishment schedule.

- DNGS non-normalized performance declined in 2023 compared to 2022 due to reduced 3-year generation related to the Refurbishment outage schedule (as per above), higher OM&A costs in 2023 from increased unionized compensation as a result of the Bill 124 court ruling (as per above), and increased capital investment requirements for life post-refurbishment, partially offset by lower fuel costs due to refurbishment schedule.
- PNGS normalized and non-normalized performance is similar to 2022, reflecting reduced capital spending while maintaining reliable operations in the period leading up to the end of commercial operations, partially offset by higher OM&A costs from increased unionized compensation as a result of the Bill 124 court ruling (as per above).
- PNGS units are the smallest in the peer group at 540 MW/unit compared to the peer average of 1,026 MW, a factor for which results have not been normalized.

**Initiatives to Improve and Sustain Favourable Performance Include:**

- Maximizing generation: See initiatives to improve and sustain favourable performance for Reliability Metrics UCF and FLR.
- Continue to utilize opportunities to reduce operating costs through strategic initiatives, excellence plans, technology deployment and resource planning.
- Employing a portfolio and asset management approach to assess, prioritize and deliver all nuclear operations projects which are developed to meet regulatory commitments (e.g., from the Canadian Nuclear Safety Commission), increase system or unit reliability, address system obsolescence, or optimize station generation.

**3-Year Non-Fuel Operating Cost per MWh**



\* DNGS – Unit 2, Unit 4 until Q3, Unit 3 in-service Q2 (U1 in Refurbishment)

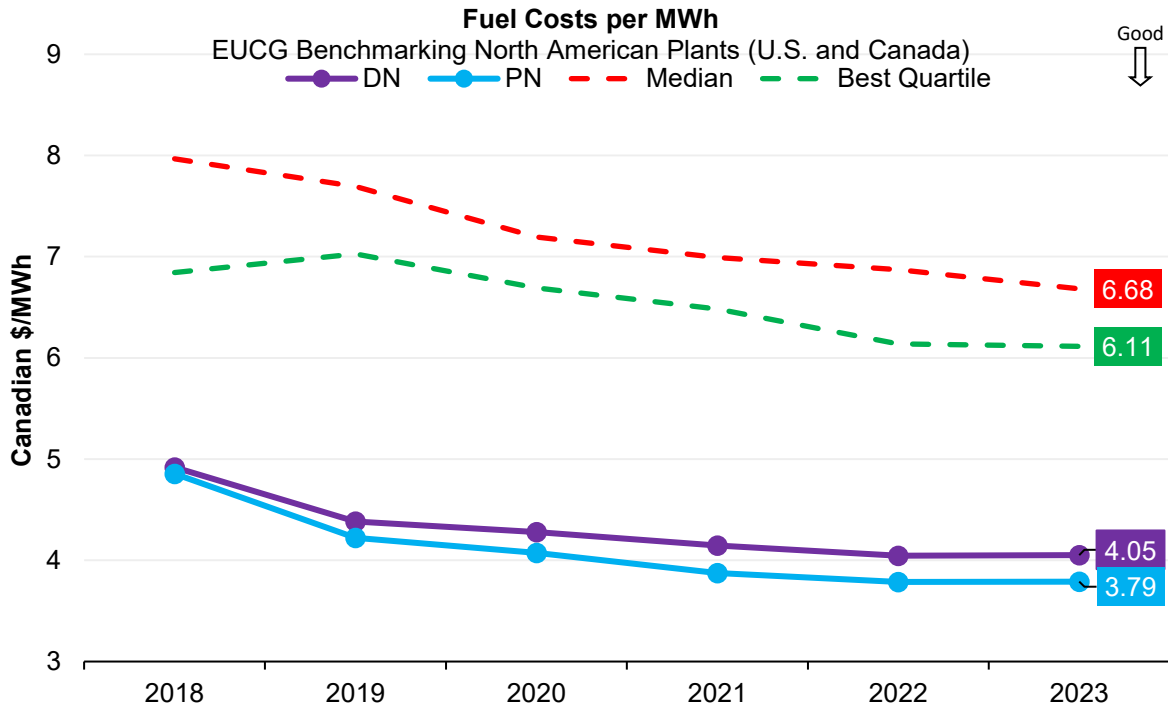
	2023 Non-Normalized Value	2023 Normalized Value
DN	62.76	43.89
PN	58.30	-
Best Quartile	19.64	19.64
Median	24.64	24.64

**Factors Contributing to Performance**

- DNGS normalized and non-normalized performance declined primarily due to reduced 3-year generation related to the Refurbishment outages schedule with the equivalent of two units being in refurbishment outages the full year in 2023 (Unit 1 full year, Unit 4 offline in Q3 and Unit 3 in-service Q2) compared to one unit for 9 months in 2020 (Unit 2 in-service Q2 and Unit 3 offline in Q3) and higher OM&A costs in 2023 from increased unionized compensation as a result of the Ontario Superior court decision finding Bill 124 of limiting annual wage increases to one percent for a 3-year period unconstitutional.
- PNGS non-normalized performance reflects higher OM&A costs in 2023 from increased unionized compensation as a result of the Bill 124 court ruling (as per above).
- PNGS units are the smallest in the peer group at 540 MW/unit compared to the peer average of 1,026 MW, a factor for which results have not been normalized.

**Initiatives to Improve and Sustain Favourable Performance** – refer to TGC/MWh.

### 3-Year Fuel Cost per MWh



\* DNGS – Unit 2, Unit 4 until Q3, Unit 3 in-service Q2 (U1 in Refurbishment)

	2023 Value
DN	4.05
PN	3.79
Best Quartile	6.11
Median	6.68

#### Factors Contributing to Performance

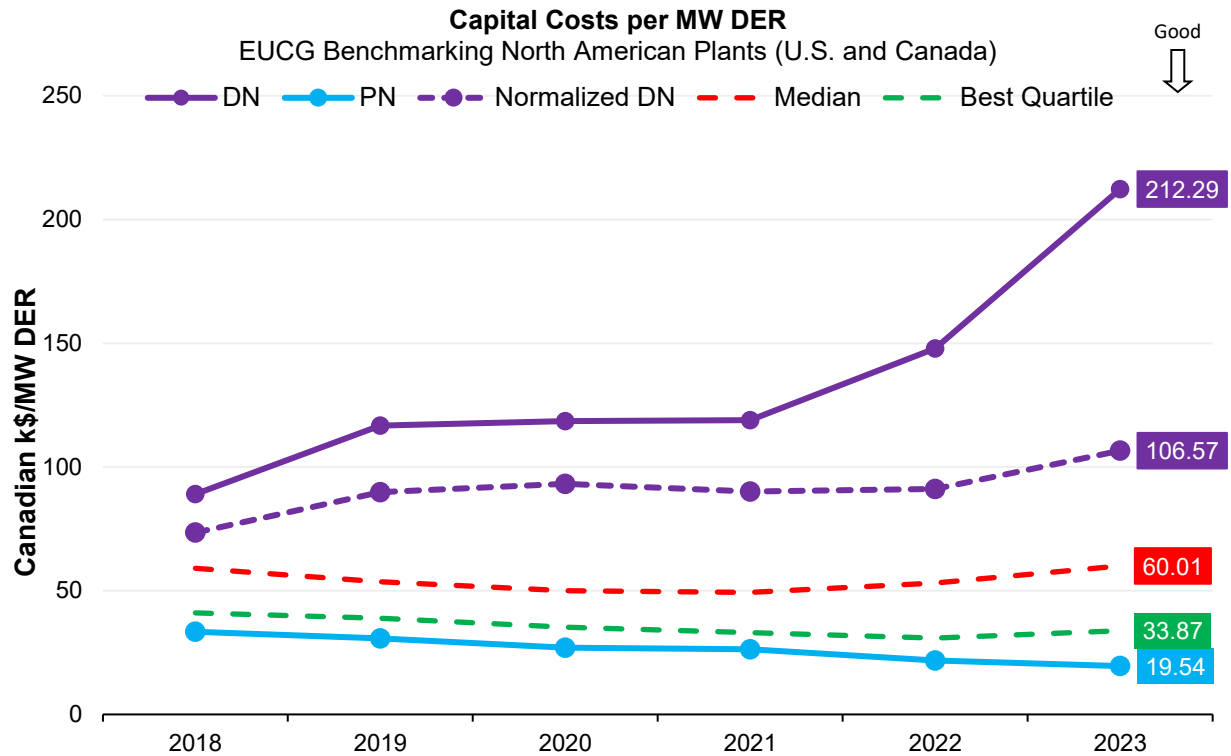
- Fuel costs are lower for OPG than most North American Pressurized Water Reactors or Boiling Water Reactors (PWR/BWR) reactors as CANDUs do not require enriched uranium like PWRs and BWRs.
  - Raw uranium is processed directly into uranium dioxide to make fuel pellets, without the additional cost and process complexity of enriching the fuel as required in light water reactors.
  - CANDU reactors are also the most efficient reactors in using uranium, requiring less uranium than PWRs and BWRs for each megawatt hour of electricity.
  - These two factors provide a significant advantage for OPG and other CANDUs in this cost category.
  
- Regular entry into the uranium market has allowed OPG to reduce uranium input costs year over year for the past several years. Historical multi-year contracts signed between 2015 and 2021, and for which deliveries were made in 2021, 2022 and 2023, have allowed OPG to take deliveries of uranium on a both fixed price and market price basis during a period of historically low uranium spot market prices (2015-2021) not seen since 2005 and earlier.

- In 2017, the uranium spot market price reached its cyclical low point and has continued an increasing trend up to the present, and this trend is projected to continue. Over the coming years, as historical uranium contracts are completed and new contracts are entered into, the effect of the more recent increasing uranium price trend is expected to place upward pressure on the 3-year rolling average fuel cost per MWh. A slight increase in fuel costs at PNGS from 2022 to 2023 can be attributed to this uranium price trend and by general escalation in fuel conversion and fuel fabrication costs.

### **Initiatives to Improve and Sustain Favourable Performance**

- Certain factors are expected to place upward cost pressures on nuclear fuel supply chains over the next several years, including:
  - Resurgence in global demand for nuclear power due to carbon emissions targets of world governments, leading to increased global demand for uranium, conversion, and enrichment services.
  - Uranium supply constrained by many years of under-investment in new mine development due to low prices, as well as constrained Western conversion and enrichment capacities.
  - Global conflicts, including the war in Ukraine, leading to a bifurcation of global nuclear fuel supply chains, along with legislative actions such as the recent U.S. ban on the import of Russian nuclear fuel products.
- OPG will continue to seek improvements in contract pricing for its nuclear fuel supply to sustain favorable comparative fuel costs, while also ensuring a resilient and robust nuclear fuel supply chain, given recent and ongoing geopolitical and economic events

**3-Year Capital Cost per MW DER (Design Electrical Rating)**



\* DNGS – Unit 2, Unit 4 until Q3, Unit 3 in-service Q2 (U1 in Refurbishment)

	2023 Non-Normalized Value	2023 Normalized Value
DN	212.29	106.57
PN	19.54	-
Best Quartile	33.87	33.87
Median	60.01	60.01

**Factors Contributing to Performance**

- PNGS is performing in the first quartile with a slight improvement in 2023 and the improvement over the trend period. This reflects reductions in spending while maintaining reliable operations in the period leading up to the end of commercial operations, which is consistent with spending trends observed at other nuclear facilities approaching their end of commercial operations.
- DNGS performance in 2023 showed an increase on a normalized basis as compared to 2022, as the station remained in the third quartile. The large increase in the absolute DNGS Capital Cost per MW in 2023 is mainly due to the reduction in available MW as two units were in refurbishment outages throughout the majority of the 3-year period as well as increased spending on sustaining investments to ensure long term reliability. The change over the trend period reflects increased spending on life extension, performance improvements, sustaining investments, information technology and capital spares to support operations before, during and after Darlington refurbishment.

- Historically, DNGS capital expenditures were better than the industry median. Once the decision to refurbish Darlington and extend end of life was made, OPG began an extensive program to replace obsolete and/or life-expired plant equipment to support performance and reliability of Darlington’s unit’s post-refurbishment.

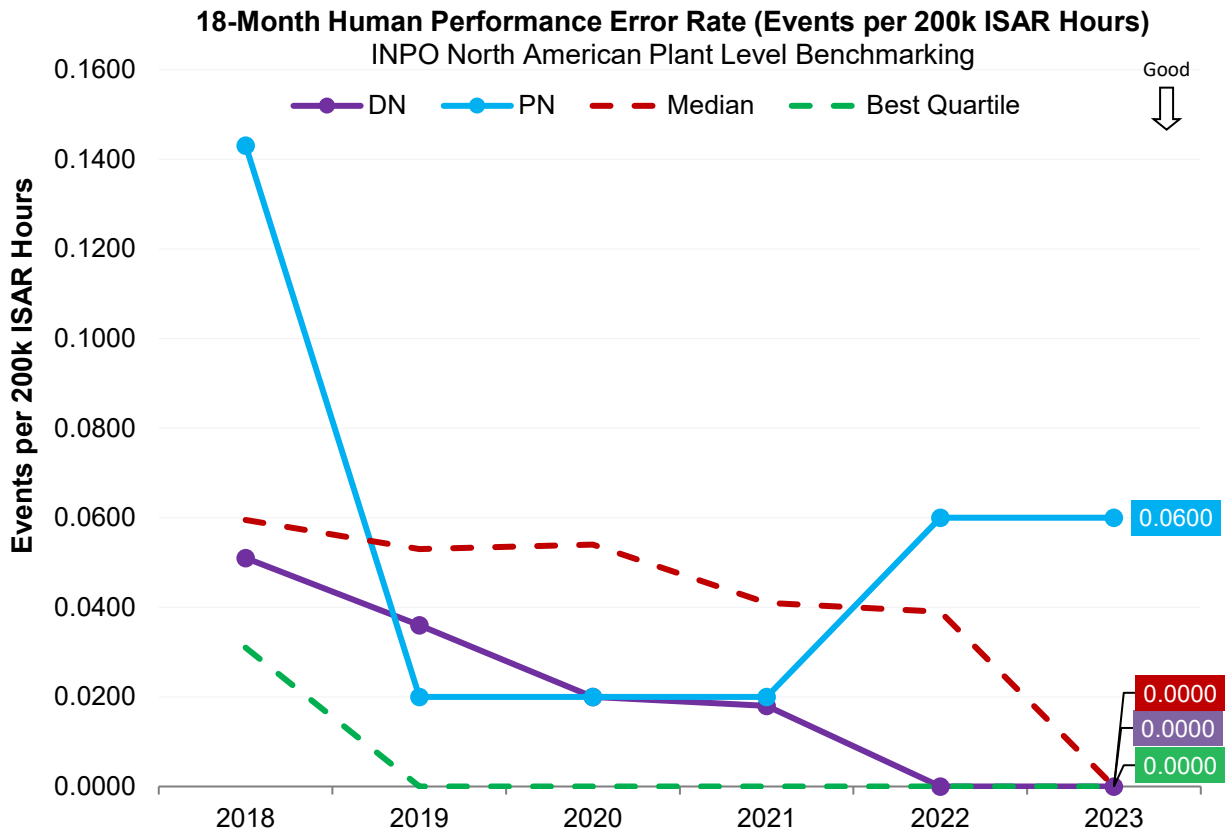
**Initiatives to Improve and Sustain Favourable Performance Include:**

- Employing a portfolio and asset management approach to assess, prioritize, and deliver all nuclear operations projects which are developed to meet regulatory commitments (i.e. from the Canadian Nuclear Safety Commission), increase system or unit reliability, address system obsolescence, or optimize station generation.

## Methodology and Sources of Data

The Human Performance Error Rate metric is used to benchmark the performance of OPG's Nuclear fleet against other INPO utilities in the area of Human Performance.

### 18-Month Human Performance Error Rate



	2023 Value
DN	0.0000
PN	0.0600
Best Quartile	0.0000
Median	0.0000

## Factors Contributing to Performance

- DNGS maintained best quartile performance and did not experience any Site Event Free Day Reset (S-EFDR)s in 2023 or in 2022.
- PNGS experienced one S-EFDR event in Q4 2023. Event causes were identified, and corrective actions implemented to address the gaps. All actions have been completed.

**Initiatives to Improve and Sustain Favourable Performance Include:**

- Continuing to build upon Fail Safe Strategies across the fleet through Pre-Job Briefs (PJB) and Observation & Coaching programs
- Trigger training continued to be deployed
- Supervisors continued to complete Coaching to Enhance Performance training, also with expected completion in Q1 2024.
- Revision and enhancement of Holiday and Outage planning to include more proactive activities, such as the HU Safety Light, becoming Yellow in anticipated higher risk periods.
- Continued focus on the Stop When Unsure campaign as part of the Observation and Coaching improvement plan.
- Further engagement with the TPI (Trending, Prevention, and Intervention) program to provide additional oversight on identified trends.
- Utilization of Validation of Trend (VOT) process to proactively identify and verify emerging trends adverse to safety and quality

**Acronyms**

<b>Acronym</b>	<b>Meaning</b>
ABF	Auxiliary Boiler Feed
ABFP	Auxiliary Boiler Feedwater Pump
AC	Alternating Current
ACU	Air Conditioning Units
ALARA	As Low as Reasonably Achievable
BLC	Boiler Level Control
BWR	Boiling Water Reactor
CANDU	CANada Deuterium Uranium (type of PHWR)
CC	Corrective Critical
CM	Corrective Maintenance
CN	Corrective Non-Critical
CNSC	Canadian Nuclear Safety Commission
COG	CANDU Owners Group
CPI	Chemistry Performance Index
CRE	Collective Radiation Exposure
CTCS	Condenser Tube Cleaning System
D2O	Heavy Water
DC	Deficient Critical
DER	Design Electrical Rating
DM	Deficient Maintenance
DN	Deficient Non-Critical
DNGS	Darlington Nuclear Generating Station
EACP	Emergency AC Power
EC	Electricity Canada
ECI	Emergency Coolant Injection
ECR	Engineering Change Request
EPS	Emergency Power Supply
eSWP	Electronic Safe Work Plans
EUCG	Electric Utility Cost Group
FIN	Fix It Now
FLR	Forced Loss Rate
FRI	Fuel Reliability Index
GWH	Gigawatt Hours
HIT	High Impact Team
HPER	Human Performance Error Rate
HPSI	High Pressure Safety Injection
HPU	Hydraulic Power Unit

<b>Acronym</b>	<b>Meaning</b>
HTHT	Heat Transport High Temperature
HTS	Heat Transport System
HU	Human Performance
INPO	Institute of Nuclear Power Operators
ISAR	Industrial Safety Accident Rate
ISB	Integrated Station Brief
LBL	Low Boiler Level
MW	Mega-Watt
NFOC	Non-Fuel Operating Cost
NPI	Nuclear Performance Index
O&C	Observation & Coaching
OM&A	Operating, Maintenance & Administrative
OPEX	Operating Experience
OPG	Ontario Power Generation
PAWCS	Post-Accident Water Cooling System
PJB	Pre Job-Brief
PNGS	Pickering Nuclear Generating Station
PHTS	Primary Heat Transport System
PHWR	Pressurized Heavy Water Reactor
PM	Preventive Maintenance
PPP	Purchasing Power Parity
PRL	Plant Reliability List
PWR	Pressurized Water Reactor
QSP	Quality of Safety Practices
RDM	Rapid Delivery Machine
RTR	Reactor Trip Rate
RWPB	Retube Waste Processing Building
SATPS	Systematic Approach to Technical Problem Solving
SCL	Safety Classification and Learning
SDS	Shutdown System
SPNMDI	System Does Not Meet Design Intent
S-EFDR	Site event free day resets
SG	Standby Generators
SIF	Significant Injuries and Fatalities
SIR	Significant Issue Response
SPOC	Single Point of Contact
TGC	Total Generating Costs
TGC/MWH	Total Generating Costs per Mega-Watt Hour
TPI	Trending, Prevention, and Intervention

<b>Acronym</b>	<b>Meaning</b>
TRIF	Total Recordable Injury Rate
TRF	Tritium Removal Facility
UCF	Unit Capability Factor
VOT	Validation of Trend
WANO	World Association of Nuclear Operators
WM	Work Management

## **Safety and Reliability Definitions**

The following definitions are summaries extracted from industry peer group databases.

### **Total Recordable Injury Frequency (TRIF)**

The number of fatalities, lost time injuries, medical treatment injuries and restricted work injuries per 200,000 hours worked.

### **Industrial Safety Accident Rate (ISAR)**

Number of accidents for all utility personnel (permanently or temporarily) assigned to the station, that result in one or more days away from work (excluding the day of the accident) or one or more days of restricted work (excluding the day of the accident), or fatalities, per 200,000 man-hours worked. The selection of 200,000 man-hours worked or 1,000,000 man-hours worked for the indicator will be made by the country collecting the data, and international data will be displayed using both scales. Contractor personnel are not included for this indicator.

### **Collective Radiation Exposure (CRE)**

Total external and internal whole-body exposure determined by a dose control device (e.g., electronic personal dosimeter, dose recording device, etc.) and internal exposure calculations. All measured exposure should be reported for station personnel, contractors, and those personnel visiting the site or station on official utility business.

Visitors, for purposes of this indicator, include only those monitored visitors who are visiting the site or station on official utility business.

### **Airborne Tritium Emissions per Unit**

Tritium emissions to air.

### **Fuel Reliability Index (FRI)**

Inferred from fission product activities present in the reactor coolant. Due to design differences, this indicator is calculated differently for different reactor types. For PHWR's, the indicator is defined as the steady-state primary coolant iodine-131 activity (Becquerels/gram or Microcuries/gram), corrected for the tramp uranium contribution and power level, and normalized to a common purification rate.

### **Unplanned automatic reactor trips (SCRAMS)**

Number of unplanned automatic reactor trips (reactor protection system logic actuations) that occur per 7,000 hours of critical operation. The indicator is further defined as follows:

- Unplanned means that the trip was not an anticipated part of a planned test.
- Trip means the automatic shutdown of the reactor by a rapid insertion of negative reactivity (e.g., by control rods, liquid injection shutdown system, etc.) that is caused by actuation of the reactor protection system. The trip signal may have resulted from exceeding a set point or may have been spurious.
- Automatic means that the initial signal that caused actuation of the reactor protection system logic was provided from one of the sensors' monitoring plant parameters and conditions, rather than the manual trip switches or, in certain cases described in the clarifying notes, manual turbine trip switches (or pushbuttons) provided in the main control room.

- Critical means that, during the steady-state condition of the reactor prior to the trip, the effective multiplication factor ( $k_{\text{eff}}$ ) was essentially equal to one.
- The value of 7,000 hours is representative of the critical hours of operation during a year for most plants and provides an indicator value that typically approximates the actual number of scrams occurring during the year.

**Safety System Performance Indicators** include the following:

- Auxiliary boiler feedwater system
- Emergency AC power
- High pressure emergency coolant injection system

These systems were selected for the safety system performance indicator based on their importance in preventing reactor core damage or extended plant outage. They include the principal systems needed for maintaining reactor coolant inventory following a loss of coolant, for decay heat removal following a reactor trip or loss of main feedwater, and for providing emergency AC power following a loss of plant off-site power. (Gas cooled reactors have an additional decay heat removal system instead of the coolant inventory maintenance system).

#### **Nuclear Performance Index (NPI) Method 4**

INPO sponsored performance measure and is a weighted composite of 10 WANO Performance Indicators related to safety and production performance reliability.

#### **Forced Loss Rate (FLR)**

Ratio of all unplanned forced energy losses during a given period of time to the reference energy generation minus energy generation losses corresponding to planned outages and any unplanned outage extensions of planned outages, during the same period, expressed as a percentage.

##### *Unplanned Energy Losses*

Either unplanned forced energy losses (unplanned energy generation losses not resulting from an outage extension) or unplanned outage extension of planned outage energy losses.

##### *Unplanned Forced Energy Loss*

Energy that was not produced because of unplanned shutdowns or unplanned load reductions due to causes under plant management control when the unit is considered to be at the disposal of the grid dispatcher. Causes of forced energy losses are considered to be unplanned if they are not scheduled at least four weeks in advance. Causes considered to be under plant management control are further defined in the clarifying notes.

##### *Unplanned Outage Extension Energy Loss*

Energy that was not produced because of an extension of a planned outage beyond the original planned end date due to originally scheduled work not being completed, or because newly scheduled work was added (planned and scheduled) to the outage less than four weeks before the scheduled end of the planned outage.

##### *Planned Outage Energy Losses*

Corresponding to outages or power reductions which were planned and scheduled at least four weeks in advance (see clarifying notes for exceptions).

*Reference Energy Generation*

Energy that could be produced if the unit were operated continuously at full power under reference ambient conditions throughout the given period. Reference ambient conditions are environmental conditions representative of the annual mean (or typical) ambient conditions for the unit.

**Unit Capability Factor (UCF)**

Ratio of the available energy generation over a given time period to the reference energy generation over the same time period, expressed as a percentage. Both of these energy generation terms are determined relative to reference ambient conditions.

*Available Energy Generation*

Energy that could have been produced under reference ambient conditions considering only limitations within control of plant management, i.e., plant equipment and personnel performance, and work control.

*Reference Energy Generation*

Energy that could be produced if the unit were operated continuously at full power under reference ambient conditions.

*Reference Ambient Conditions*

Environmental conditions representative of the annual mean (or typical) ambient conditions for the unit.

**Chemistry Performance Indicator (CPI)**

CPI compares the concentration of selected impurities and corrosion products to corresponding limiting values. Each parameter is divided by its limiting value, and the sum of these ratios is normalized to 1.0. If an impurity concentration is equal to or better than the limiting value, the limiting value is used as the concentration. This prevents increased concentrations of one parameter from being masked by better performance in another. As a result, if a plant is at or below the limiting value for all parameters, its indicator value would be 1.0, the lowest chemistry indicator value attainable under the indicator definition.

The following is used to determine each unit's chemistry indicator value for PHWRs:

- \*Inconel-600 or Monel tubes
  - Steam generator blowdown chloride
  - Steam generator blowdown sulfate
  - Steam generator blowdown sodium
  - Final feedwater iron
  - Final feedwater copper
  - Final feedwater dissolved oxygen
  
- Incoloy-800 tubes
  - Steam generator blowdown chloride
  - Steam generator blowdown sulfate
  - Steam generator blowdown sodium
  - Final feedwater iron
  - Final feedwater dissolved oxygen

**Online Deficient Maintenance (DM) Backlog**

Average number of active on-line maintenance work orders per operating unit classified as Deficient Critical (DC) or Deficient Non-Critical (DN) that can be worked on without requiring the unit shutdown. This metric identifies deficiencies or degradation of plant equipment components that need to be remedied, but which do not represent a loss of functionality of the component or system.

**Online Corrective Maintenance (CM) Backlog**

Average number of active on-line maintenance work orders per operating unit classified as Corrective Critical (CC) or Corrective Non-Critical (CN) that can be worked on without requiring the unit shutdown. This metric identifies deficiencies or degradation of components that need to be remedied and represents a loss of functionality of a major component or system.

*On-line Maintenance*

Performed with the main generator connected to the grid.

**Value for Money Definitions**

The following definition summaries are taken from the January 2022 EUCG Nuclear Committee Data Definitions and Nuclear Integrated Information Database.

**Capital Costs**

All costs associated with improvements and modifications made during the reporting year. These costs should include design and installation costs in addition to equipment costs. Other miscellaneous capital additions such as facilities, computer equipment, moveable equipment, and vehicles should also be included. These costs should be fully burdened with indirect costs, but exclude AFUDC (interest and depreciation), spent fuel storage costs and/or reimbursements, capital write-off expenditures, taxes (except Payroll), and COVID response costs.

**Nuclear Fuel Costs**

Total cost associated with a load of fuel in the reactor which is burned up in a given year. Fuel burn costs should NOT include spent fuel storage costs or fuel impairment.

Fuel impairment is the write-down of the value of the Nuclear fuel and thus reduces the amortization or fuel expense, occurs in plants either announcing shutdown or are in a pending shutdown.

**Net Generation**

Gross electrical output of the unit measured at the output terminals of the turbine-generator minus the normal station service loads during the hours of the reporting period, expressed in Gigawatt hours (GWh).

**Design Electrical Rating (DER)**

Nominal net electrical output of a unit specified by the utility and used for plant design (DER net expressed in MWe). Design Electrical Rating should be the value that the unit was certified/designed to produce when constructed. The value would change if a power uprate was completed. After a power uprate, the value should be the certified or design value resulting from the uprate.

**Operating Costs (Non-Fuel Operating Costs - NFOC)**

All costs associated with normal operations, maintenance, and outage periods that occur within the current EUCG data reporting year. These costs should be fully burdened and reflect the total operating costs for labour, materials & equipment, outside services and other costs, but exclude depreciation, interest, taxes (except Payroll), COVID response costs, spent fuel storage costs and/or reimbursements, capital write-off expenditures, and new plant expenditures

*New Plant Expenditures*

All costs for supporting new nuclear generation and licensing efforts

**Total Generating Costs (TGC)**

Sum of operating costs, fuel costs and capital costs

**Total Generating Costs (TGC) per MWh**

Sum of operating costs, fuel costs and capital costs divided by Net Generation

**Total Generating Costs (TGC) per Unit**

Sum of operating costs, fuel costs and capital costs divided by Number of Units at Station

**Non-Fuel Operating Costs (NFOC) per MWh**

Operating costs divided by Net Generation

**Fuel Costs per MWh**

Nuclear Fuel costs divided by Net Generation

**Capital Cost per MW DER**

Capital costs divided by Design Electrical Rating (DER)

**Human Performance Definitions**

The following definition summary is taken from the Institute of Nuclear Power Operations (INPO) database.

**Human Performance Error Rate (HPER)**

Represents the number of site level human performance events in an 18-month period per 200,000 Industrial Safety Accident Rate (ISAR) hours worked (including on site supplemental personnel).

Formula =  $\{(\# \text{ of S-EFDRs}) / (\text{Total ISAR Hours} + \text{Total Contractor Hours})\} \times 200,000 \text{ Hours}$   
(Calculated as an 18-month rolling average)

*Non-utility Personnel*

Includes contractor, supplemental personnel assigned to perform work activities on site or at other buildings that directly support station operation. This includes personnel who deliver and receive equipment, deliver fuel oil, remove trash and radioactive waste, and provide building and grounds maintenance within the owner-controlled areas or facilities that support the station.

*Event*

An initiating action (error) by an individual or group of individuals (event resulting from an active error) or an initiating action (not an error) by an individual or group of individuals during an activity conducted as planned (event resulting from a flawed defense or latent organizational weakness). They may be related to Nuclear Safety, Radiological Safety, Industrial Safety, Facility Operations or considered to be a Regulatory Event reportable to a regulator or governing agency. OPG Nuclear’s criteria for defining station event free day resets have been developed based on INPO guidelines.

**Industry Peer Groups**

All data provided by the peer groups (WANO, INPO, EC, and EUCG) is confidential. A redacted version of this report, which removes individual plant and unit names, is available from Nuclear Business Planning and Benchmarking should there be a requirement to publicly release this report.

**Table 2: Industry Peer Groups**

	COG CANDUs (WANO)	All North American PWR and PHWRs (WANO)	INPO AP-928 Workgroup	INPO	EC	EUCG North American Plants (US and Canada)
<b>Safety</b>						
Total Recordable Injury Frequency					X	
Rolling Average Industrial Safety Accident Rate**		X				
Rolling Average Collective Radiation Exposure**	X					
Airborne Tritium Emissions (Curies) per Unit	X					
Fuel Reliability Index*	X					
2-Year Reactor Trip Rate*	X					
3-Year Auxiliary Feedwater System Unavailability*	X					
3-Year Emergency AC Power Unavailability*	X					
3-Year High Pressure Safety Injection Unavailability*	X					
<b>Reliability</b>						
Rolling Average WANO NPI +	X					
Rolling Average Forced Loss Rate**	X					
Rolling Average Unit Capability Factor**	X					
Rolling Average Chemistry Performance Indicator**	X					
1-Year On-line Deficient Maintenance Backlog			X			
1-Year On-line Deficient Critical Backlog			X			
1-Year On-line Corrective Maintenance Backlog			X			
1-Year On-line Corrective Critical Backlog			X			
<b>Value for Money</b>						
3-Year Total Generating Costs / MWh						X
3-Year Non-Fuel Operating Costs (OM&A) / MWh						X
3-Year Fuel Costs / MWh						X
3-Year Capital Costs / MW DER						X
<b>Human Performance</b>						
18-Month Human Performance Error Rate				X		

\* Sub-indicator of WANO NPI

+ Rolling 2 Year Average PNGS ; Rolling 3 Year Average DNGS

**Safety and Reliability Peer Groups**

Primary source of benchmarking data for operational performance (Safety and Reliability) indicators is the World Association of Nuclear Operators (WANO). Eleven out of the twenty benchmarking metrics have been compared to the COG CANDU (WANO) panel. Industrial Safety Accident Rate (ISAR) is compared to the All North American PWR and PHWR (WANO) panel.

All WANO performance indicators are presented at the unit and plant levels except the Industrial Safety Accident Rate (ISAR) and Emergency AC Power Unavailability which are only measured at the plant level.

Different peer groups were used for 5 specialized operating metrics which are not tracked through WANO:

- *Total Recordable Injury Frequency*: Electricity Canada panel was utilized. OPG benchmarks against EC Group 1 peers (a subset of all EC members), which incorporates organizations with more than 1,500 employees, including most provincial utilities.
- *On-line Deficient Maintenance Backlog, On-line Deficient Critical Backlog, On-line Corrective Maintenance Backlog, On-line Corrective Critical Backlog*: Institute of Nuclear Power Operations (INPO) AP-928 working group was utilized.

### **Value for Money Peer Group**

For financial performance comparisons, data compiled by the Electric Utility Cost Group (EUCG) was utilized. EUCG is a nuclear industry operating group and the recognized source for cost benchmark information. EUCG cost indicators are presented at the plant level and compared on a net megawatt hour generated basis and on a per megawatt (MW) design electrical rating (DER) basis. The only CANDU operators reporting data to EUCG were OPG and Bruce Power which is not a sufficiently large panel to provide a basis for comparison; hence, the data sets were not limited to a CANDU specific panel. Should more CANDU operators choose to join EUCG in the future, comparisons to a CANDU specific panel will be reconsidered.

### **Human Performance Peer Group**

For human performance comparisons, data was obtained from INPO.

**Panels/Members**

**Table 3: WANO Panel**

<b>Operator</b>	<b>Plant</b>	<b>Operator</b>	<b>Plant</b>	
Ameren Missouri	Callaway	International CANDU	Cernavoda	
American Electric Power Co.	Cook		Embalse	
Arizona Public Service Co.	Palo Verde		Qinshan 3	
Bruce Power	Bruce A Bruce B		Wolsong A	
			Wolsong B	
Dominion Energy	Millstone North Anna Surry V.C. Summer		Luminant Generation	Comanche Peak
			New Brunswick Power	Point Lepreau
			NextEra Energy Resources	Point Beach Seabrook
			Northern States Power Company	Prairie Island
Duke Energy	Catawba Harris Mcguire Oconee Robinson		Ontario Power Generation	Darlington Pickering
		Pacific Gas & Electric Co.	Diablo Canyon	
Entergy Nuclear	Waterford	Public Service Enterprise Group Nuclear	Salem	
		Southern Nuclear Operating Co.	Farley Vogtle	
Constellation Energy	Braidwood Byron Calvert Cliffs R.E. Ginna	STP Nuclear Operating Co.	South Texas	
		Tennessee Valley Authority	Sequoyah Watts Bar	
		Wolf Creek Nuclear Operating Corp.	Wolf Creek	
FirstEnergy Nuclear Operating Co.	Beaver Valley Davis-Besse			
Florida Power & Light Co.	St. Lucie Turkey Point			

**Table 4: EUCG Panel**

Operator	Plant	Operator	Plant
AmerenUE	Callaway	FirstEnergy Nuclear Operating Co.	Beaver Valley
American Electric Power Co. Inc.	Cook		Davis-Besse
Arizona Public Service Co.	Palo Verde	Florida Power & Light Co.	Perry
			St Lucie
Bruce Power	Bruce	Luminant Generation	Turkey Point
			Comanche Peak
Dominion Generation	Millstone North Anna Surry V.C. Summer	Nebraska Public Power District	Cooper
		NextEra Energy Resources	Point Beach
			Seabrook
		Northern States Power Company	Monticello
Prairie Island			
DTE Energy	Fermi	Ontario Power Generation	Darlington
Duke Energy	Brunswick		Pickering
	Catawba	Pacific Gas & Co.	Diablo Canyon
	Harris		Public Service Enterprise Group Nuclear
	Mcguire	Salem	
	Oconee	Southern Nuclear Operating Co.	Farley
	Robinson		Hatch
Energy Northwest	Columbia	STP Nuclear Operating Co.	Vogtle
Entergy Nuclear	Arkansas Nuclear One Grand Gulf Indian Point River Bend Waterford		South Texas
		Talen Energy	Susquehanna
			Tennessee Valley Authority
		Sequoyah	
		Constellation Energy	Braidwood Byron Calvert Cliffs Clinton Dresden Fitzpatrick Lasalle Limerick Nine Mile Peach Bottom Quad Cities R.E. Ginna
Wolf Creek			

**Table 5: COG CANDUs**

<b>Operator</b>	<b>Plant</b>
Bruce Power	Bruce A Bruce B
China (CNNP)	Qinshan 3
NASA	Embalse
Korea (KHNP)	Wolsong A Wolsong B
New Brunswick Power	Point Lepreau
OPG	Darlington Pickering
Romania	Cernavoda

**Table 6: Electricity Canada Members**

<b>Companies</b>	<b>Companies</b>
Alectra Inc.	IESO
Algonquin Power	London Hydro
AltaLink	Manitoba Hydro
ATCO Electric (Alberta Power Ltd.)	Maritime Electric
Atura Power	New Brunswick Power
BC Hydro	Newfoundland and Labrador Hydro
Canada Power Holdings	Newfoundland Power
Capital Power	Northwest Territories Power Corporation
City of Medicine Hat	Nova Scotia Power/Emera
City of Red Deer	Oakville Enterprises Corporation
Elexicon	Ontario Power Generation
ENMAX	Qulliq Energy Corporation
EPCOR	Rio Tinto
Evolugen	Saint John Energy
FortisAlberta	Saskatoon Light & Power
FortisBC	SaskPower
FortisOntario	TC Energy
Heartland Generation	Toronto Hydro
Hydro One	TransAlta
Hydro Ottawa	Utilities Kingston
Hydro-Québec	Yukon Energy

**Table 7: INPO Members for On-Line Maintenance Backlogs**

Plant	
Arkansas Nuclear One (ANO)	Millstone
Beaver Valley	Monticello
Braidwood	Nine Mile Point
Browns Ferry	North Anna
Brunswick	Oconee
Byron	Oyster Creek
Callaway	Palo Verde
Calvert Cliffs	Peach Bottom
Catawba	Perry
Clinton	Pilgrim
Columbia Gen	Point Beach
Comanche Peak	Prairie Island
Cook	Quad Cities
Cooper	River Bend
Davis-Besse	Robinson
Diablo Canyon	Salem
Dresden	Seabrook
Duane Arnold	Sequoyah
Farley	South Texas
Fermi 2	St. Lucie
Fitzpatrick	Summer
Ginna	Surry
Grand Gulf	Susquehanna
Harris	Turkey Point
Hatch	Vogtle
Hope Creek	Waterford
LaSalle	Watts Bar
Limerick	Wolf Creek
McGuire	

**Table 8: INPO Members for Human Performance Error Rate**

Plant	
Arkansas Nuclear One (ANO)	Millstone
Beaver Valley	Monticello
Braidwood	Nine Mile Point
Browns Ferry	North Anna
Brunswick	Oconee
Byron	Oyster Creek
Callaway	Palo Verde
Calvert Cliffs	Peach Bottom
Catawba	Perry
Clinton	Pilgrim
Columbia Gen	Point Beach
Comanche Peak	Prairie Island
Cook	Quad Cities
Cooper	River Bend
Davis-Besse	Robinson
Diablo Canyon	Salem
Dresden	Seabrook
Duane Arnold	Sequoyah
Farley	South Texas
Fermi 2	St. Lucie
Fitzpatrick	Summer
Ginna	Surry
Grand Gulf	Susquehanna
Harris	Turkey Point
Hatch	Vogtle
Hope Creek	Waterford
LaSalle	Watts Bar
Limerick	Wolf Creek
McGuire	