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2020 Nuclear Benchmarking Report

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Nuclear Finance – Business Planning and Benchmarking

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1.0 EXECUTIVE SUMMARY

OPG benchmarked favourably relative to its peers in 2019 in a number of key nuclear cornerstone areas, while certain metrics were impacted by plant life extension activities (i.e., Pickering Extended Operations) and refurbishment at Darlington.

Safety

Under the Safety cornerstone, OPG's nuclear generating stations continued to achieve strong performance in a majority of the safety performance metrics. Improvements at Pickering and Darlington since 2014 contributed to OPG Nuclear achieving its lowest Total Recordable Injury Rate (TRIF) in the history of the company in 2019. OPG was the top TRIF performer in 2019 compared to its peer group.

OPG Nuclear Stations continue to lead in Safety with stronger results

Darlington Nuclear Generating Station (DNGS) achieved maximum WANO Nuclear Performance Index (NPI) results or best quartile performance for six of the seven NPI sub-metrics under the Safety cornerstone. Pickering Nuclear Generating Station (PNGS) improved to show maximum WANO NPI results or top quartile performance for all seven NPI sub-metrics under the Safety cornerstone.

Collective Radiation Exposure (CRE) performance improved. PNGS benefited from an optimized outage plan and improved performance resulting in maximum NPI points achieved. DNGS dose improved from last year, and remains in the third quartile. Positive gains were seen from site innovations such as leveraging technology to avert dose using robotic equipment and remote monitoring of systems, and the early completion of planned outages contributed to the positive change. The innovative enhancements are also expected to continually improve performance.

Airborne Tritium Emissions at PNGS and DNGS continue to be less than one percent of regulatory limits, and both sites achieved second quartile performance. 2019 PNGS performance improved, advancing to the second quartile, as previous years' issues, such as tritiated water in the Fuel Transfer Conveyor Tunnel being vented to monitored stacks, leaks and dryer performance were resolved. DNGS performance remained in the second quartile, despite being challenged with leaks and dryer performance issues. Repairs to equipment are expected to help improve results.

Pickering's Fuel Reliability Index (FRI) jumped from fourth to first quartile, and achieved maximum Nuclear Performance Index (NPI) points. Enhancements made over the past few years improved the ability to locate and mitigate the very few fuel bundles with a defect. DNGS continues to achieve first quartile performance. No fuel issues of significance arose in 2019. Continual focus on improving FRI performance by preventing potential fuel defects includes improving methods of surveillance and eliminating foreign materials from entering into the Heat Transport System due to Fuel Handling and Outage practices.

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Reliability

Several key performance indicators improved across the fleet even while OPG's nuclear facilities are transitioning through Darlington refurbishment and Pickering life extension.

Pickering achieved its best ever performance as a six-unit station for NPI, FLR and UCF.

OPG Nuclear Stations have significantly improved in reducing maintenance backlogs.

Pickering's performance metrics showed favourable results in 2019 when compared to 2018, including the Nuclear Performance Index (NPI), Forced Loss Rate (FLR), and Unit Capability Factor (UCF), which all recorded best ever performance as a combined six-unit station[1] due to improved equipment reliability and optimized outage performance. Significant improvements were recorded for On-line Deficient Maintenance Backlogs (59% improvement compared to 2018), and On-line Corrective Maintenance Backlogs (47% improvement compared to 2018). PNGS On-line Corrective Critical Backlog declined to fourth quartile due to the standby generator and fuelling machine repair work orders, which were completed in January of 2020. PNGS Deficient Critical backlogs also improved by 44%, which was largely attributed to a deliberate focus on scheduling deficient critical maintenance. The backlog improvement has been supported by the move to a Condition Based Maintenance Program from a time based system.

UCF at DNGS improved to first quartile in 2019 due to strengthened equipment reliability and certain DNGS backlog metrics showed improved performance (e.g., On-line Deficient and Corrective Maintenance Backlogs). DNGS improved their On-line Corrective Maintenance Backlogs by reducing the number of outstanding work orders/unit relative to 2018 as a result of continued station focus, overall maintenance efficiency and improved schedule quality.

The 2019 NPI of 82.5 was the best NPI achieved by PNGS, and a 7.6 gain from 2018, which placed station NPI in third quartile. Longer planned outage durations, which are necessary to extend the life of the Pickering station, directly impact Unit Capability Factor (UCF) and Collective Radiation Exposure (CRE), and thus preclude the station from obtaining full points in NPI despite showing excellence in nuclear safety and consistently achieving full points in associated sub-metrics. DNGS continued with second quartile performance in 2019 and was impacted by forced outages caused by the Heat Transport and Secondary side leakages along with Fuel Handling bridge repairs. Actions have been taken to increase scope in future outages for the instrument line visual inspections to minimize heat transport system leaks to containment. A Fuel Handling Life Extension and Reliability plan addresses the most critical fuel handling scope to sustain Forced Loss Rate performance.

Chemistry Performance Index (CPI) results were impacted by transients following outage start-up. Darlington had condenser tube leaks while Pickering experienced high chloride and sodium levels. Both PNGS and DNGS reported values remained unchanged from 2018 at 1.02 and 1.03 respectively, and Pickering improved into the third quartile compared to the peer group. Initiatives to further improve CPI across the fleet include chemistry data trending and the implementation of

[1] The units at Pickering A and Pickering B were amalgamated in 2012.

new innovations for improved chemistry control, reliability and safety such as new personal protective equipment for hydrazine vapour hazards at Pickering as well as film forming amine and EPRI Smart Chemistry online analyzer application at Darlington.

Value for Money

DNGS Total Generating Cost (TGC)/MWh performance was in the third quartile in 2019 after normalizing[2] for refurbishment as well as CANDU technology (including outage duration) and age-related impacts. Before normalization, DNGS was in the fourth quartile, driven largely by cost impacts for life post-refurbishment and reduced generation associated with refurbishment work. DNGS continues to sustain top quartile performance in Fuel Cost/MWh while capital investment requirements for life post-refurbishment impacted its Capital Costs per MW Design Electrical Rating (DER) which moved to fourth quartile.

PNGS normalized (TGC)/MWh performance in 2019 improved by $4.44/MWh when compared to 2018. PNGS TGC/MWh before and after normalizing (for CANDU technology, including outage duration and age-related impacts) showed similar improvement and remained within the fourth quartile. Pickering managed cost pressures over the 2014-2019 period with a compound growth rate of -1.9%. Improved performance in 2019 reflects higher generation and associated OM&A cost reduction due to fewer outage days as well as decreased capital investment and improved Fuel Costs/MWh. Fuel Cost/MWh continued to maintain top quartile performance compared to peers. PNGS Capital Cost/MW DER maintained best quartile performance.

TGC/MWh was impacted by life extension and refurbishment.

PNGS TGC per generating unit continued to demonstrate strong performance, placing among the best in the peer group in first quartile, while DNGS normalized TGC per generating unit was in second quartile.

Human Performance

Human performance showed improvements at both sites. Of note, PNGS performance moved from the fourth to second quartile in 2019. DNGS results improved and it continued to perform in second quartile.

Industry-leading practices and innovation helped improve human performance at Pickering and Darlington

Adopting industry-leading practices and innovation helped achieve these results, including use of analytical tools for early detection of declining performance, and specialized training using a simulator to teach Human Performance concepts and behaviours.

[2] See section 4.0 for more information about the TGC/MWh normalization methodology.

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Benchmarking Results – Plant Level Summary

Table 1 provides a summary of 2019 performance compared to benchmark results.

Table 1: Plant Level Performance Summary

Metric	NPI Max	2019 Actuals			
		Best Quartile	Median	Pickering	Darlington
Safety					
Total Recordable Injury Frequency (#/200k hours worked) [3]		0.81	N/A	0.11	0.00
Rolling Average[2] Industrial Safety Accident Rate (#/200k hours worked)[1]	0.20	0.00	0.01	0.02	0.04
Rolling Average[2] Collective Radiation Exposure (Person-rem per unit)[1]	80.00	38.54	70.32	70.32	83.23
Airborne Tritium Emissions (Curies) per Unit [3]		982	2,772	2,517	1,213
Fuel Reliability (microcuries per gram)[1]	0.000500	0.000001	0.000007	0.000187	0.000295
2-Year Reactor Trip Rate (# per 7,000 hours)[1]	0.50	0.00	0.00	0.24	0.00
3-Year Auxiliary Feedwater System Unavailability (#)[1]	0.0200	0.0000	0.0000	0.0039	0.0000
3-Year Emergency AC Power Unavailability (#)[1]	0.0250	0.0008	0.0016	0.0003	0.0026
3-Year High Pressure Safety Injection Unavailability (#)[1]	0.0200	0.000000	0.000000	0.00013	0.00000
Reliability					
Rolling Average[2] WANO NPI (Index)[1]		92.68	87.64	82.50	88.90
Rolling Average[2] Forced Loss Rate (%)[1]	1.00	1.08	2.43	3.39	2.56
Rolling Average[2] Unit Capability Factor (%)[1]	92.00	87.06	86.14	83.31	87.06
Rolling Average[2] Chemistry Performance Indicator (Index)[1]	1.01	1.00	1.00	1.02	1.03
1-Year Online Deficient Maintenance Backlog (work orders per unit)[1]		30	39	114	110
1-Year Online Deficient Critical Backlog (work orders per unit) [1]		0	0	5	3
1-Year Online Corrective Maintenance Backlog (work orders per unit) [1]		2	3	9	4
1-Year Online Corrective Critical Backlog (work orders per unit) [1]		0	0	1	0
Value for Money[4]					
3-Year Total Generating Costs per MWh ($ per Net MWh)[1]		34.63	41.85	62.39	67.00
Normalized 3-Year Total Generating Cost per MWh ($ per Net MWh)[1]		30.83	36.12	44.85	38.84
3-Year Total Generating Cost per Unit (M $ per Unit)[1]		275.21	310.29	228.27	442.14
Normalized 3-Year Total Generating Cost per Unit (M $ per Unit)[1]		239.49	290.39	176.31	270.46
3-Year Non-Fuel Operating Costs per MWh ($ per Net MWh)[1]		20.84	24.65	53.85	47.10
3-Year Normalized Non-Fuel Operating Cost per Net MWh ($/MWh)[1]		20.84	24.65	--	37.85
3-Year Fuel Costs per MWh ($ per Net MWh)[1]		7.03	7.69	4.22	4.38
3-Year Capital Costs per MW DER (k$ per MW)[1]		38.82	53.64	30.66	116.67
Normalized 3-Year Capital Cost per MW DER (k$ per MW)[1]		38.82	53.64	--	89.78
Human Performance					
18-Month Human Performance Error Rate (# per 200k ISAR and contractor hours)[1]		0.0000	0.0530	0.0200	0.0360

1. Best Quartile, Median and Third Quartile are from Q4 2019 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 2018, 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 both in Canada and worldwide. The results of this report 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 7.0, and divided into categories aligned with OPG Nuclear's four cornerstones of safety, reliability, value for money, and human performance.

Each indicator reflects a particular duration of historical performance in accordance with peer group expectations. For example, 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.[3]

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 6 of Section 7.0 and panel members are detailed in Tables 7 to 12 of Section 7.0.

Report Structure

Sections 2.0 to 5.0 of the report focus on the four OPG Nuclear cornerstone areas, with detailed comparisons at the plant, and where applicable, unit level.

Section 6.0 of the report provides an operator level summary across a few key metrics. The operator level analysis looks at fleet operators, 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 consistent with ScottMadden's Evaluation of 2019 OPG Nuclear Benchmarking, in which ScottMadden recommended that OPG focus on site-level comparisons of performance for Pickering and Darlington rather than operator-level comparisons. The detailed data in sections 2.0 to 5.0 of the report provide a more complete picture of plant by plant performance.

[3] 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.

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Section 7.0 provides an appendix of supporting information, including common acronyms, definitions, panel composition details and a WANO NPI plant level performance summary of OPG nuclear stations against the North American panel.

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2.0 SAFETY

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 are obtained and consolidated with previous benchmarking data. The Embalse plant has been excluded since it was taken offline since December 31, 2015 for refurbishment.

The Total Recordable Injury Frequency (TRIF) was calculated using data from the Canadian Electricity Association (CEA). Median information and individual company information are not available for this metric. Therefore, only trend and best quartile information have been presented. The peer group for this metric is limited to Group I members of CEA (Section 7.0, Table 10).

Airborne Tritium Emissions per unit data were collected from the CANDU Owners Group (COG) as displayed in the historical trend line chart. The peer group for this metric is all CANDUs who are a member of COG. As noted, there is a one-year lag for the industry values associated with this metric.

Nine metrics are included in this benchmarking report reflect safety performance, including seven of the ten metrics, which comprise the WANO Nuclear Performance Index: Industrial Safety Accident Rate, Collective Radiation Exposure, Fuel Reliability Index, Automatic Reactor Trips, Auxiliary Feedwater Safety System Unavailability, Emergency AC Power Safety System Unavailability, and High Pressure Safety Injection Unavailability. The remaining WANO NPI metrics are included in Section 3.0 under the Reliability cornerstone. In addition to the WANO sub-indicators listed above, the CEA Total Recordable Injury Frequency and the COG Airborne Tritium Emissions per unit are included in this section of the report.

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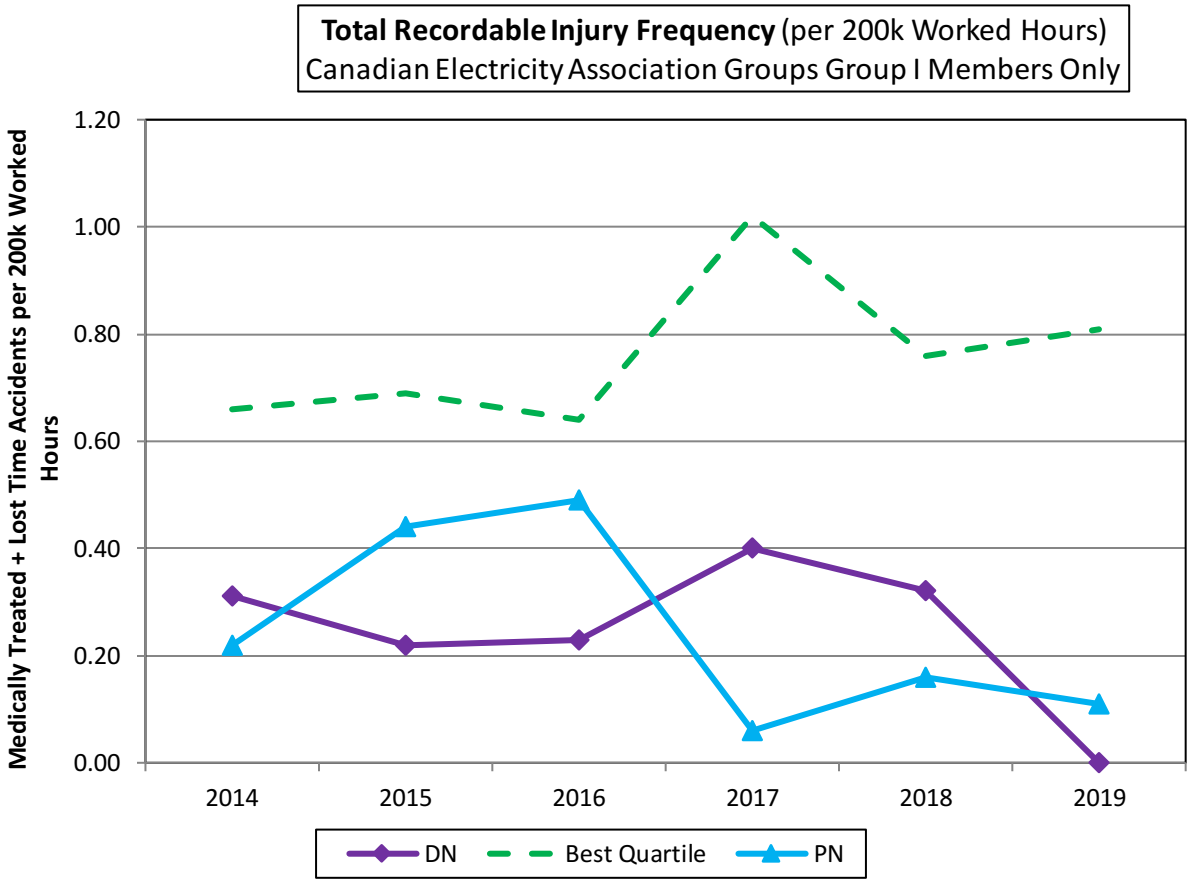
Total Recordable Injury Frequency



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Observations – Total Recordable Injury Frequency (TRIF) (Canadian Electricity Association - CEA)

2019 (Annual Value)

- In 2019, OPG Nuclear achieved its lowest TRIF in the history of the company.
- Pickering, Darlington, and OPG Nuclear as a fleet all performed better than the CEA top quartile value of 0.81.
- Darlington's TRIF had its best performance ever and showed a significant improvement in performance compared to 2018 from 0.32 to 0.00 in 2019.
- Pickering's TRIF has also shown a steady improvement from 0.16 in 2018 to 0.11 in 2019.
- OPG benchmarks against CEA Group 1 (a sub-set of all CEA members), which incorporates organizations with more than 1,500 employees, including most provincial utilities.
- OPG was the top performer of all Group 1 members in 2019.

Trend

- Darlington, Pickering and OPG Nuclear have consistently performed significantly better than the benchmark value and improved over the trend period.

Factors Contributing to Performance

- Conventional Safety performance trends are monitored and action plans to support continuous improvement are implemented. These action plans incorporate Human Performance based objectives, which are aimed at positively improving employees' risk based decision making processes.
- OPG encourages a proactive reporting culture that seeks to identify and address hazards before they lead to employee injuries. Proactive reporting is tracked, trended and managed via the Station Condition Record process.
- OPG continues to progress an organization-wide '*iCare Enough to Act*' initiative aimed at renewing employee commitment to their own and each other's safety and well-being, including Nuclear conventional safety trainings, safety communications, and in-field safety observations via an *iCare* Snapshot program.

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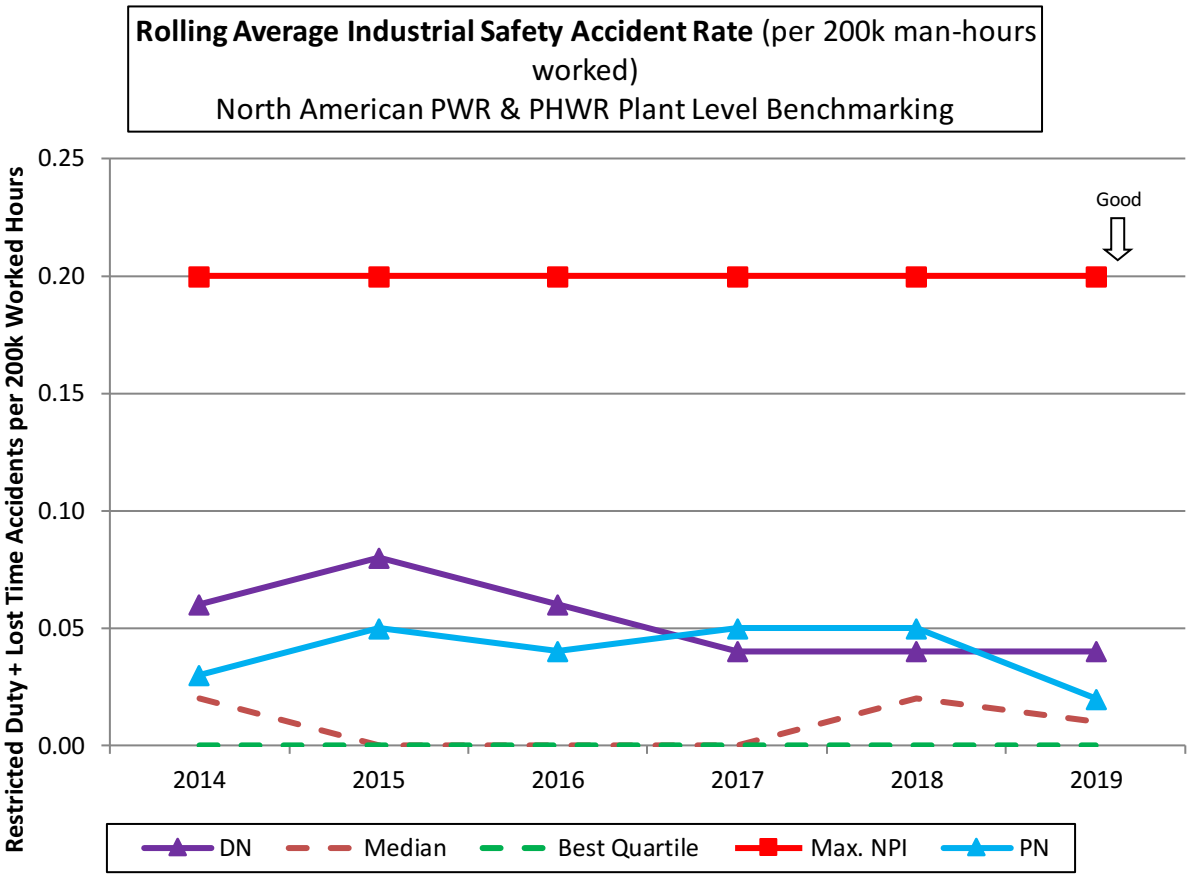
Rolling Average Industrial Safety Accident Rate



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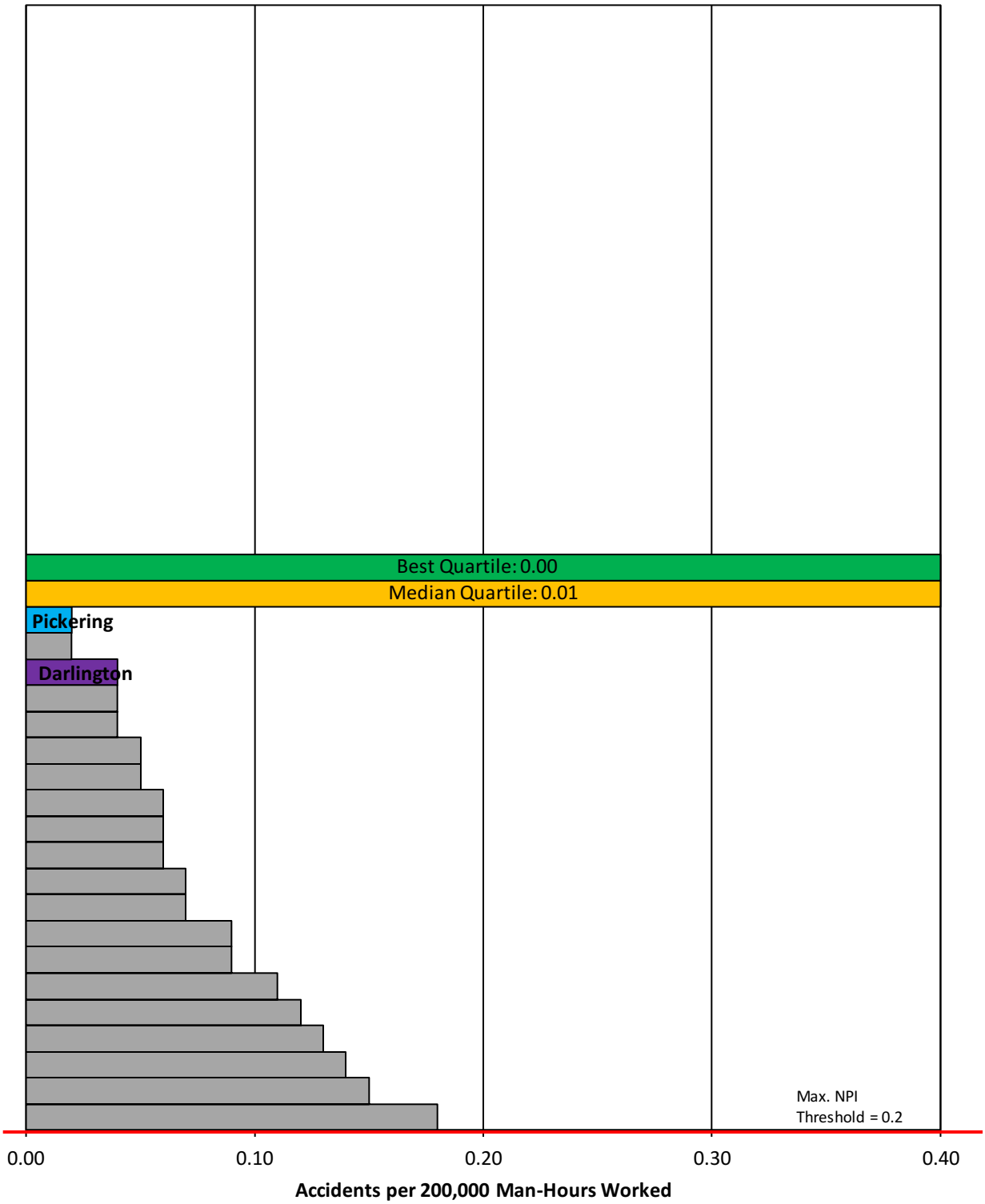
2019 Rolling Average Industrial Safety Accident Rate (per 200,000 man-hours worked)

North American PWR & PHWR Plant Level Benchmarking



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Observations – Rolling Average Industrial Safety Accident Rate (ISAR) (World Association of Nuclear Operators - WANO)

2019 (Rolling 2 Year Average Pickering, Rolling 3 Year Average Darlington)

- WANO top quartile in 2019 remained unchanged from 2018 at 0.00 (i.e. zero ISAR events). Median performance was 0.01, which was a decrease from 0.02 in 2018.
- Both Pickering and Darlington achieved maximum Nuclear Performance Index points for ISAR in 2019.
- Pickering ISAR performance showed improvement from 2018 to 2019 (0.05 to 0.02).
- Darlington ISAR performance remained steady from 2018 to 2019 (0.04 to 0.04).

Trend

- Darlington's ISAR rolling average showed an overall improved performance over the trend period.
- Pickering's ISAR rolling average has shown a generally stable performance over the past five years.
- The ISAR median has seen a slight decrease in 2019 to 0.01 and shows steady performance since 2014. The industry best quartile has remained at zero for the past six years.

Factors Contributing to Performance

- ISAR is a measure of "permanent utility personnel" and does not include contractors. Many of the utilities in the benchmarking group utilize contractors to a greater extent than OPG Nuclear for higher risk work activities (e.g. outages). This can negatively impact OPG Nuclear's ISAR in comparison to the reported industry benchmark quartile and median.
- OPG Nuclear continues to monitor performance trends in the area of conventional safety and implements timely and specific action plans to support continuous improvement. These action plans incorporate Human Performance based objectives, which are aimed at positively improving employees risk based decision making process.
- OPG continues its aim to address safety as a value beyond compliance. To support a 'value-based mindset', OPG Nuclear has emphasized personal reasons why everyone must choose to work safely. An 'iCare' branding has been applied in multiple training forums, safety communications, and in safety observations in the field.

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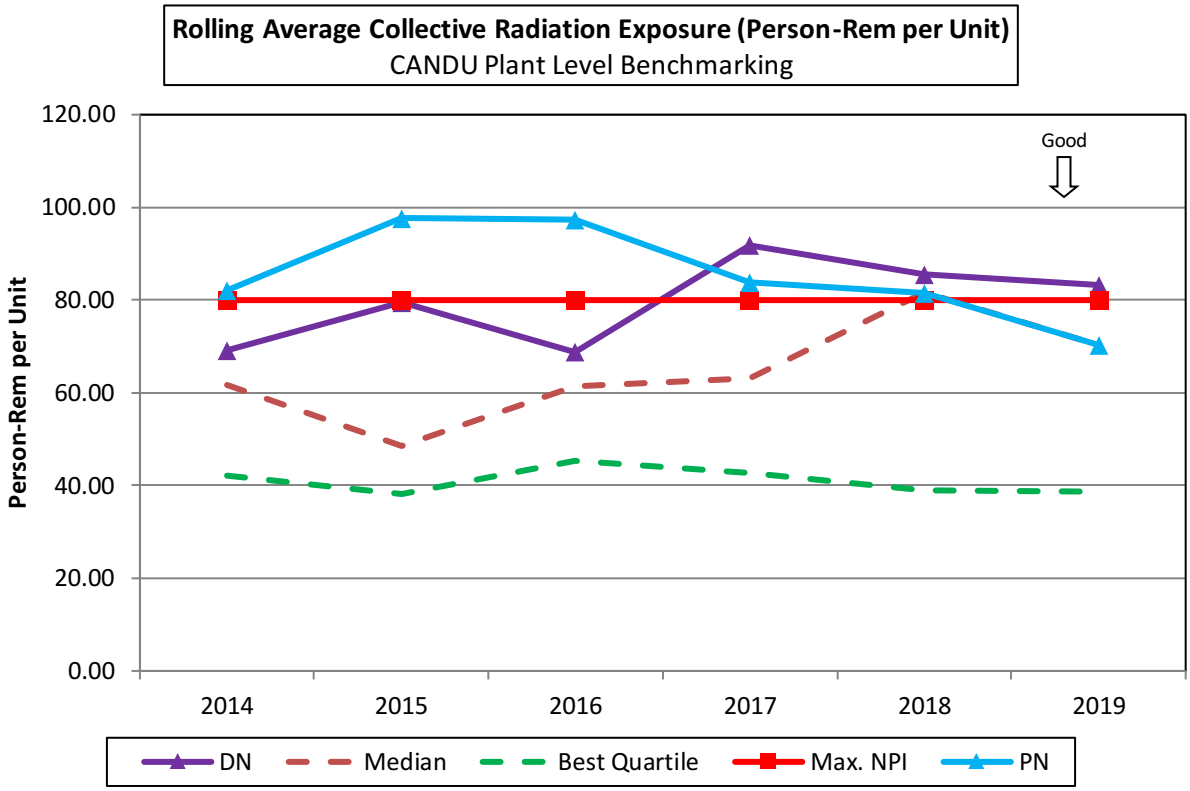
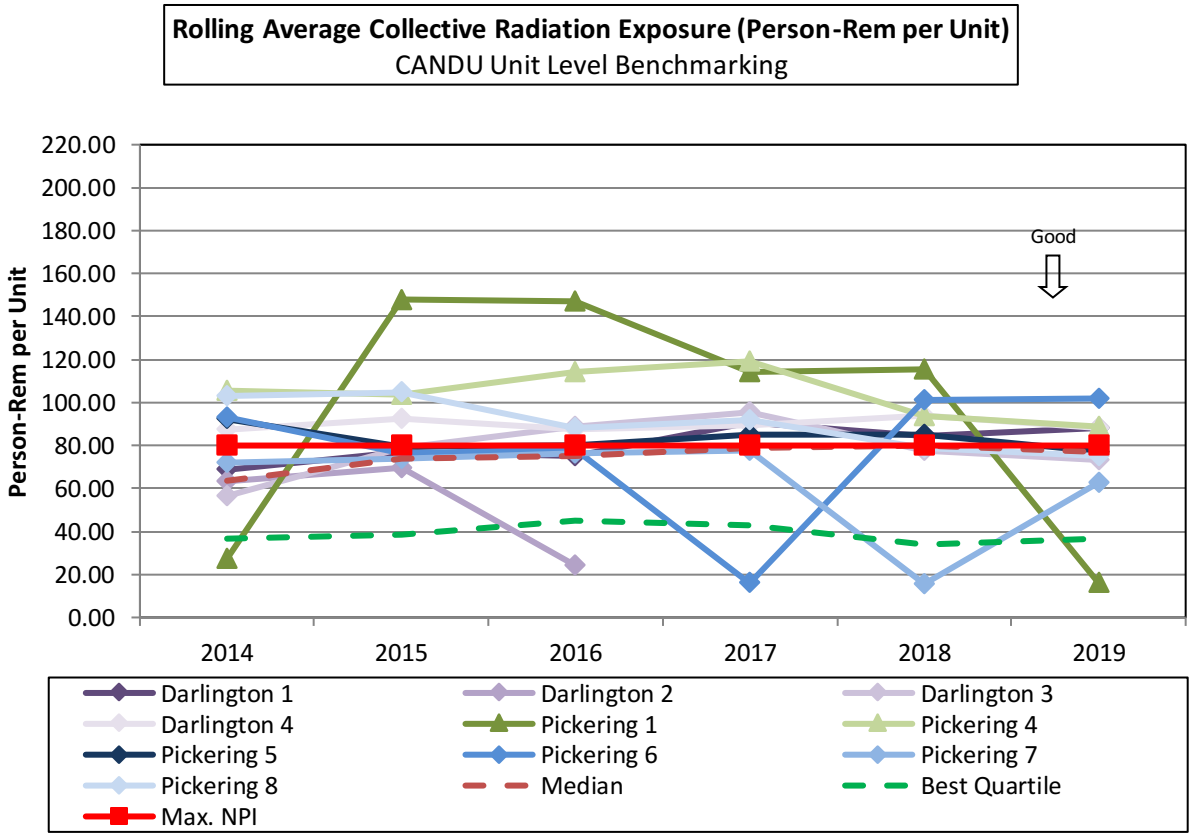
Rolling Average Collective Radiation Exposure





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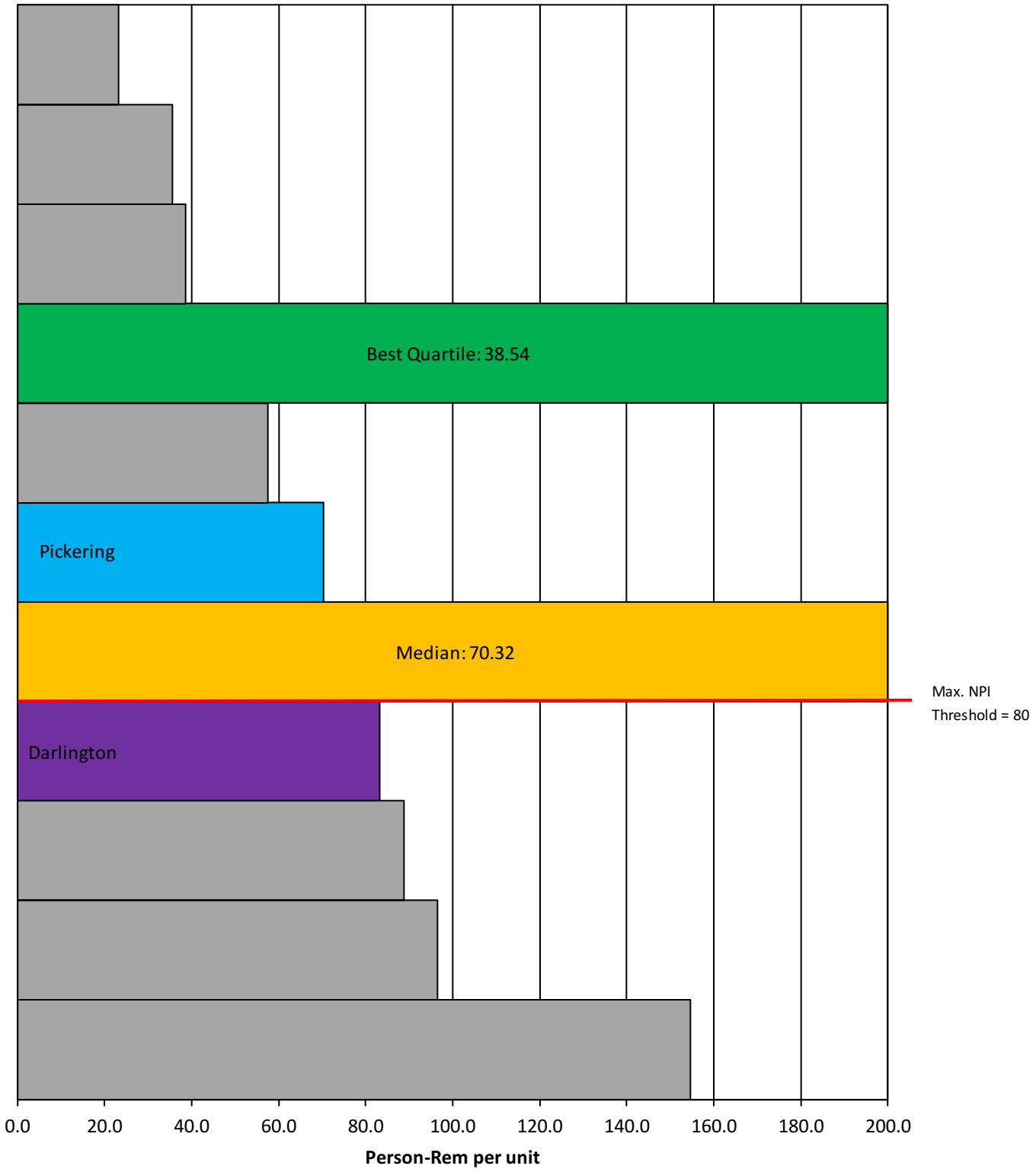
2019 Rolling Average Collective Radiation Exposure (Person-Rem per Unit) CANDU Plant Level Benchmarking



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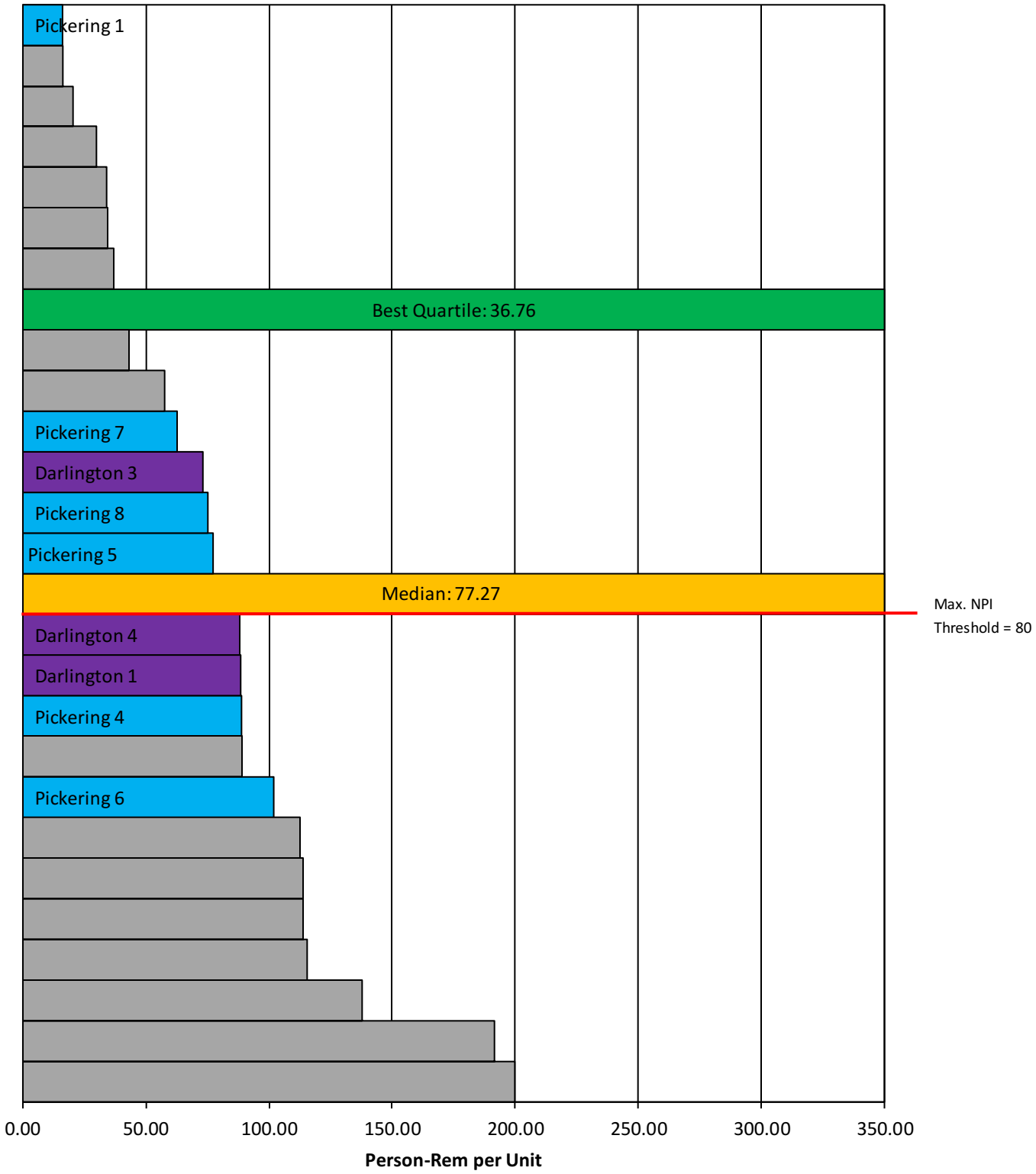
2019 Rolling Average Collective Radiation Exposure (Person-Rem per Unit) CANDU Unit Level Benchmarking



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Observations – Rolling Average Collective Radiation Exposure (CANDU)

2019 Value (Rolling 2 Year Average Pickering, Rolling 3 Year Average Darlington)

- CANDU plant-level - The 2019 best quartile value was lower than the 2018 value (38.54 vs. 38.93 person-rem/unit, respectively). The 2019 median value was also lower than the 2018 value (70.32 vs. 81.65 person-rem/unit, respectively). Full NPI Points were obtained at 80 person-rem/unit or less; no points were earned at 140 person-rem/unit or more.
- At the plant level, PNGS dose performance was 70.32 person-rem/unit and achieved the maximum NPI points.
- At the plant level, DNGS dose performance was 83.23 person-rem/unit. Darlington Unit 2 began a long-term refurbishment outage on October 15, 2016. Dosage associated with Refurbishment activities has been excluded from benchmarking.

Trend

- Pickering plant-level CRE performance has improved since 2014 and achieved the maximum NPI value in 2019.
- After rising in the early part of the trend period, Darlington plant-level CRE performance improved in 2018 and 2019.
- Installing the post-Fukushima enhancement project in operating units concluded in 2016. As a result, dose related to this nuclear project was reduced during the 2019 3-year rolling average period. Also, dose improvement was complemented by the success of dose reduction initiatives.

Factors Contributing to Performance

- The following factors play a significant role in the CANDU reactors' CRE performance: planned outage scope and outage duration, forced outages, tritiated ambient air in accessible and access-controlled areas, effectiveness of mitigation measures, initiatives implemented to reduce identified sources of radiological hazards, and human performance during execution of radiological tasks.
- *Number of Planned Outages*: The number of planned outages, work scope as well as outage duration significantly contributed to plant level and unit rolling average CRE performance. In 2019 the following outages occurred:
    - PNGS**:** two planned outages (Unit 5, Unit 7), and three forced outages (Unit 1, 5 and 6).
    - DNGS**:** one planned outage (Unit 4), and three forced outages (two on Unit 3 and one on Unit 4).

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Rolling Average Collective Radiation Exposure (CANDU) - continued

- *Outage Scope/Duration*: The CRE reflects total work scope performed during the year and it varies year by year. Therefore, an increase or decrease in the rolling average CRE may be attributable to work scope, not necessarily deficiencies in Radiation Protection program and dose reduction initiatives. The rolling average is also impacted by longer outage duration. For example PNGS is impacted due to the amount of life extension work and scope required to extend life to 2024/2025.

Initiatives: Key nuclear fleet-wide and site-specific dose reduction initiatives have been implemented:

  - Improved Radiation Protection (RP) worker practices through the Radiation Protection Excellence Index. This index is based on nine individual RP human performance metrics, enabling various departments at both PNGS and DNGS to assess their respective performance and create action plans that are targeted to drive excellence.
  - The implementation of Lanxess Dose Reducing Resin was installed during PNGS outages for Unit 5 and Unit 7 and DNGS Units 1 and 3 to reduce primary heat transport source term.
  - Remote reading of radiation instrumentation provides real-time information of non-radiological conditions and minimizes time and dose.
  - Leveraging technology to avert dose using robotic equipment and remote monitoring of systems and for intrusive fuel channel inspections (machine delivered scrape) to reduce human hour exposure while executing high radiological hazard work on reactor face platform.
- At DNGS, implemented specialized Emergency Coolant Injection line permanent galvanized steel bands and temporary magnetic tungsten shielding to reduce hot spot hazard levels during unit outages.
- Installed Remote Area Tritium Monitors in the East and West Fuelling Facility Auxiliary Areas to monitor and trend airborne tritium to minimize internal dose for Fuel Handling Staff.
- Installation of a Radiation-Resistant Online Periscope camera in Darlington Unit 4 to identify leaking closure plugs or any Fuelling Machine issues on the reactor face.

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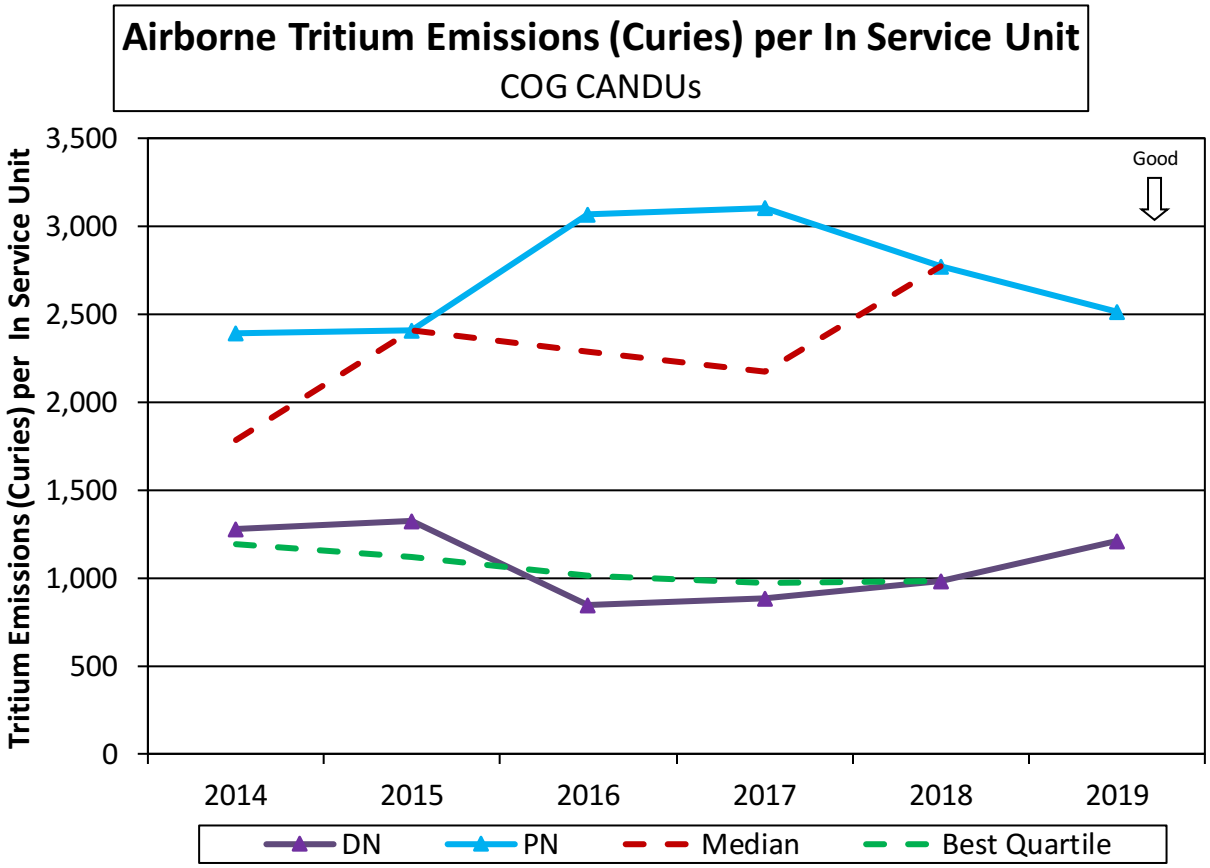
Airborne Tritium Emissions per In Service Unit



Notes:

- Median and Best Quartiles are plotted till 2018 as the 2019 results were unavailable at the time of benchmarking.
- Darlington values exclude Tritium Removal Facilities emissions consistent with COG benchmarking results.

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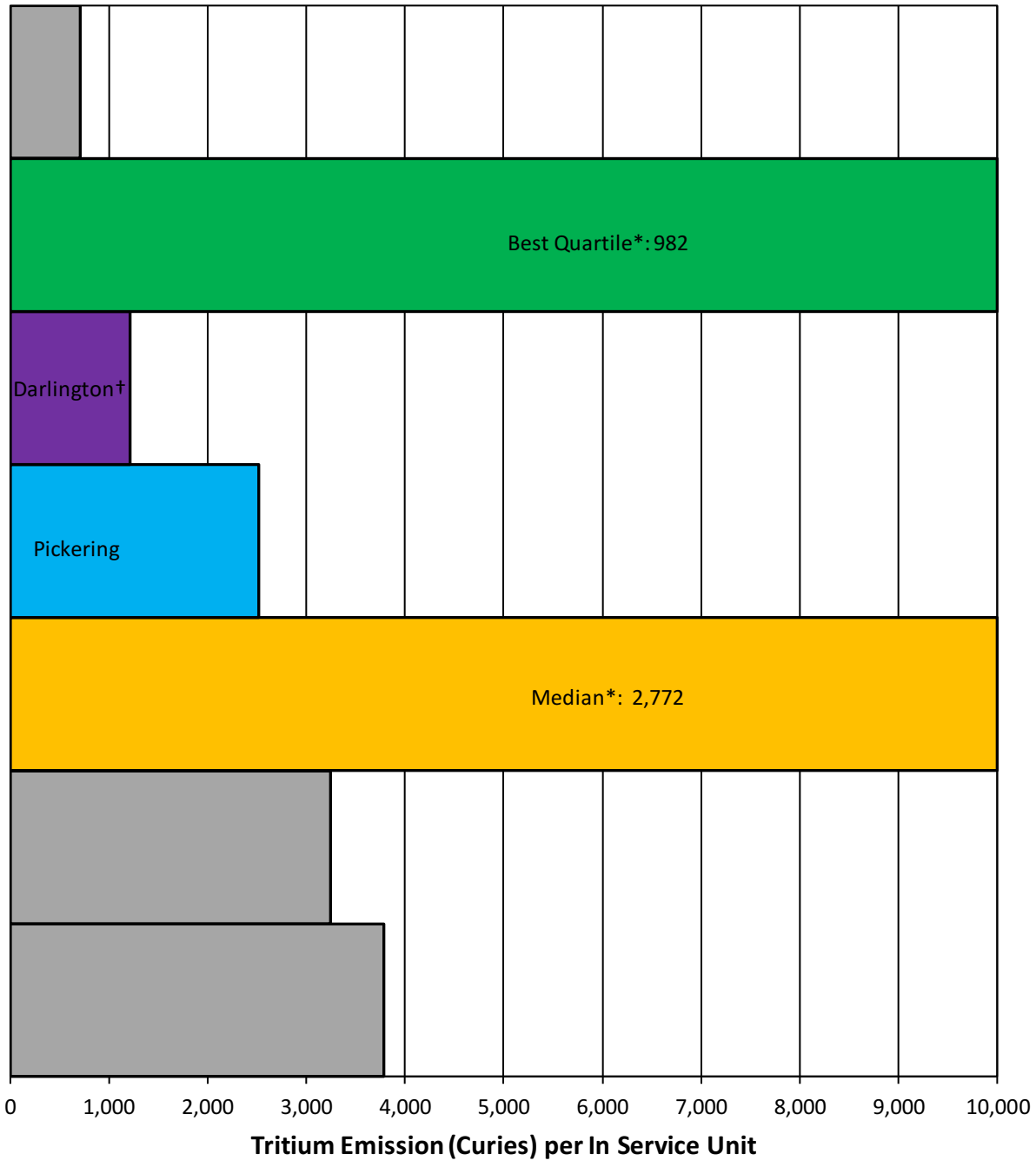
2019 Airborne Tritium Emissions (Curies) per In Service Unit
COG CANDUs



* Industry data based on 2018 as it is the best available information at the time. Pickering and Darlington results are 2019.
†Excludes emissions from Tritium Removal Facility.
Notes:

- Two plants are excluded as one plant's 2018 data is unavailable and another plant has been offline since December 31, 2015 for refurbishment.

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Observations – Airborne Tritium Emissions (Curies) per In Service Unit

2019 (Annual Value)

- Curies per in service unit at best quartile CANDU plants was 982 or lower and the industry median threshold was 2,772 curies per in service unit.
- Darlington's 2019 performance remained in the second quartile with 1,213 curies per in service unit. Emissions from Darlington Unit 2 are not included in this benchmarking report due to the shutdown of Unit 2 in October 2016 for refurbishment.
- Pickering's performance improved from third quartile in 2018 to second quartile in 2019 with 2,517 curies per in service unit.

Trend

- Darlington and Pickering tritium emissions to air continue to be less than one per cent of the regulatory limits.
- After increasing in the early part of the trend period, performance at Pickering improved since 2017. Increased emissions in 2016 and 2017 were primarily due to tritiated water in the Fuel Transfer Conveyor Tunnel being vented to monitored stacks, equipment and system leaks, and dryer performance issues.
- Performance at Darlington in 2019 was consistent with the level seen at the beginning of the trend period. Emissions at Darlington increased in 2019 compared to 2018, mainly due to the planned outage activities in Unit 4, and dryer performance and leaks issues.
- The industry trend line graph shows that industry best quartile performance has been decreasing generally since 2014.

Factors Contributing to Performance

- Key factors affecting performance at DNGS and PNGS include the following:
    - Leaks from various equipment or systems,
    - Declining vapour recovery dryer performance,
    - DNGS Unit 4 outage activities including moderator heat exchanger drain work,
    - Increased unit source term (e.g., higher moderator tritium concentrations),
    - Focus on tritium emission reduction initiatives include dedicated teams to ensure daily emissions monitoring, sustaining and improving dryer performance, heavy water leak minimization, tritium program development and innovations,
    - Other improvement initiatives include OPG's ongoing participation in COG to determine best environmental practices.

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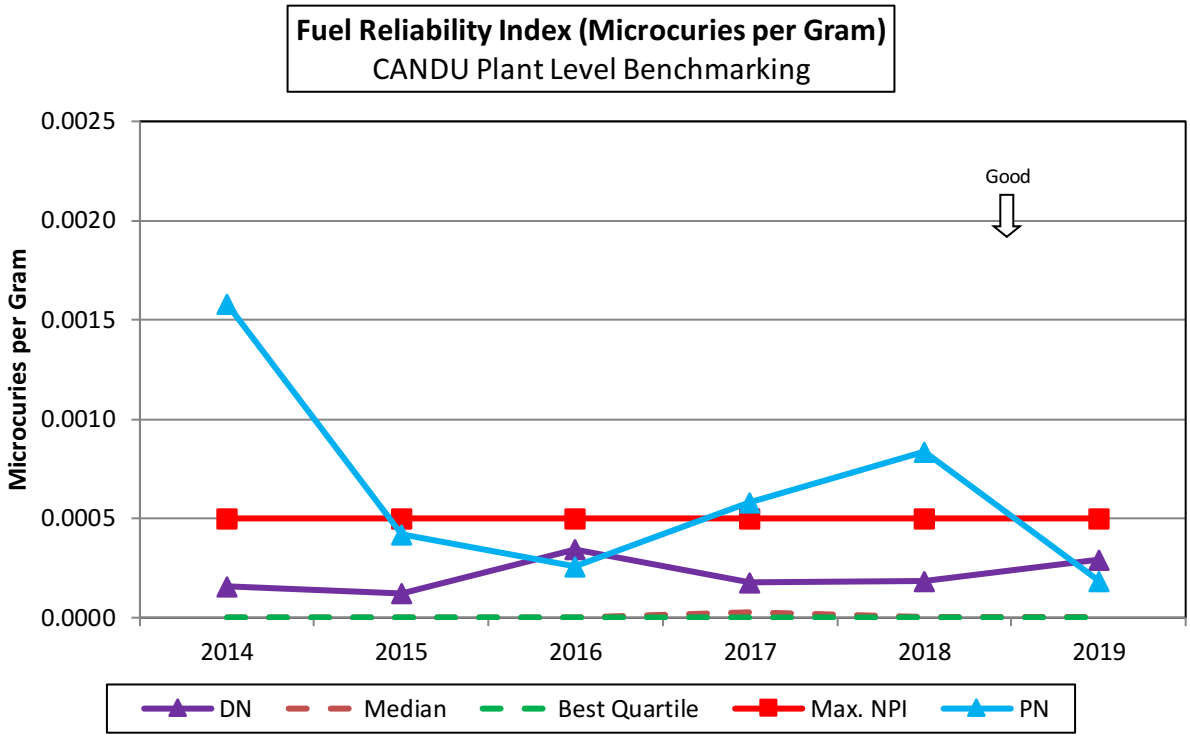
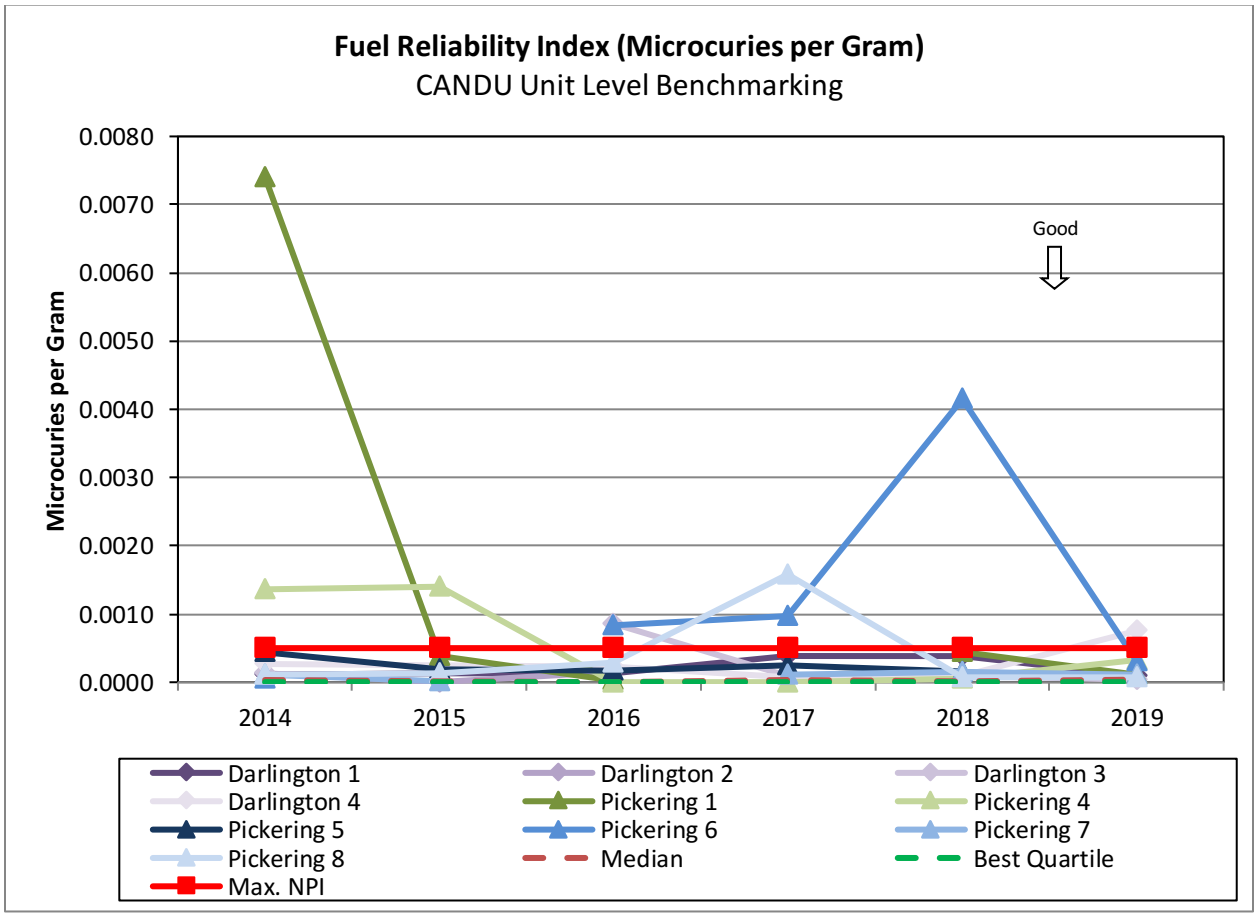
Fuel Reliability Index





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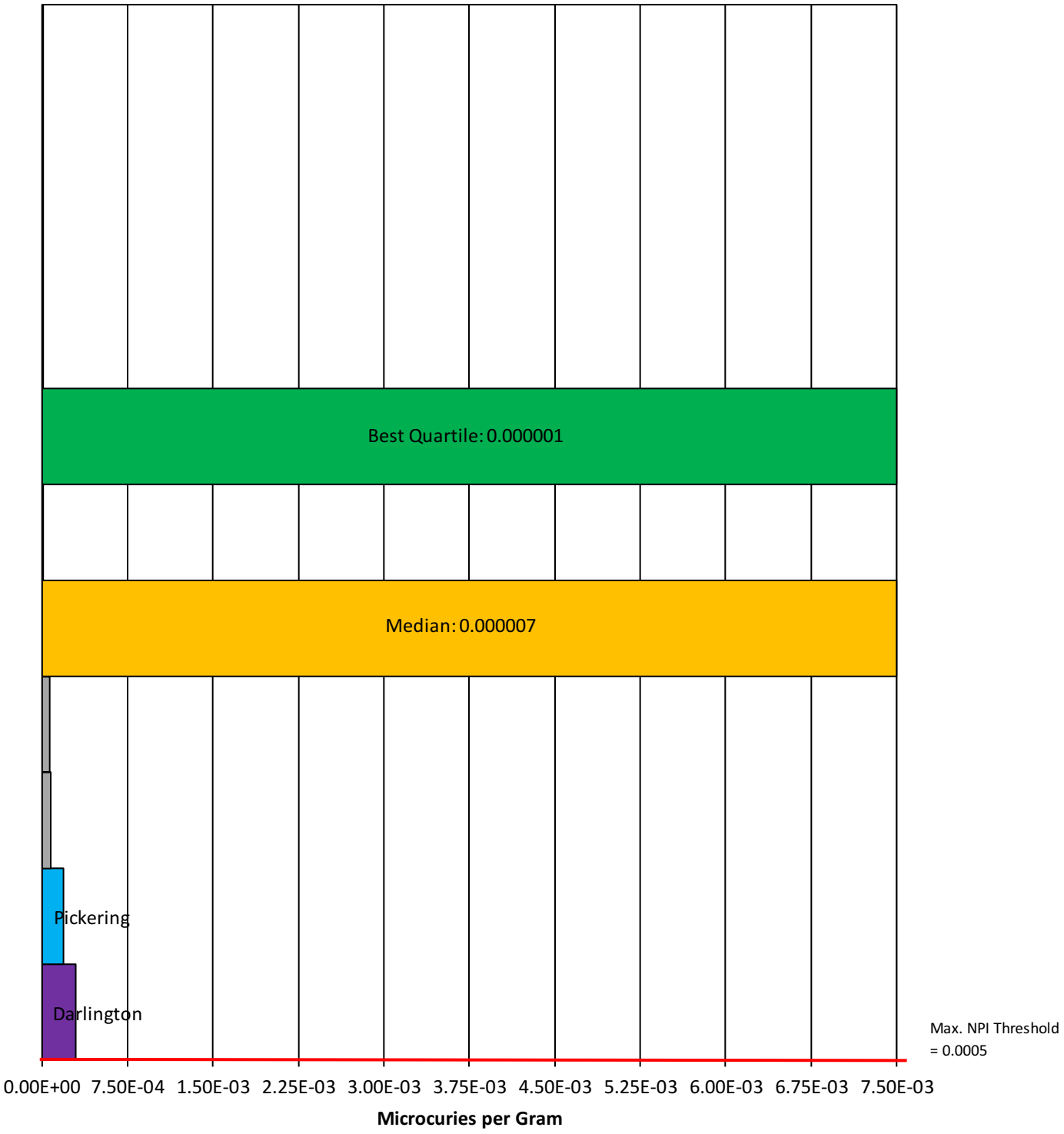
2019 Fuel Reliability Index (Microcuries per Gram)
CANDU Plant Level Benchmarking



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Observations – Fuel Reliability Index (FRI) (CANDU)

2019 (Most Recent Operating Quarter)

- The best quartile value for Fuel Reliability Index (FRI) performance for CANDU plants was 0.000001 µCi/g and the median value was 0.000007 µCi/g.
- FRI performance at PNGS was 0.000187 µCi/g and 0.000295 µCi/g for DNGS in 2019.
- First quartile rating was achieved for both PNGS and DNGS, as results achieved maximum NPI points.
- Post-discharge fuel inspections for PNGS and DNGS indicated that the overall condition of fuel inspected was acceptable and consistent with previous years.
- Fuel inspections for PNGS confirmed four fuel defects in 2019, and no fuel issues of significance arose.
- Fuel inspections for DNGS confirmed one fuel defect occurred in 2019. No fuel issues of significance arose at Darlington in 2019.

Trend

- The best quartile for CANDU plants remained consistent at 0.000001 µCi/g from 2014. The median values for CANDU plants has generally improved from 2014 and remains quite low at 0.000007 in 2019.
- PNGS FRI performance has generally improved since 2014 while DNGS has remained relatively steady. Favourable FRI performance is due to the low incident rate for fuel defects in recent years.

Factors Contributing to Performance

- Four defects were confirmed at PNGS in 2019. In a previous year, a team was formed to investigate the fuel defects incidents and the cause was found to be primarily due to debris fretting.
- Actions taken at PNGS that drove this improvement include:
    - Improved the methods of surveillance and elimination of the possibility of foreign materials entrance into the Heat Transport System due to Fuel Handling and Outage practices,
    - Developed a fuel defect guideline for Pickering,
    - Increased scope of Heat Transport System grab sampling and analysis when defects are in-core,
    - Improved capability of detecting the defected fuel bundles during the discharge from the fuelling machines, and
    - Improved the capability of the in-bay inspection of the suspected fuel bundles to be defected.

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Fuel Reliability Index (CANDU - FRI) – continued

- Darlington had only one fuel defect in 2019. Steps have been taken that have led to improved FRI performance and prevent the potential of fuel defects, including the following:
  - Greatly improved Foreign Material Exclusion practices during the Darlington Unit 2 refurbishment activities.
  - New fuel with tighter tolerances for mass was received and is being used,
  - OPG-supplier co-operation resulted in installation of an automatic loader of fuel pellets complete with a "go/no go" pellet diameter monitor,
  - Close monitoring of existing fuel bundle inventory and core load.

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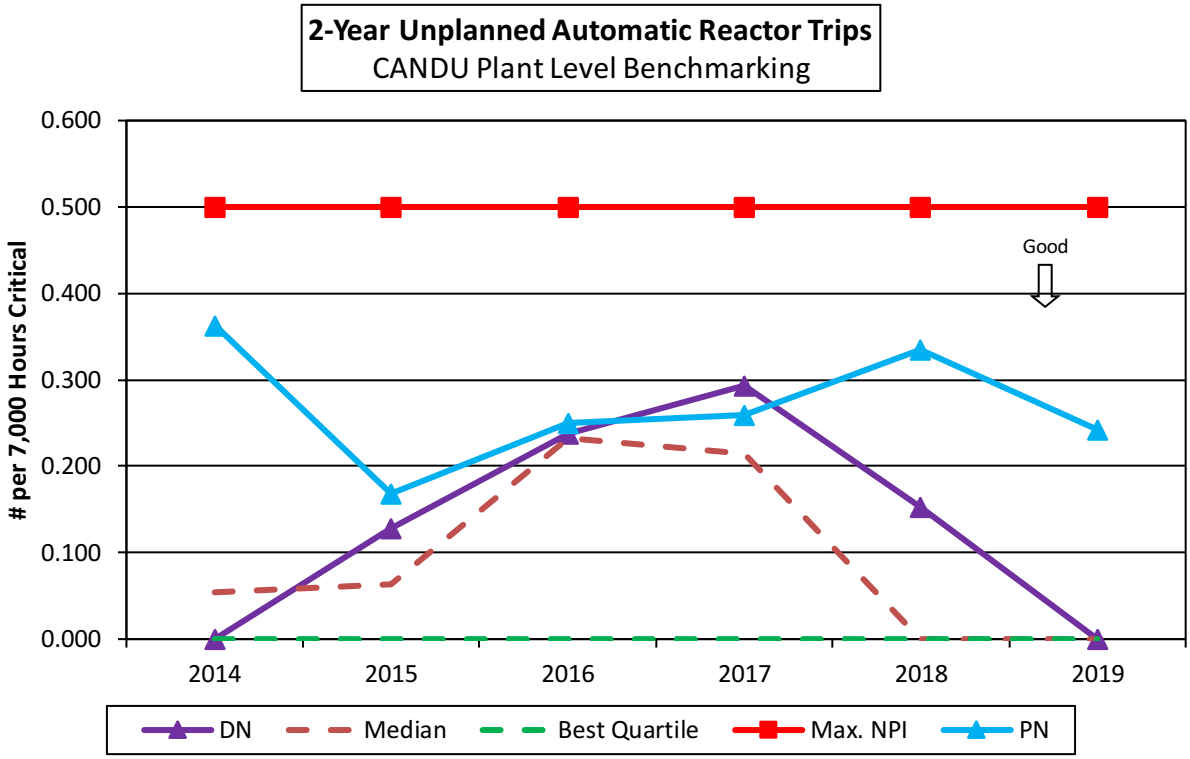
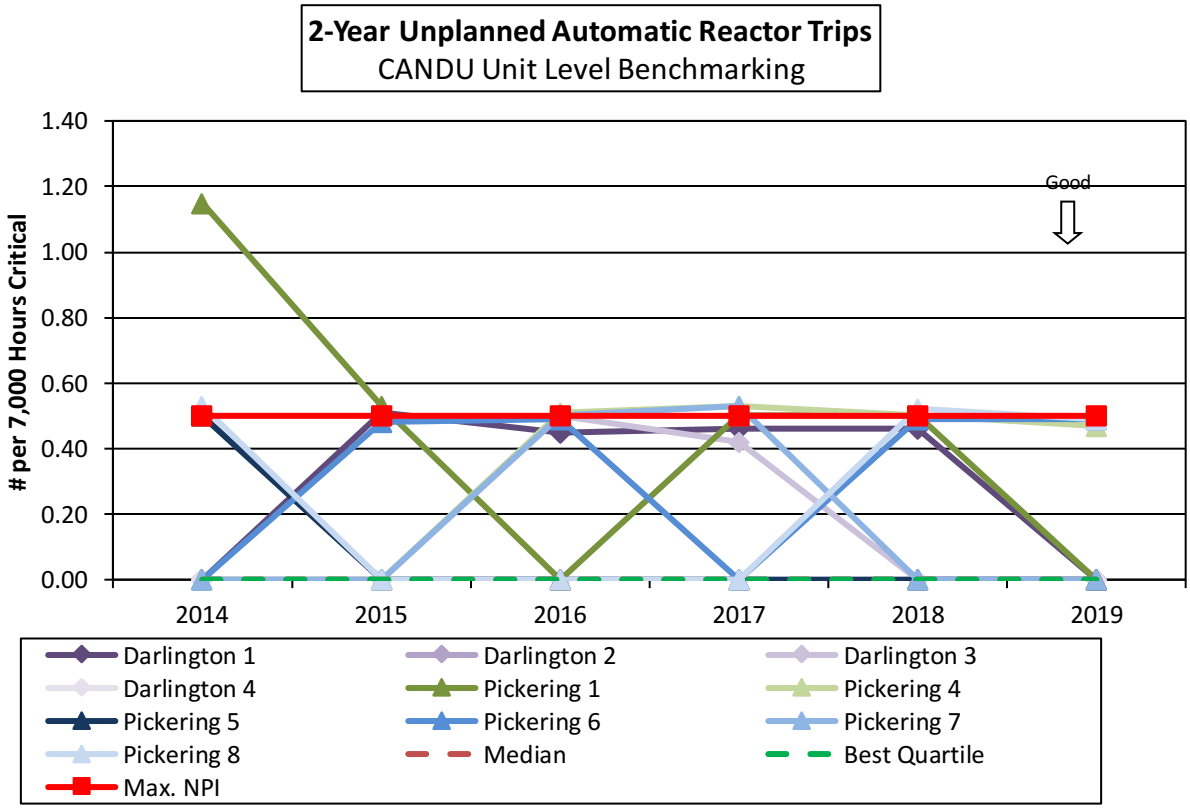
2-Year Unplanned Automatic Reactor Trips





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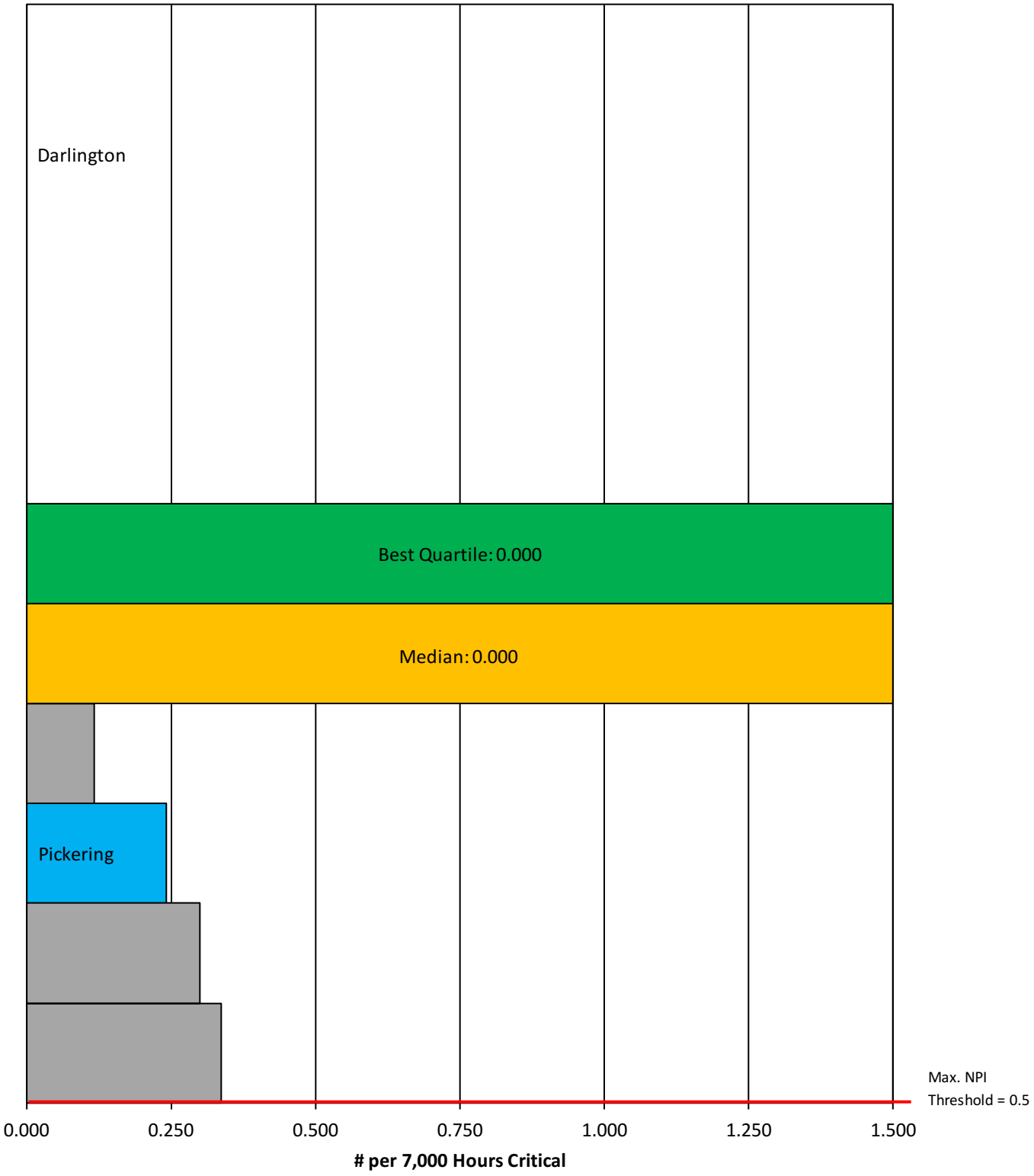
2019 2-Year Unplanned Automatic Reactor Trips
CANDU Plant Level Benchmarking



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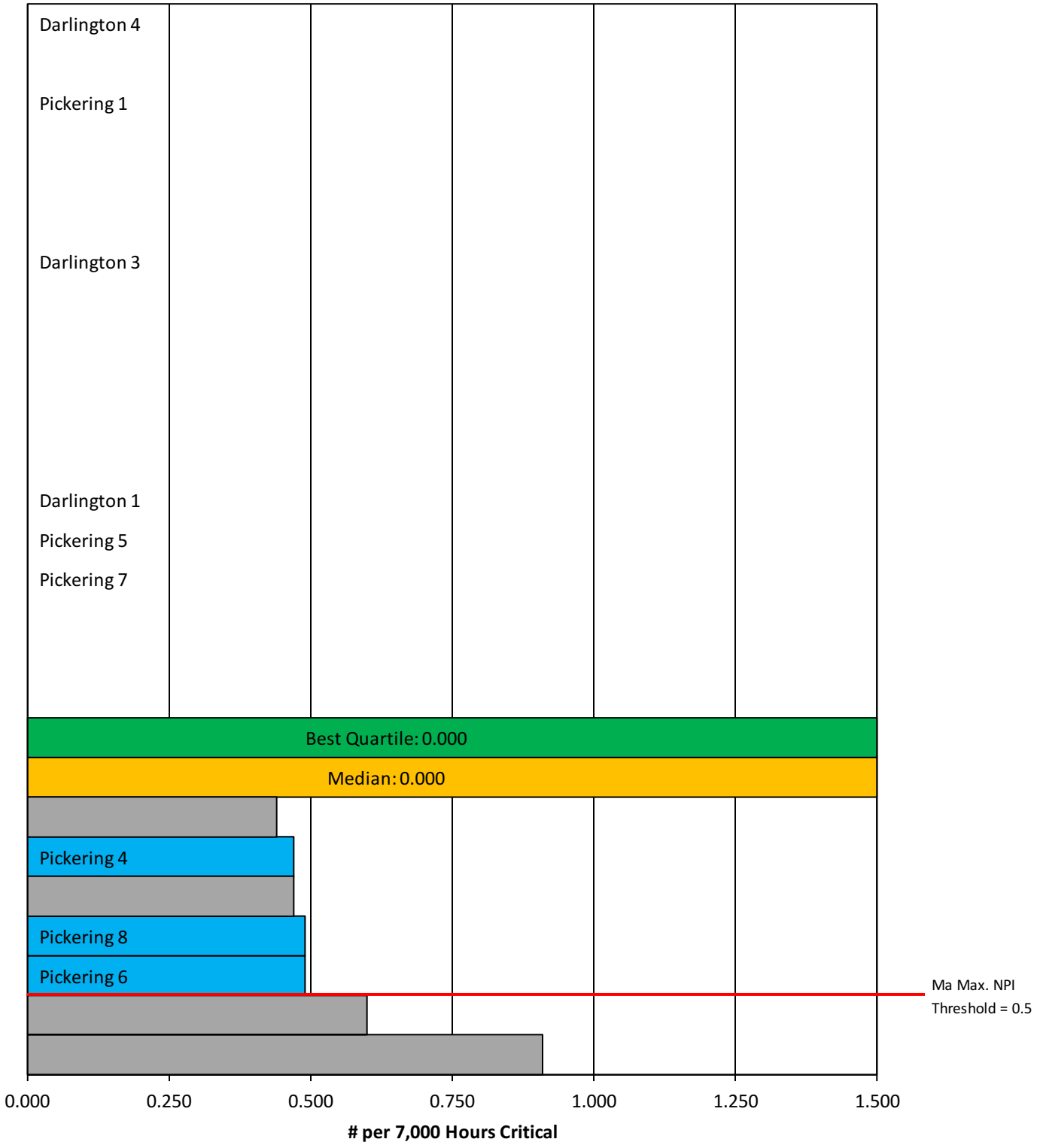
2019 2-Year Unplanned Automatic Reactor Trips
CANDU Unit Level Benchmarking



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Observations – 2-Year Unplanned Automatic Reactor Trips (CANDU)

2019 (2-Year Rolling Average)

- The 2-year rolling average unplanned automatic reactor trip best quartile and median for CANDU plants as well as individual units was 0.00.
- At the plant level, Pickering's trip rate of 0.24 achieved the maximum NPI points.
- At the plant level Darlington's trip rate of 0.00 was below the maximum NPI threshold value of 0.50 and achieving top quartile status. Darlington Unit 2 began a long-term refurbishment outage on October 15, 2016 and has been excluded from benchmarking results.
- In 2019, both PNGS and DNGS had no unplanned automatic reactor trips.

Trend

- The unplanned automatic reactor trip best quartile for CANDU plants has been zero throughout the trend period. The median value deteriorated in 2016 and 2017 from 2015. In 2018 and 2019 the median value improved to zero.
- At the plant level, PNGS performance declined in 2016 to 2018, and improved in 2019 for an overall improvement over the trend period.
- At the plant level, DNGS peaked in 2017, improved in 2018, and achieved the industry best quartile result of a zero trip rate in 2019.

Factors Contributing to Performance

- Key performance drivers for this metric include: general equipment reliability, material condition, and human performance.
- On-going due diligence by Station Operations, Engineering, and Maintenance organizations. Operating Experience (OPEX) from each event has been shared at Pickering, Darlington and at external summits.
- Training material and technical procedures have been revised based on OPEX.
- Like-for-like parts replacement has taken place to improve equipment reliability. System health teams are involved in obsolescence issues.

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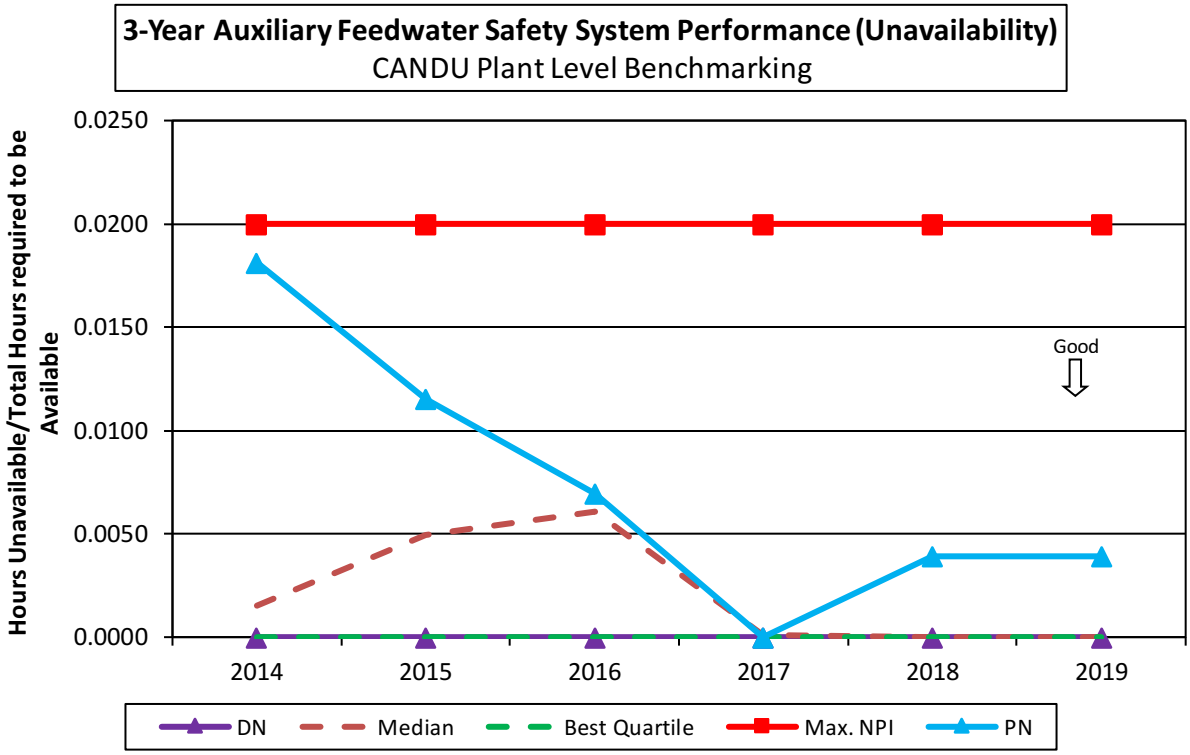
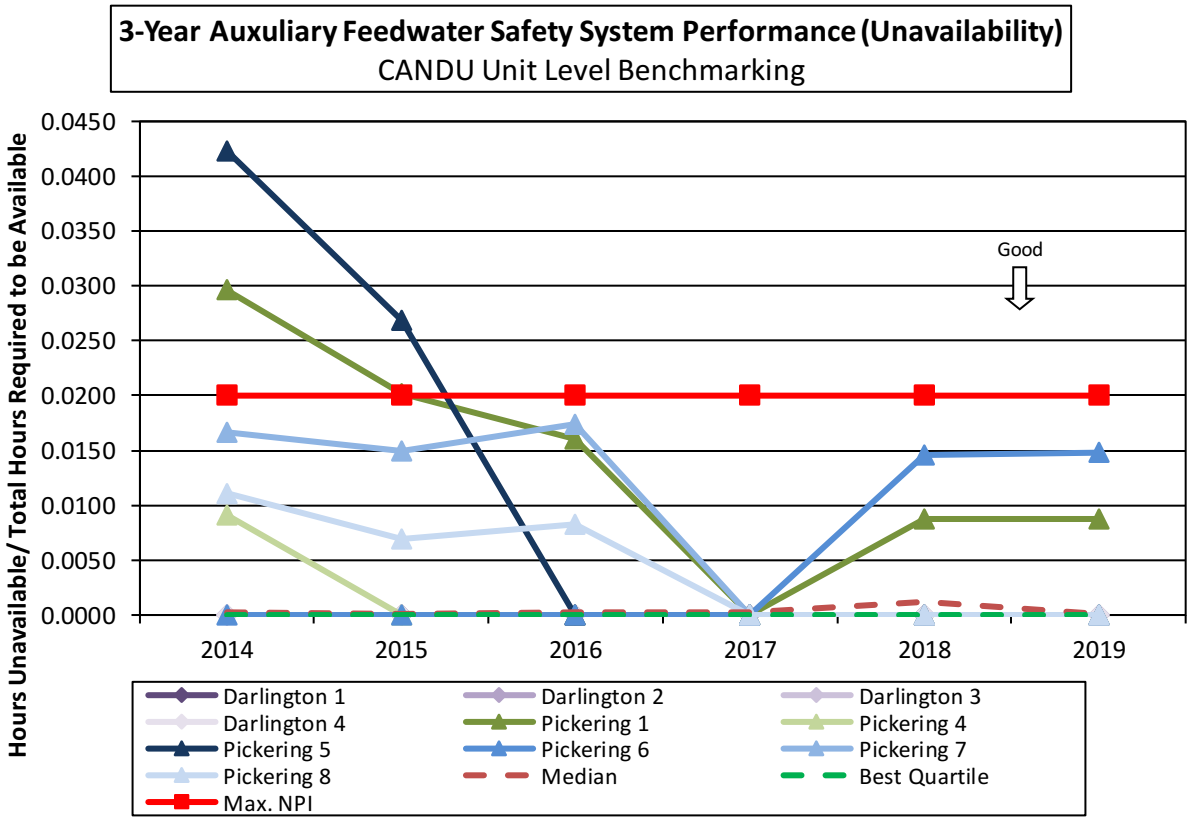
3-Year Auxiliary Feedwater Safety System Unavailability





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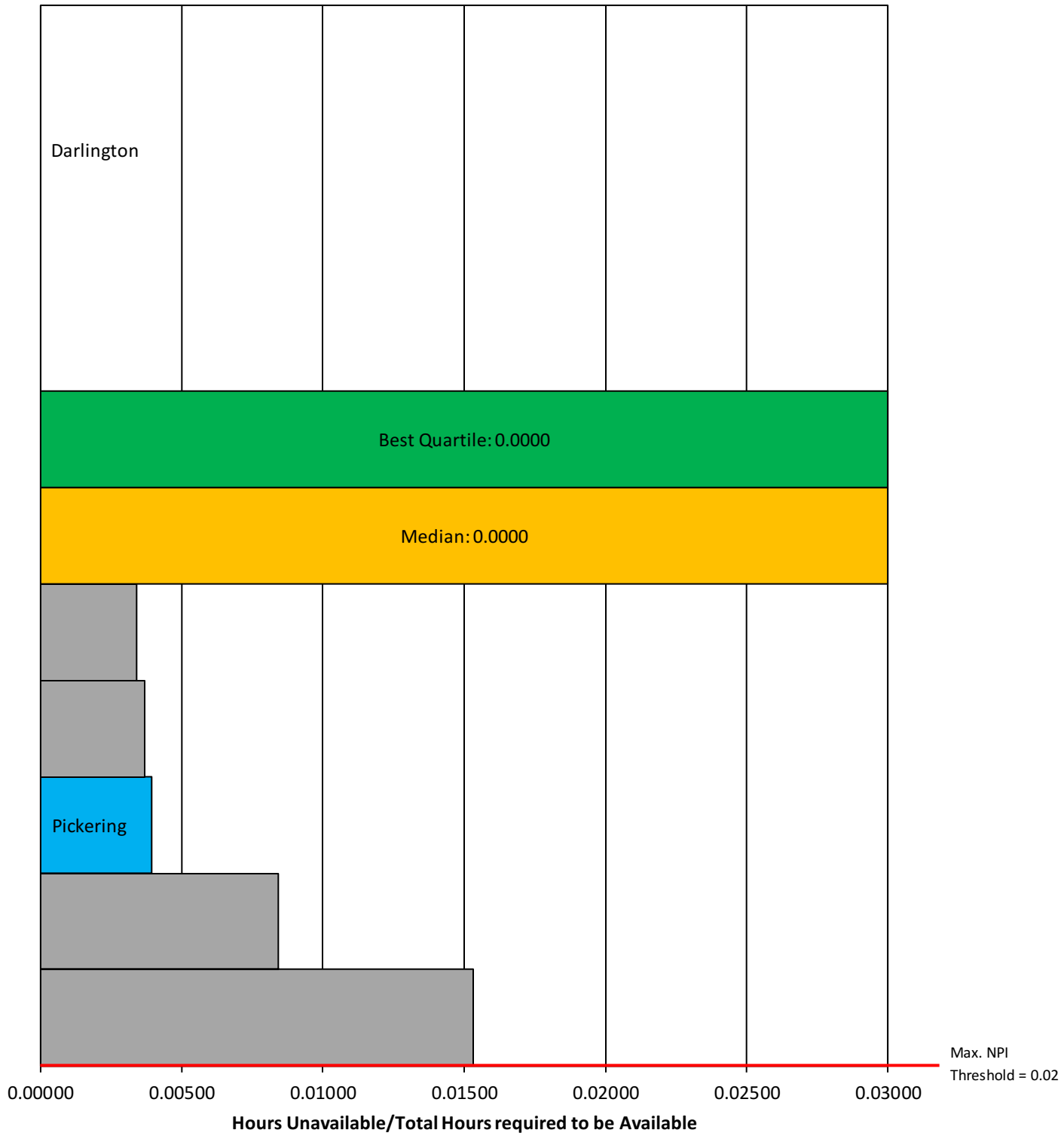
2019 3-Year Auxiliary Feedwater Safety System Performance (Unavailability) CANDU PlantLevel Benchmarking



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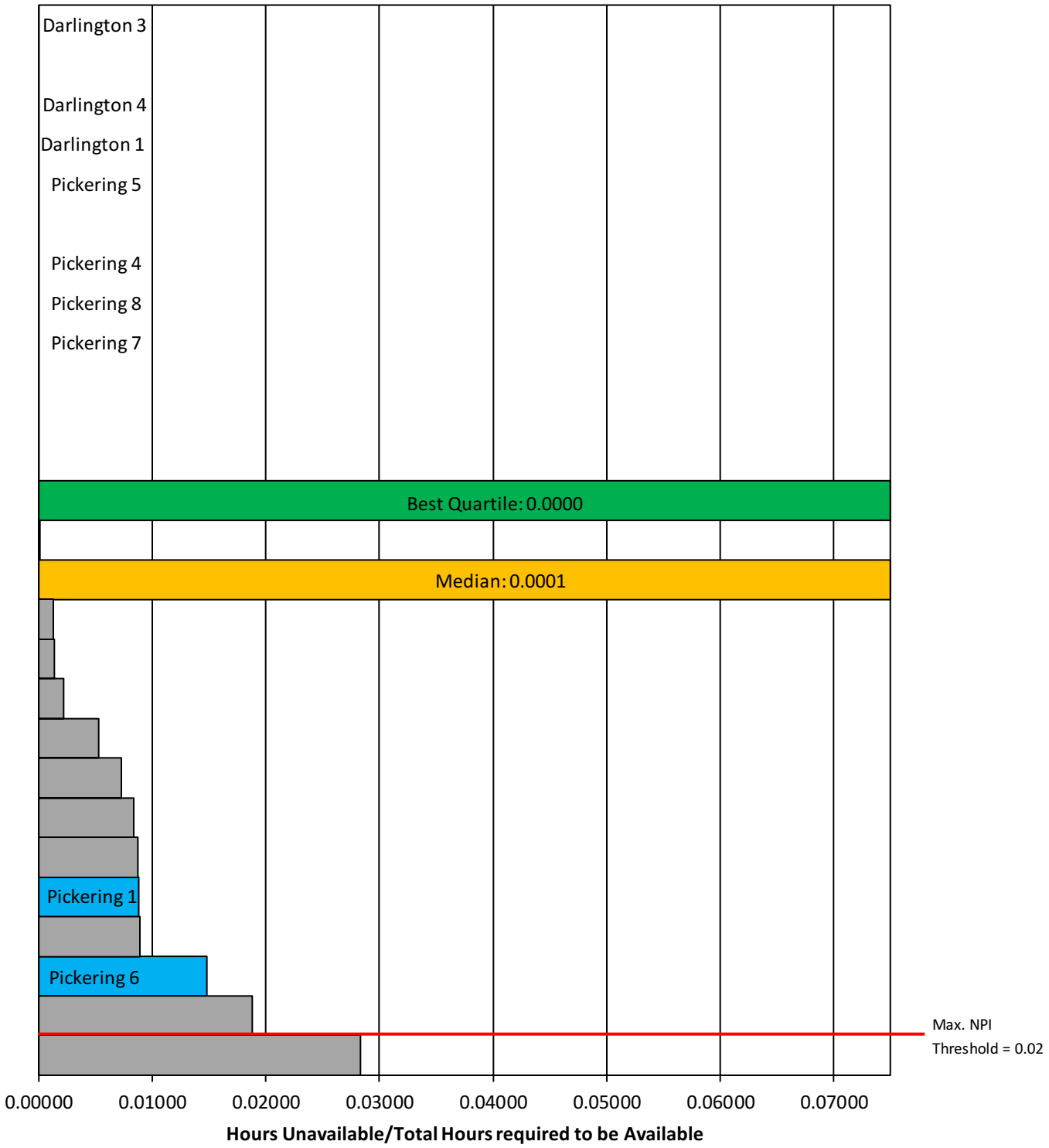
2019 3-Year Auxiliary Feedwater Safety System Performance (Unavailability) CANDU Unit Level Benchmarking



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Observations – 3-Year Auxiliary Feedwater System Unavailability (CANDU)

2019 (3-Year Rolling Average)

- Auxiliary feedwater (AFW) safety system performance at best quartile for CANDU plants was zero with a median value of 0.0000.
- At the plant level, PNGS AFS unavailability of 0.0039 achieved maximum NPI points.
- DNGS achieved best quartile performance of zero unavailability for both the station and unit levels in 2019. Darlington Unit 2 began a long-term refurbishment outage on October 15, 2016 and has been excluded from benchmarking results.

Trend

- The 3-Year AFW unavailability best quartile performance of CANDU plants maintained zero unavailability from 2014 to 2019.
- The plant level industry median value has fluctuated over the review period but has remained below the NPI maximum threshold.
- Pickering station performance fluctuated over the trend period and had an overall improvement.
- Darlington station performance has been at zero unavailability over the entire trend period.

Factors Contributing to Performance

- Key performance drivers for this metric include: general equipment reliability, material condition, and human performance.
- 2019 - Quarter 1, Pickering - Unit 6 Auxiliary Boiler Feedwater Pump (ABFP) was declared unavailable due to loss of cooling flow to non drive end (NDE) bearing. Per operating procedure, an impairment of ABF System was declared, and the unit was placed on a 72 hr shutdown clock. Following the silt/blockage removal of the inlet and discharge lines of the NDE bearing, and cleaning of the manual isolation valve, the pump was successfully tested and returned to service.

  To improve the system performance at PNGS the following actions will be taken:
  - Remove debris from the pipework.
  - Investigate failure of the instrumentation and control to indicate the cooling flow to NDE bearing and repair or replace the failed equipment.

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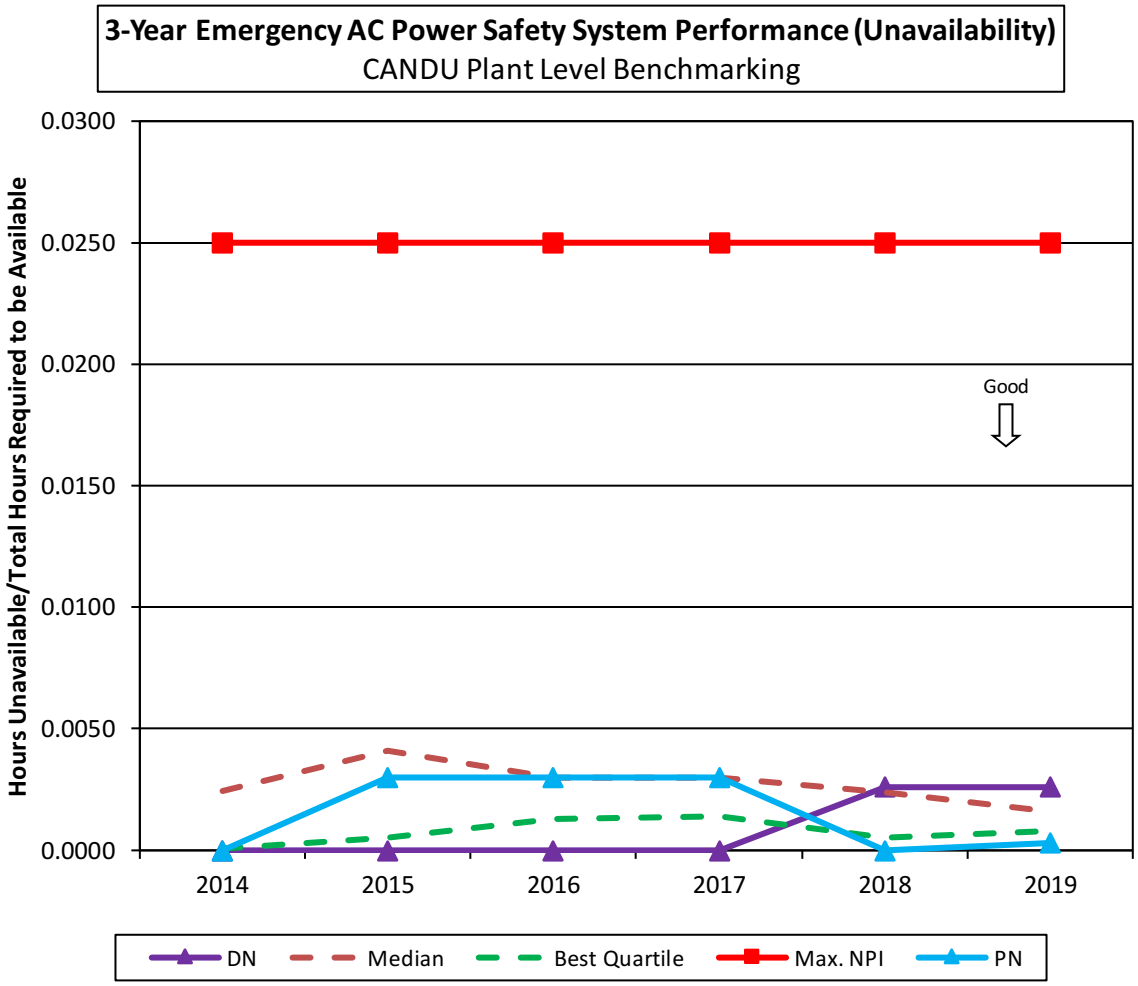
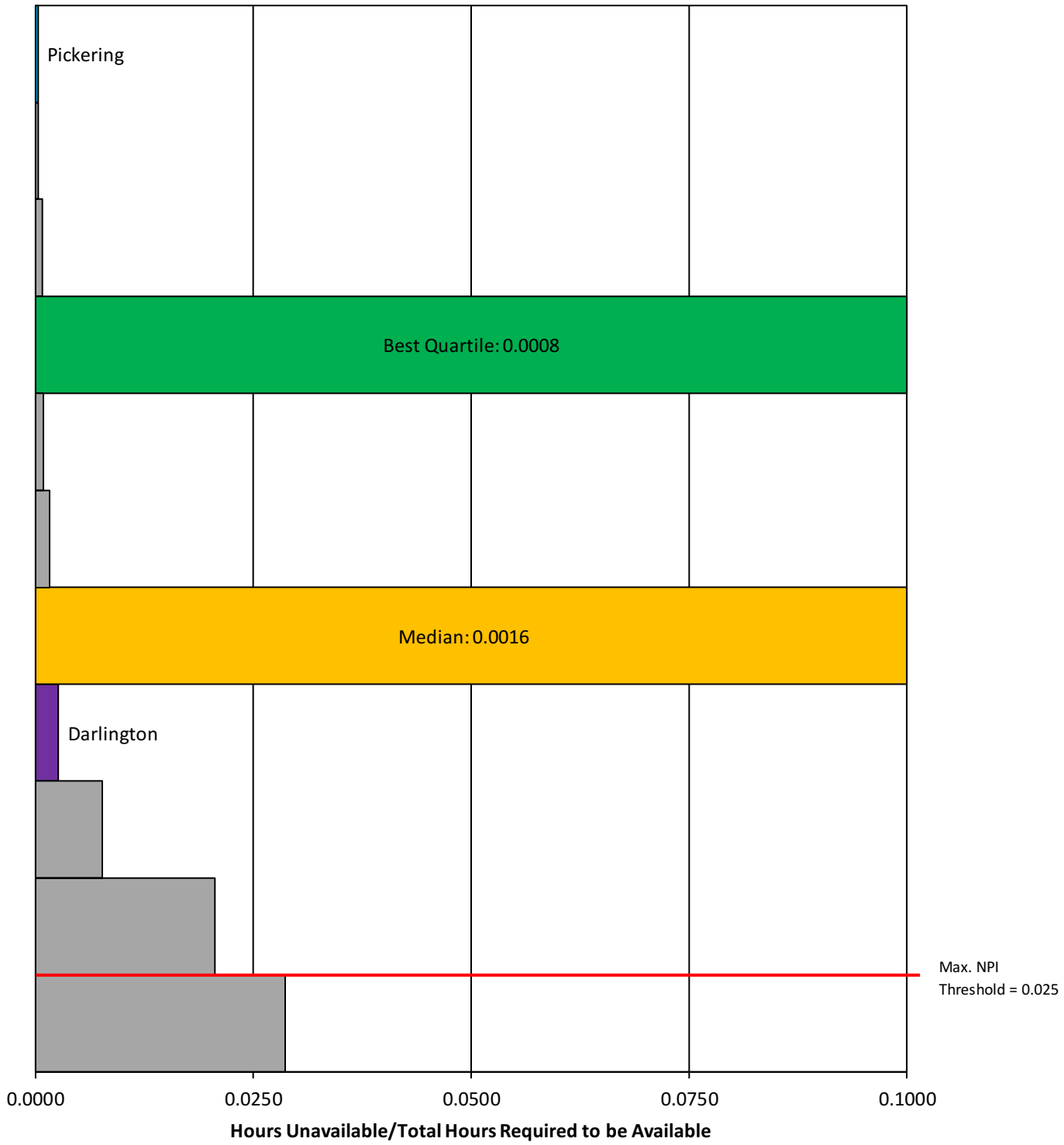
3-Year Emergency AC Power Safety Unavailability



2019 3-Year Emergency AC Power Safety System Performance (Unavailability) CANDU Plant Level Benchmarking



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Observations – 3-Year Emergency AC Power Safety System (CANDU)

2019 (3-Year Rolling Average)

- 3-Year Emergency AC Power Safety System performance at best quartile for CANDU plants was 0.0008. The industry median value was 0.0016.
- At the plant level, PNGS is one of the best performing stations in the CANDU peer group, achieving an unavailability of 0.0003.
- DNGS had an unavailability of 0.0026, and achieved the maximum NPI points.

Trend

- The 3-year Emergency AC Power Safety System unavailability industry best quartile for CANDU plants declined each year from 2015 to 2017, improved in 2018 and deteriorated in 2019 again. The industry median value improved in 2016 from 2015 and remained unchanged in 2017 with further improvement in 2018 and 2019.
- PNGS performance remained below the NPI maximum threshold throughout the trend period and the unavailability was close to zero in 2019.
- DNGS performance remained below the NPI maximum threshold throughout the trend period and remained unchanged in 2019 compared to 2018.

Factors Contributing to Performance

- Key performance drivers for this metric include: general equipment reliability, material condition, and human performance.
- 2019 Quarter 3, Pickering – During the execution of the start reliability test (Class III Standby Generators - Black Start of Standby Generator (SG)), a standby generator, SG1, tripped due to a failure of its AC motor driven fuel pump. When SG1 tripped, another standby generator, SG3, was in a planned outage, which resulted in reduction of SG redundancy.
- To improve the system performance at PNGS the following actions will be taken:
    - Perform design changes to modify the steam generators with electrical driven fuel pumps to shaft driven pumps, matching the configuration of SG2 and SG3, which do not exhibit machine breaker closure trips.
    - Replacement of the relay control logic and annunciator under the Standby Generator Reliability improvement modification Project. This project will resolve an obsolescence concern.
    - Upgrades of vibration monitoring system on SGs.
- At DNGS, an event occurred in 2018 which resulted in only one SG available out of a total of four, impacting the AC Power Safety System unavailability. As this metric is based on a 3-year rolling average, this value will carry over until Q2-2021 if no additional events occur.

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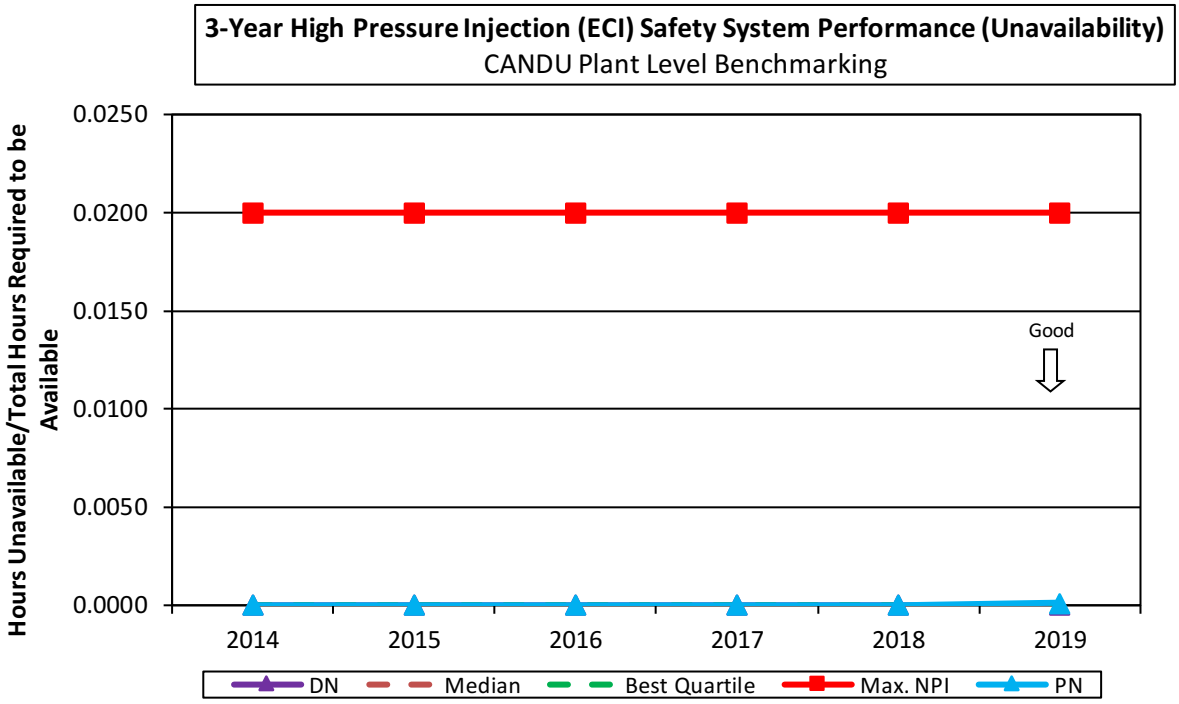
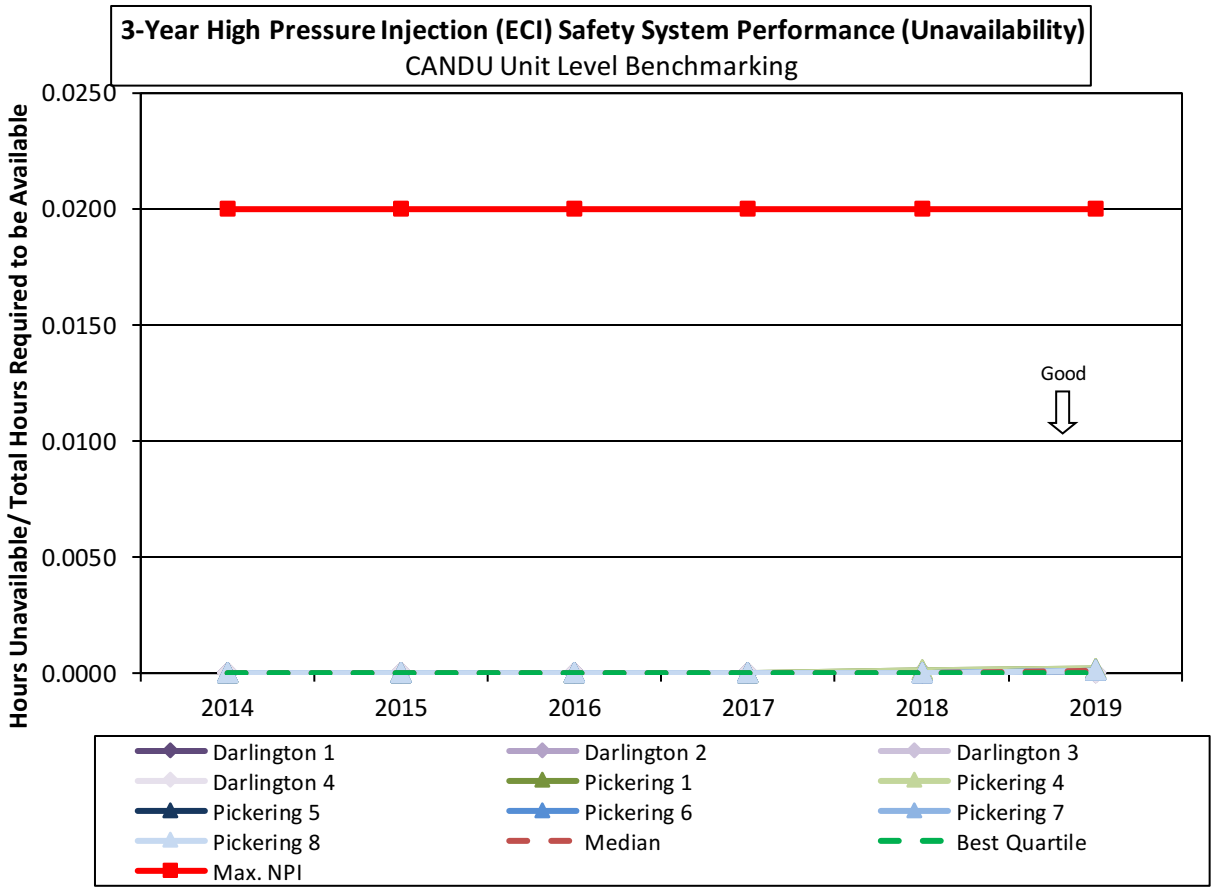
3-Year High Pressure Safety Injection





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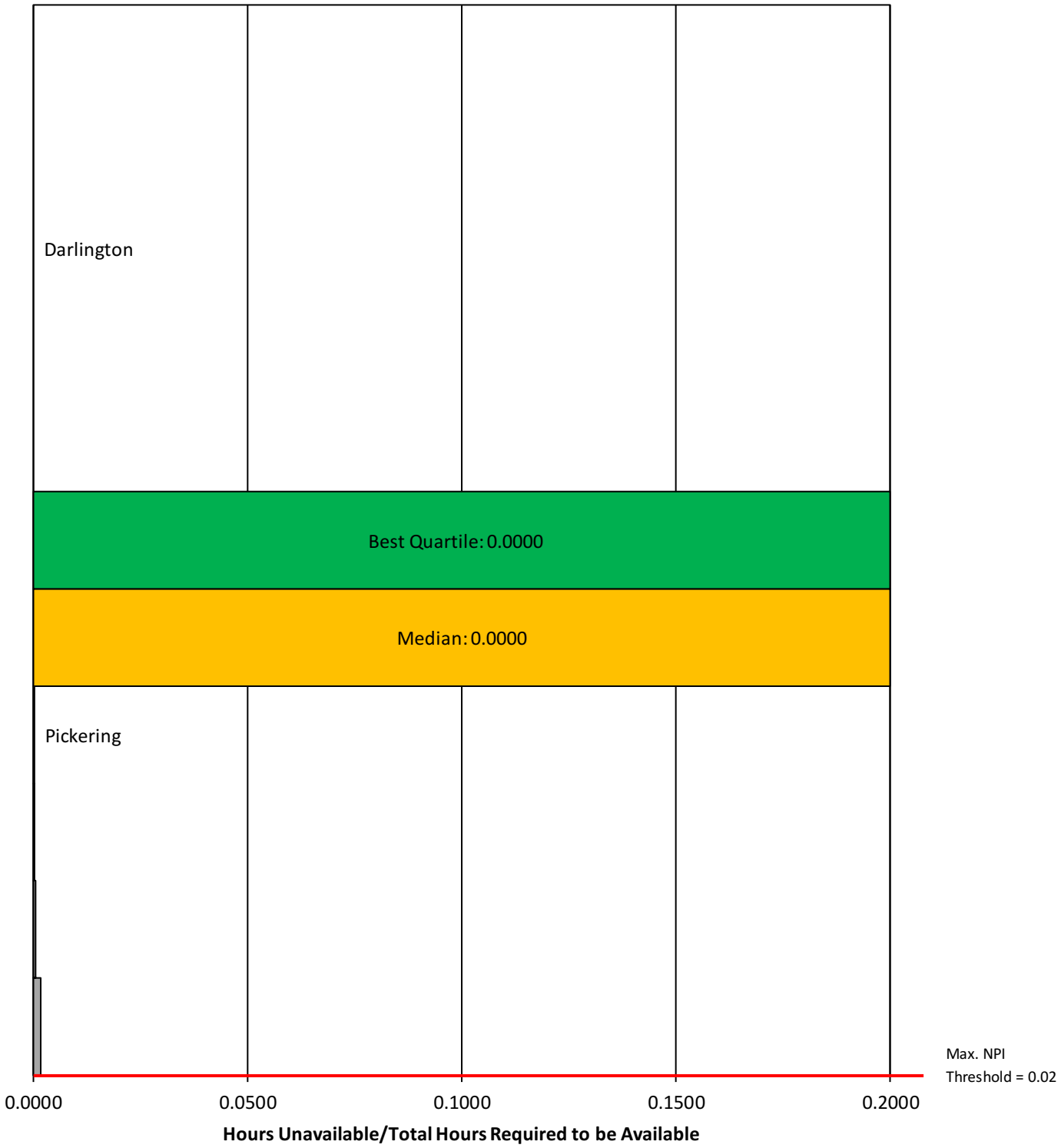
2019 3-Year High Pressure Injection (ECI) Safety System Performance (Unavailability)
CANDU Plant Level Benchmarking



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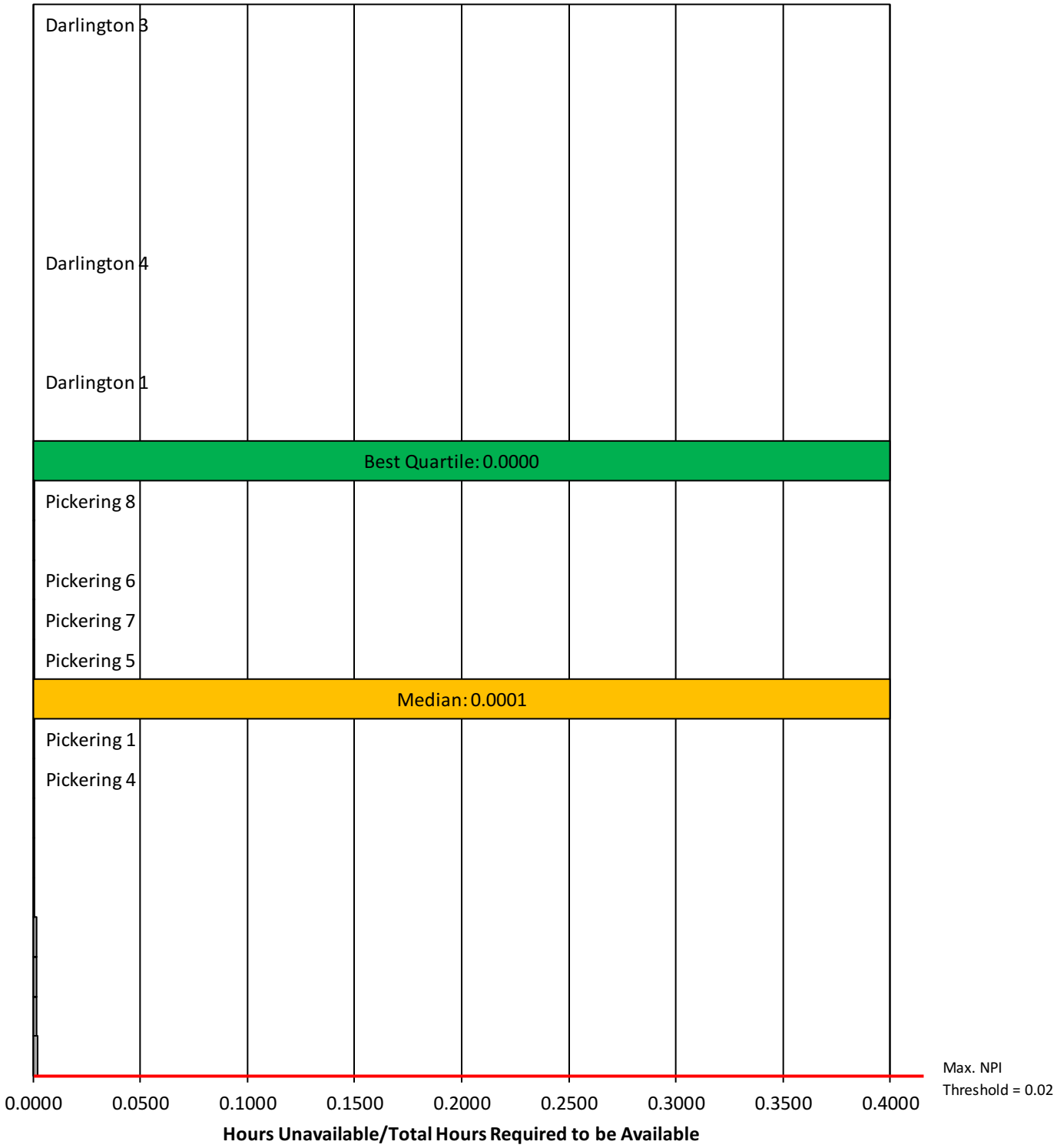
2019 3-Year High Pressure Injection (ECI) Safety System Performance (Unavailability)
CANDU Unit Level Benchmarking



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Observations – 3-Year High Pressure Safety Injection Unavailability (CANDU)

2019 (3-Year Rolling Average)

- The best quartile and median values for the 3-Year High Pressure Safety Injection (HPSI) Unavailability performance for CANDU plants were zero.
- At the plant level, PNGS with an HPSI unavailability of 0.0001 achieved maximum NPI points.
- DNGS achieved best quartile performance of zero unavailability in 2019. Darlington Unit 2 began a long-term refurbishment outage on October 15, 2016 and has been excluded from benchmarking results.

Trend

- The 3-Year HPSI unavailability best quartile and median performance of CANDU plants has been zero since 2014.
- At the plant level, PNGS performance achieved maximum NPI points throughout the trend period and was near zero in 2019.
- DNGS achieved best quartile performance of zero HPSI unavailability throughout the trend period.

Factors Contributing to Performance

- Key performance drivers for this metric include: general equipment reliability, material condition, and human performance.
    - 2019 Quarter 1, Pickering ECI Trace Heater - During routine panel monitoring, Emergency Coolant Injection (ECI) heat trace alarm was received. The water temperature in the High Pressure Emergency Coolant Injection (HPECI) piping was detected to be less than 6°C and the outdoor temperature was less than 1°C. This condition constitutes a Level 2 ECI system impairment. To establish flow in the ECI system and also heat the water, an HPECI pump was started at which point the lack of flow concern was resolved.

    - 2019, Quarter 2 – Pickering– During a routine test (Recovery System – Unit Emergency Control Centre (UECC) Tests), when UECC hand switch was selected to open, ECI recovery sump level rose rapidly and ECI storage tank level dropped to 10.8 m, which results in Level 2 ECI system impairment, applicable to Units 1, 4, and 5 to 8. The hand switch was reclosed. ECI storage tank level was restored to above 10.8 m following sump level pump back to the ECI storage tank. Test (ECI Recovery Sump Valve and Recovery Pump Discharge Valve Test) was performed in order to identify the passing check valve. The recovery pump check valve was isolated. Note that Level 2 ECI system impairment lasted for the period of time when the ECI storage tank level was below 10.8 m.
- To improve system performance at PNGS, the following actions will be taken:
    1) Investigate the failure of primary heater.
    2) Replace the degraded check valve.
    3) Align the ECI impairments Abnormal Accident Manuals, ECI Operational Safety Requirements, and test.

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3.0 RELIABILITY

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. The Embalse plant is excluded since it was taken offline since December 31, 2015 for refurbishment.

Backlog metrics, On-line Deficient and Corrective maintenance, are also included within this section and the data comes from an industry sponsored INPO AP-928 subcommittee. Data points benchmarked on backlogs are a single point in time, not a rolling average. All of the data is self-reported.

The primary metric within the reliability section is 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, Unit Capability Factor, and Chemistry Performance Indicator. The remainder of the WANO NPI components are analyzed in the safety section (Section 2.0).

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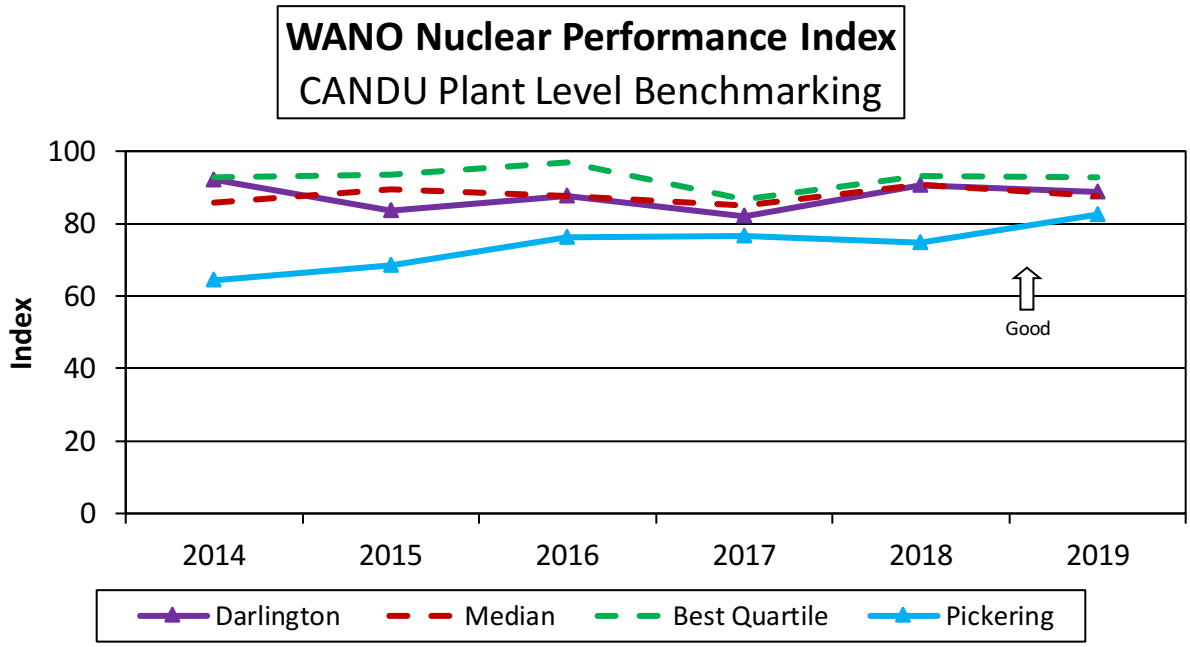
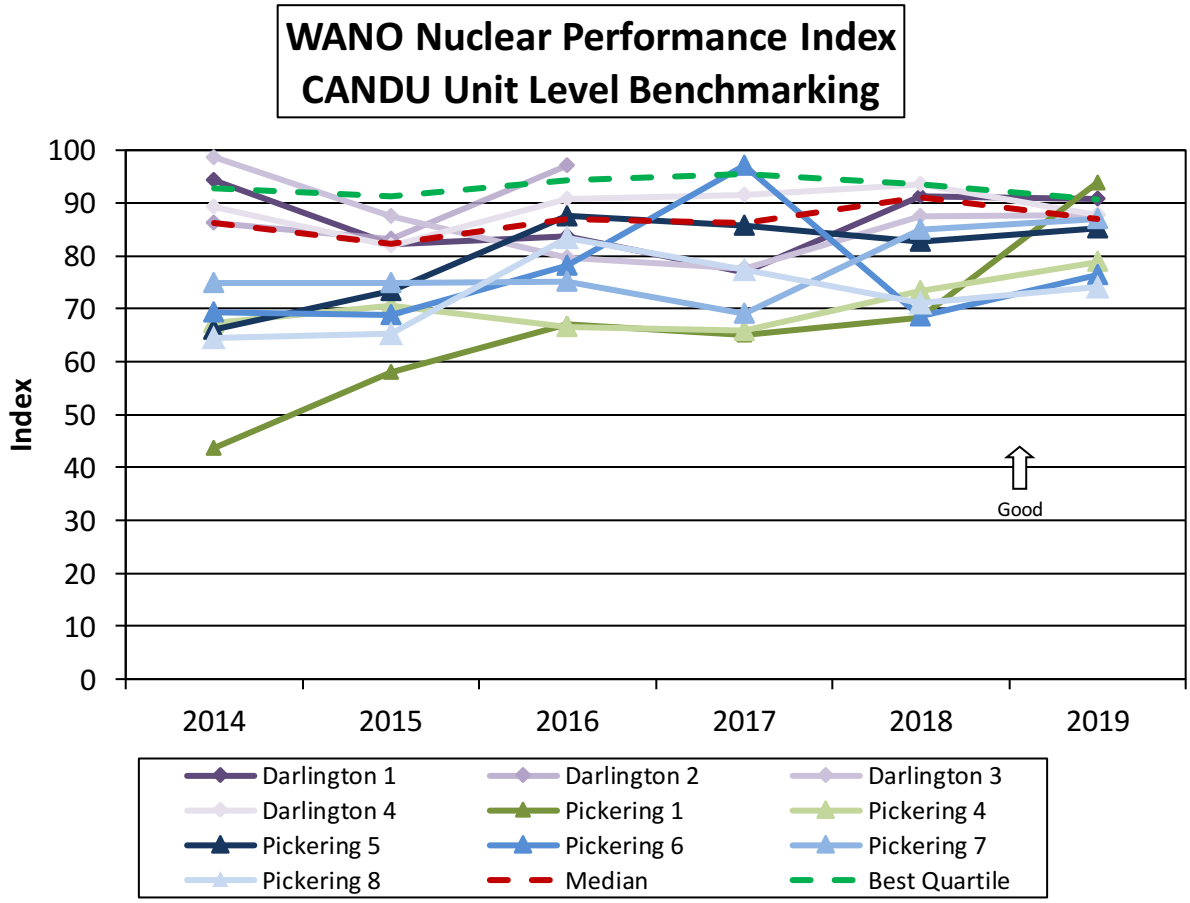
WANO Nuclear Performance Index





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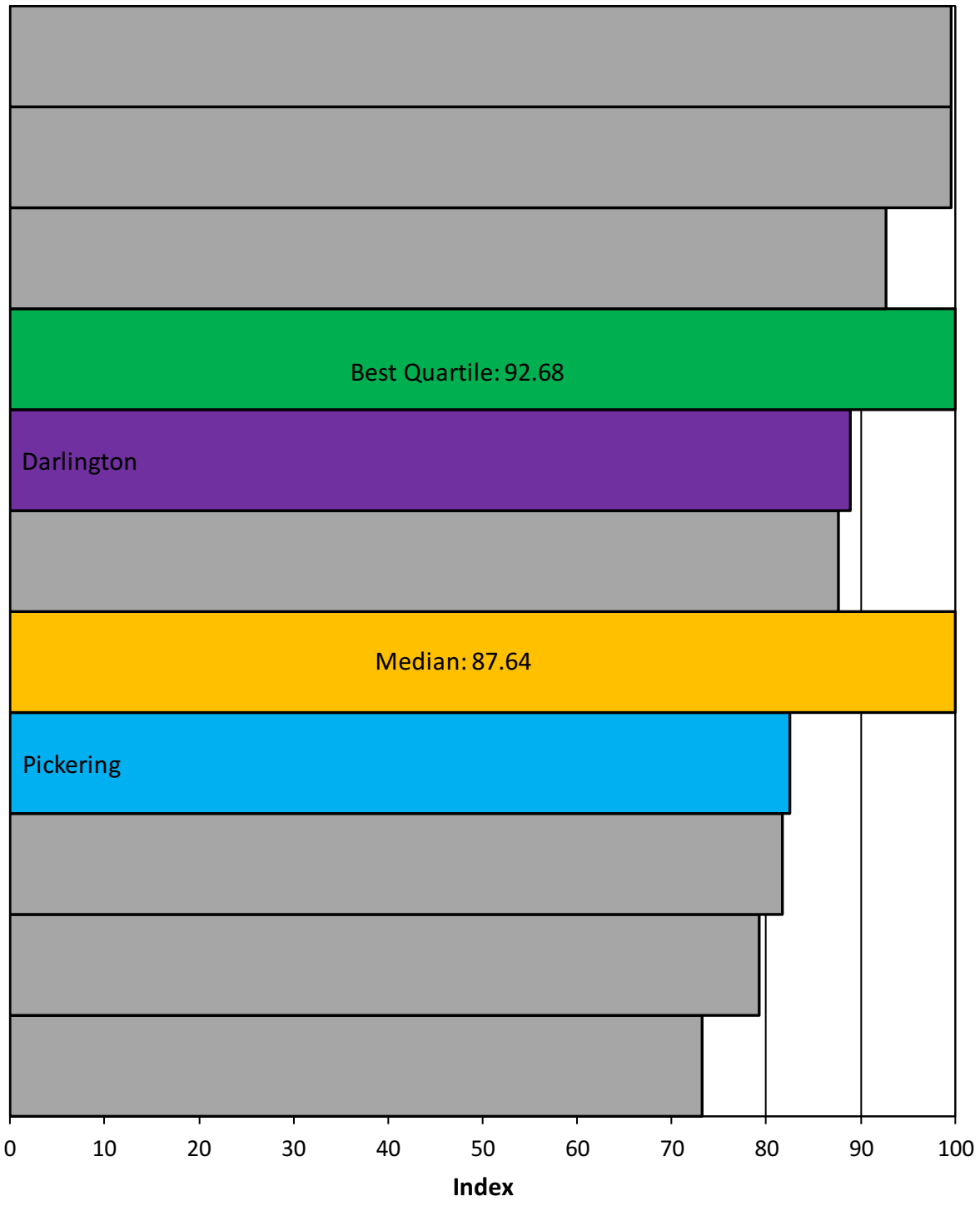
2019 WANO Nuclear Performance Index
CANDU Plant Level Benchmarking



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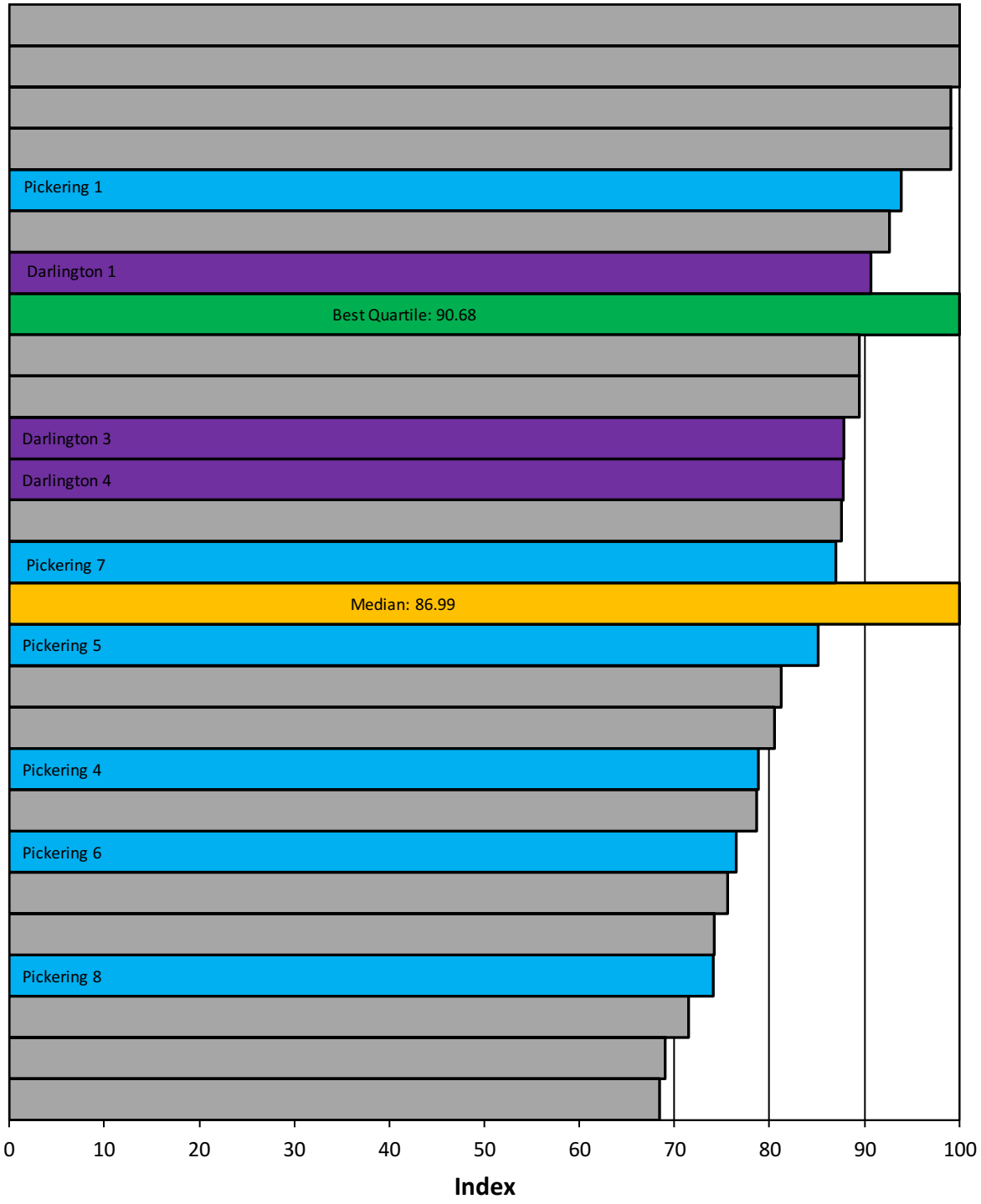
2019 WANO Nuclear Performance Index
CANDU Unit Level Benchmarking



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Observations – WANO Nuclear Performance Index (NPI) (CANDU)

2019

- 2019 best quartile of the CANDU plant comparison panel for WANO NPI is 92.68, representing a 0.32 point decrease from 2018.
- 2019 median of the CANDU plant comparison is 87.64, a 3.1 point decrease from 2018.
- PNGS NPI at 82.5, improved by 7.6 points in comparison to 2018, and achieved its best ever NPI score as a combined six-unit station; however, it placed in third quartile.
- In 2019, PNGS improvement was driven by the achievement of maximum WANO NPI results or top quartile performance for all seven NPI sub-metrics under the Safety cornerstone.
- DNGS NPI at 88.9 decreased by 1.8 points in comparison to 2018, and placed in second quartile.
- In 2019, DNGS achieved maximum WANO Nuclear Performance Index (NPI) results or best quartile performance for six of the seven NPI sub-metrics under the Safety cornerstone and UCF.

Trend

- A significant positive trend was seen by PNGS NPI as it increased by 18 points from 2014 to 2019.
- DNGS' performance ranged from 82 to 90 points from 2014-2019.

Factors Contributing to Performance

Pickering

- While the lowest scores were attained for Unit Capability Factor and Forced Loss Rate, the most significant improvements were made for both of these metrics, particularly from 2018. These metrics are weighted the heaviest within the NPI calculation.
- Pickering's NPI performance is impacted by the need for long outages to accommodate fuel channel inspection programs, which impacts Unit Capability Factor and Collective Radiation Exposure metrics.

Darlington

- Fluctuations in DNGS' year-over-year performance are attributed to:
  - 2015 - Vacuum Building Containment outage for planned regulatory maintenance.
  - 2016 Plant reliability improvements positively impacted both the FLR and UCF.
  - 2017 - Unbudgeted outages affecting Unit Capability Factor and FLR.
  - 2018 - Lower number of unbudgeted and forced outages.
  - 2019 – Forced outages caused by the Heat Transport and Secondary side leakages along with Fuel Handling bridge repairs. Actions have been taken to increase scope in future outages for the instrument line visual inspections to minimize heat transport system leaks to containment. A Fuel Handling Life Extension and Reliability plan is being implemented to facilitate commissioning of the most critical fuel handling scope and sustain favourable Forced Loss performance.

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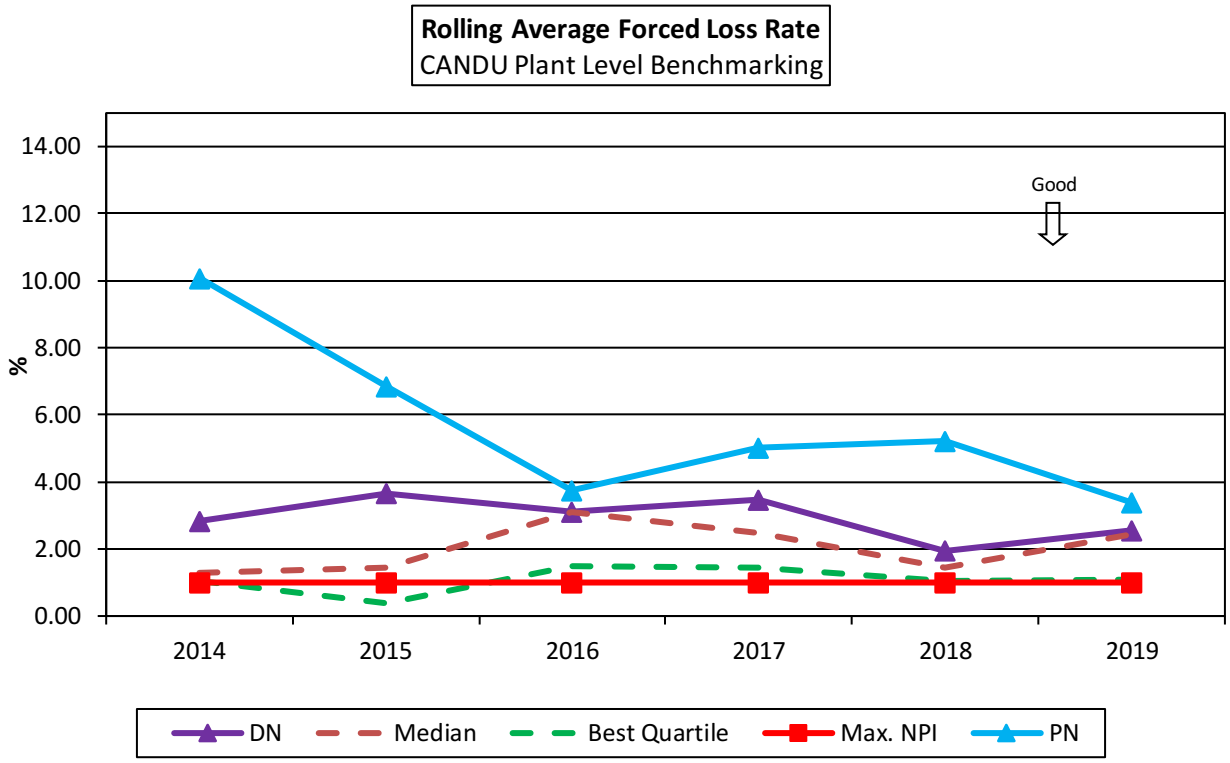
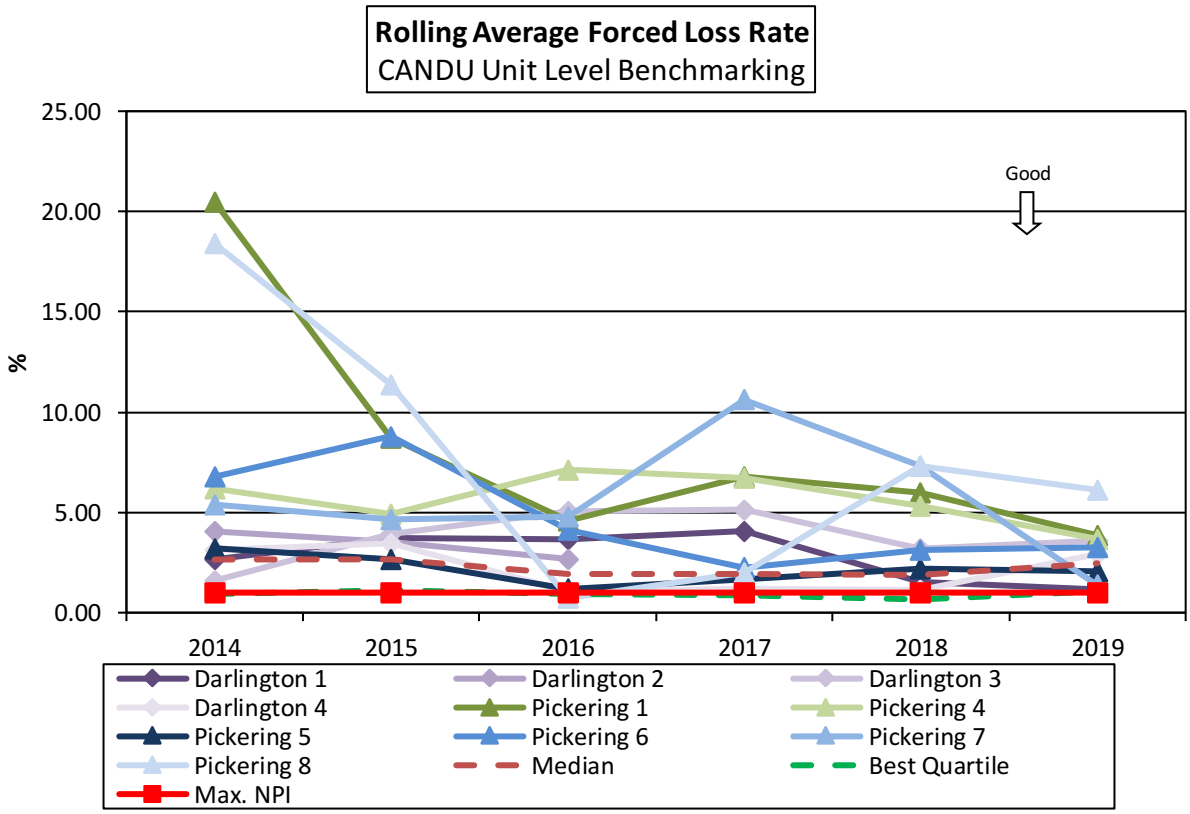
Rolling Average Forced Loss Rate





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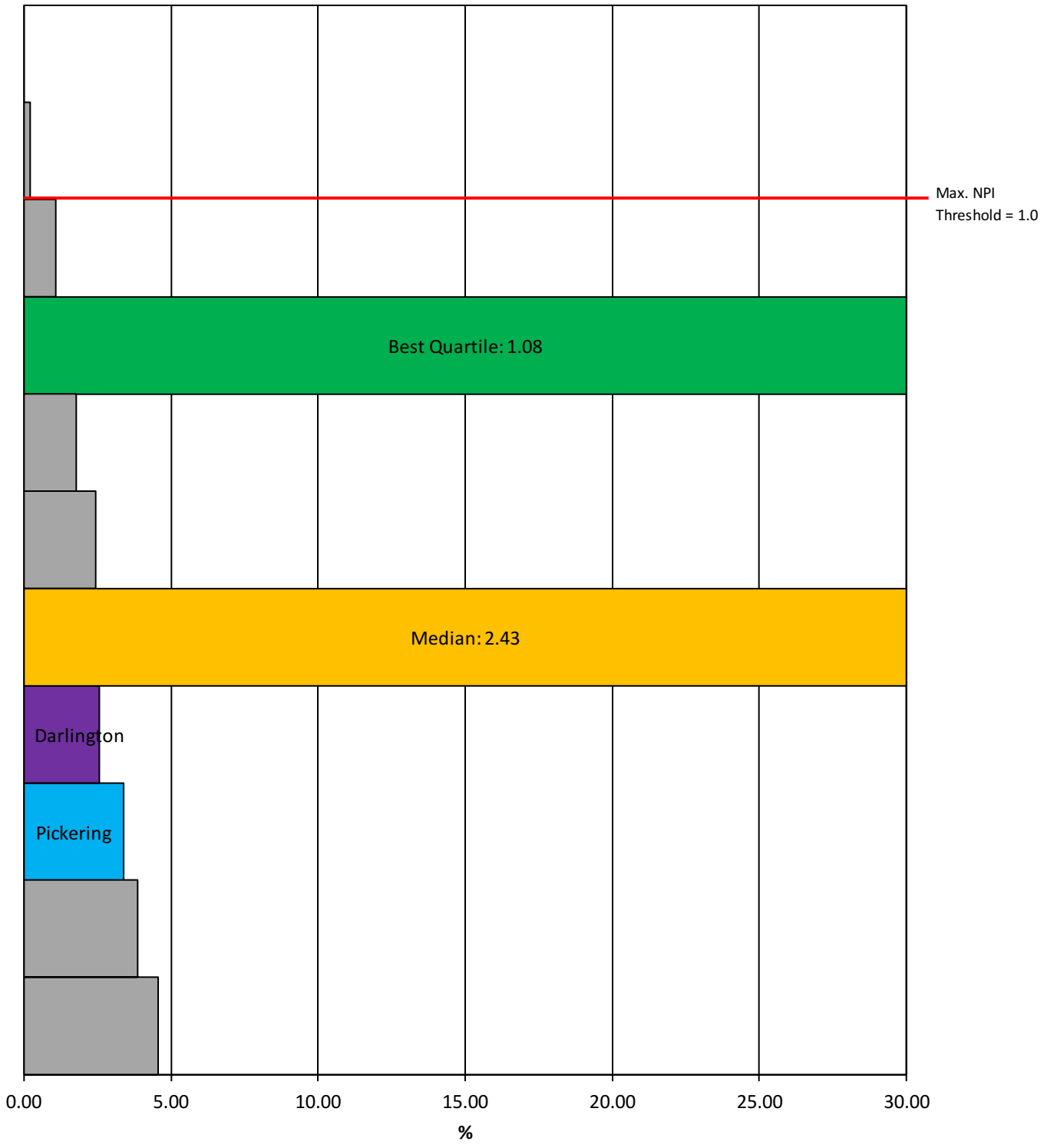
2019 Rolling Average Forced Loss Rate
CANDU Plant Level Benchmarking



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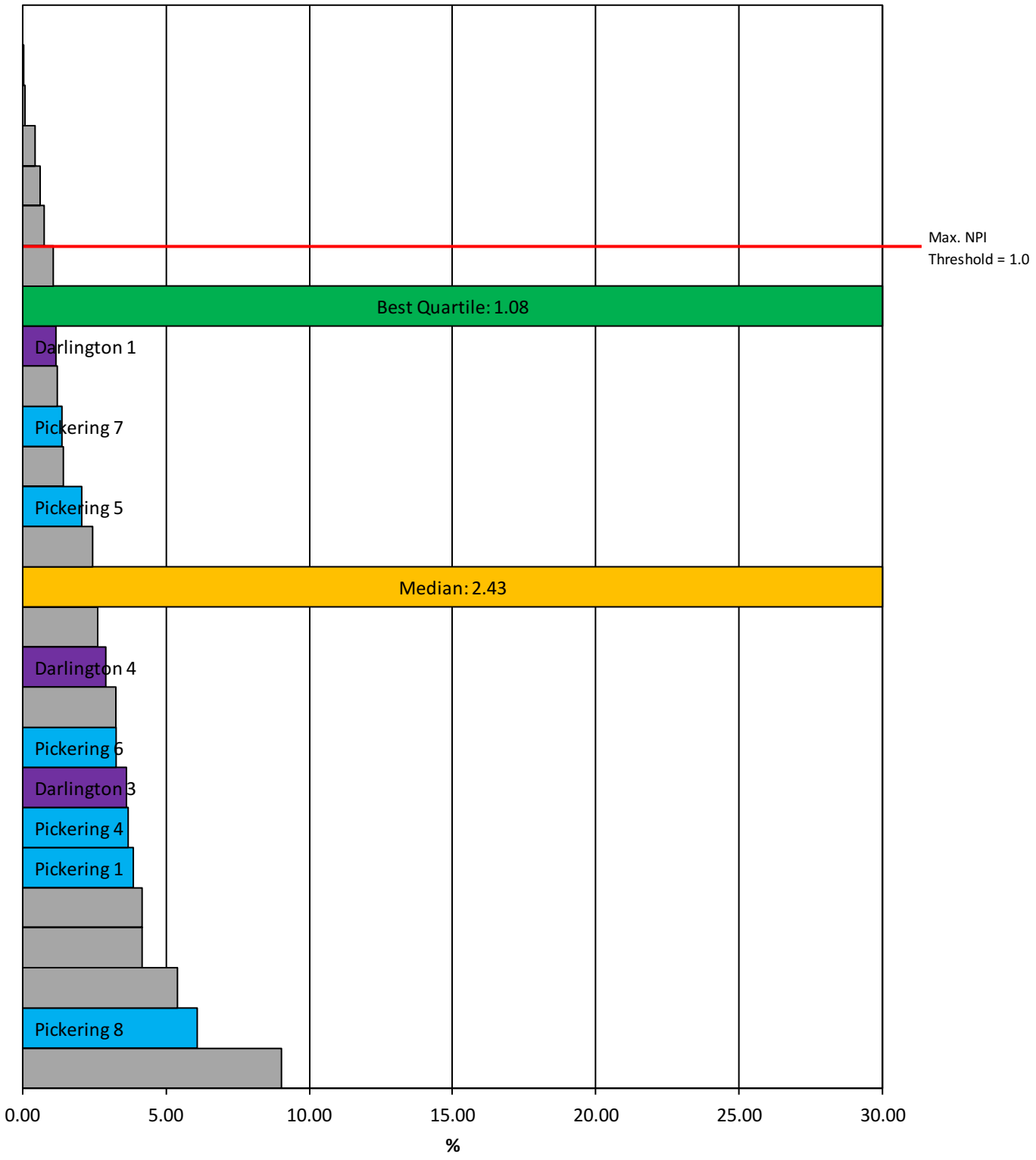
2019 Rolling Average Forced Loss Rate
CANDU Unit Level Benchmarking



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Observations – Rolling Average Forced Loss Rate (CANDU)

2019 (Rolling 2 Year Average, Pickering %; Rolling 3 Year Average, Darlington %)

- The industry plant level best quartile was 1.08 and the industry median was 2.43.
- PNGS Forced Loss Rate (FLR) results showed an improvement in performance to third quartile, decreasing from 5.20 in 2018 to 3.39 in 2019, achieving its best ever FLR in the process, as a combined six-unit station.
- DNGS FLR performance went from 1.94 in 2018 to 2.56 in 2019 and maintained third quartile performance. Darlington Unit 2 began a long-term refurbishment outage on October 15, 2016 and has been excluded from benchmarking results.

Trend

- Industry plant median FLR trend went up and experienced variability over the trend period.
- PNGS overall FLR trend has shown marked improvement year-over-year, from double digit values in 2014 to 3.39 in 2019, which is the lowest FLR for PNGS.
- DNGS overall trend shows an improvement from 2014 when it was 2.85 to 2.56 in 2019.

Factors Contributing to Performance

- PNGS and DNGS have seen significant reductions to frequency of forced outages by conducting the Preventative Maintenance program, through the implementation of Value Based Maintenance initiatives, which enables sites to complete the right work at the right time, improving equipment reliability.
- Both PNGS and DNGS continue to drive plant reliability via the system health improvement process and recovery actions. The Plant Reliability List of important work orders are implemented to improve system health.
- At PNGS, the 2019 causes for forced losses were varied, including:
  - Unit 1, dual Reactor Control System failure.
  - Unit 5, turbine trip on boiler high level.
  - Unit 6, spurious closure of all 4 governor valves caused boiler pressure error to initiate Steam Relief Valve opening.
- At DNGS, the 2019 causes for forced losses were varied, including:
  - Unit 3, heat transport system leak
  - Unit 3, cross shaft failure and fueling unavailability
  - Unit 4, leak & auxiliary lube pump.

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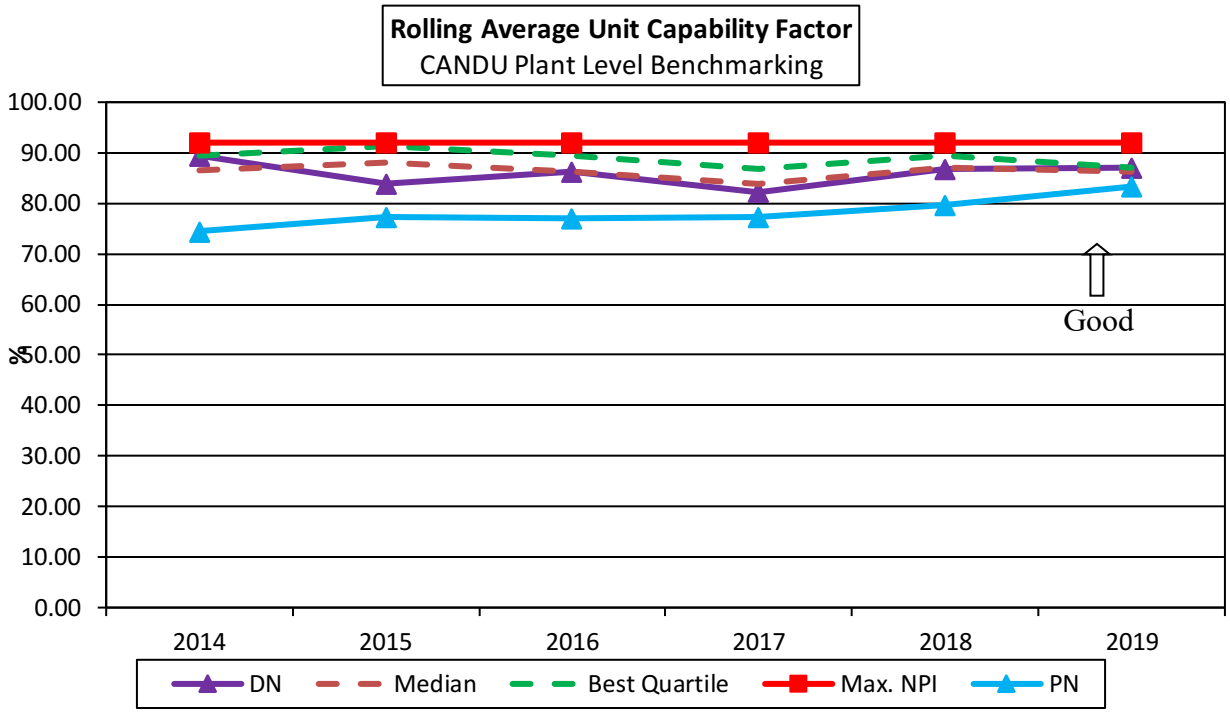
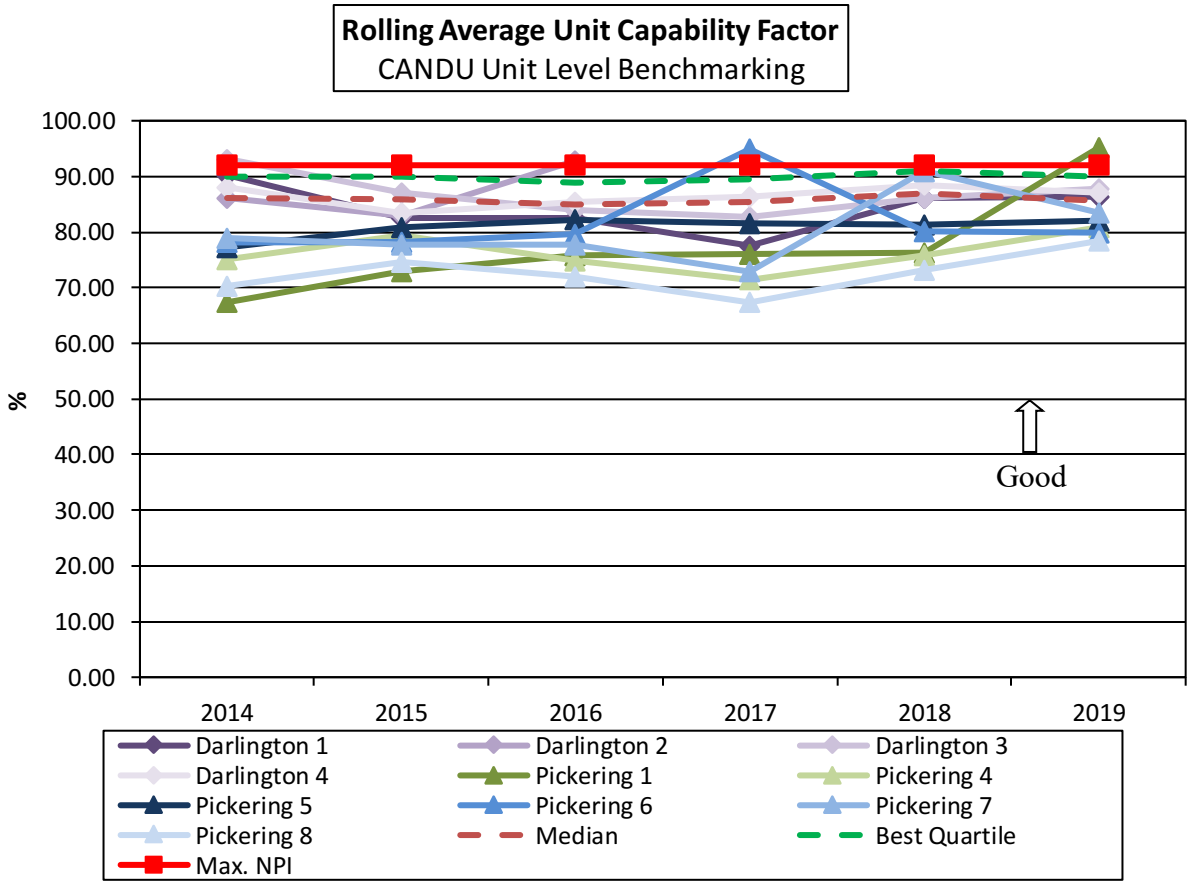
Rolling Average Unit Capability Factor





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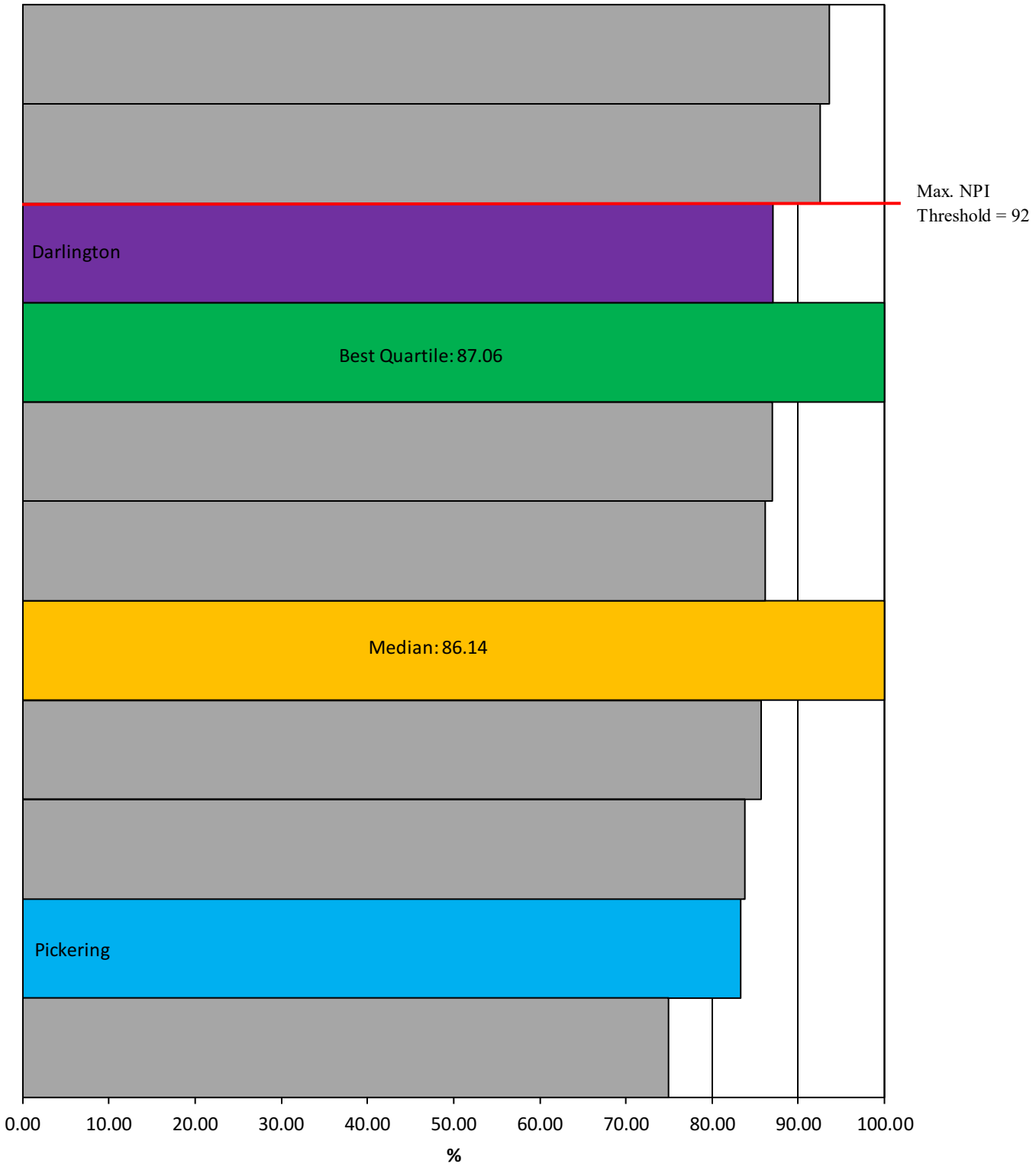
2019 Rolling Average Unit Capability Factor
CANDU Plant Level Benchmarking



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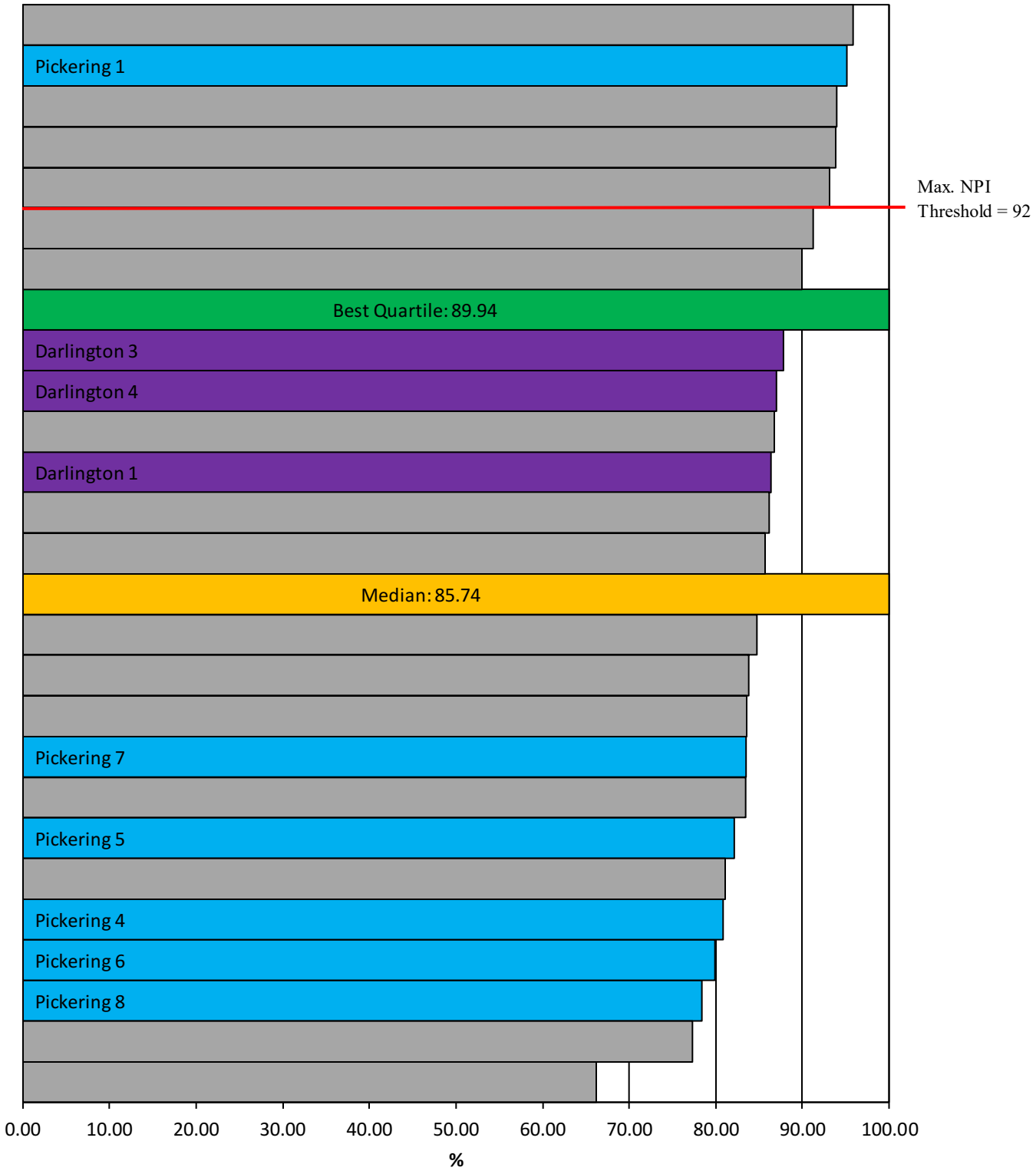
2019 Rolling Average Unit Capability Factor
CANDU Unit Level Benchmarking



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Observations – Rolling Average Unit Capability Factor (UCF) (CANDU)

2019 (Rolling 2 Year Average, Pickering %; Rolling 3 Year Average, Darlington %)

- The industry best quartile was 87.06 and the industry median was 86.14.
- PNGS UCF performance improved from 79.55 in 2018 to 83.31 in 2019, achieving its best ever performance as a combined six-unit station, while remaining in fourth quartile.
- DNGS UCF performance improved from 86.89 to 87.06, and advanced to the best quartile of CANDU plants.
- Darlington Unit 2 began a long-term refurbishment outage on October 15, 2016 and has been excluded from benchmarking results.

Trend

- PNGS UCF trended favourably, increasing year over year for the past 4 years, with 2019 as the highest value. The overall trend of Pickering's UCF demonstrates continuous improvement.
- DNGS overall trend shows variability over the review period, with consistent improvements from 2017 to 2019.
- Plant median and best quartile UCF benchmarks have also shown variability and both decreased in 2019.

Factors Contributing to Performance

- Higher number of planned outage days contribute to lower UCF values when compared to CANDU peers, even though all 2019 planned outages were completed safely and ahead of schedule.
- The higher UCF at PNGS in 2019 compared to 2018 reflected fewer planned outage days in line with the station's cyclical maintenance schedule, the favourable execution of planned outage work, and fewer unplanned outage days.
- UCF performance at DNGS in 2019 improved compared to 2018, and the increase in the number of unplanned outage days was largely offset by fewer planned outage days due to the favourable execution of planned outage work.
- FLR performance challenges negatively impact UCF.
- Improvements in equipment reliability have correlated with improved FLR and UCF performance.

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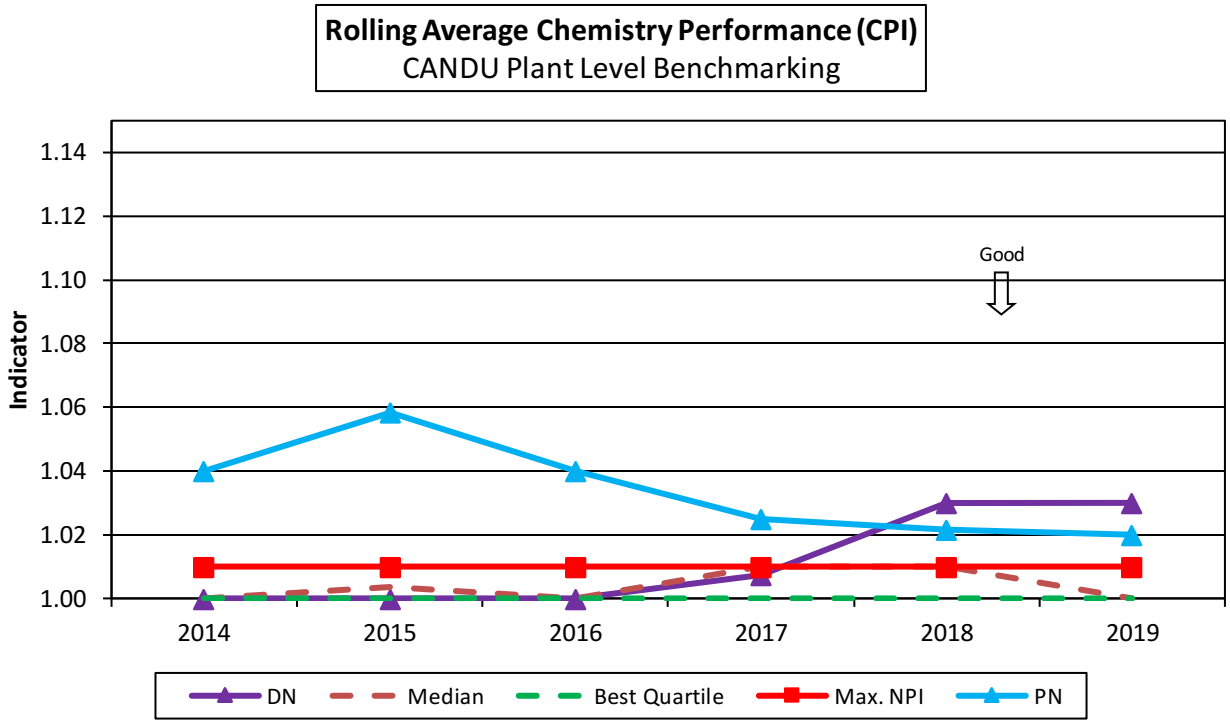
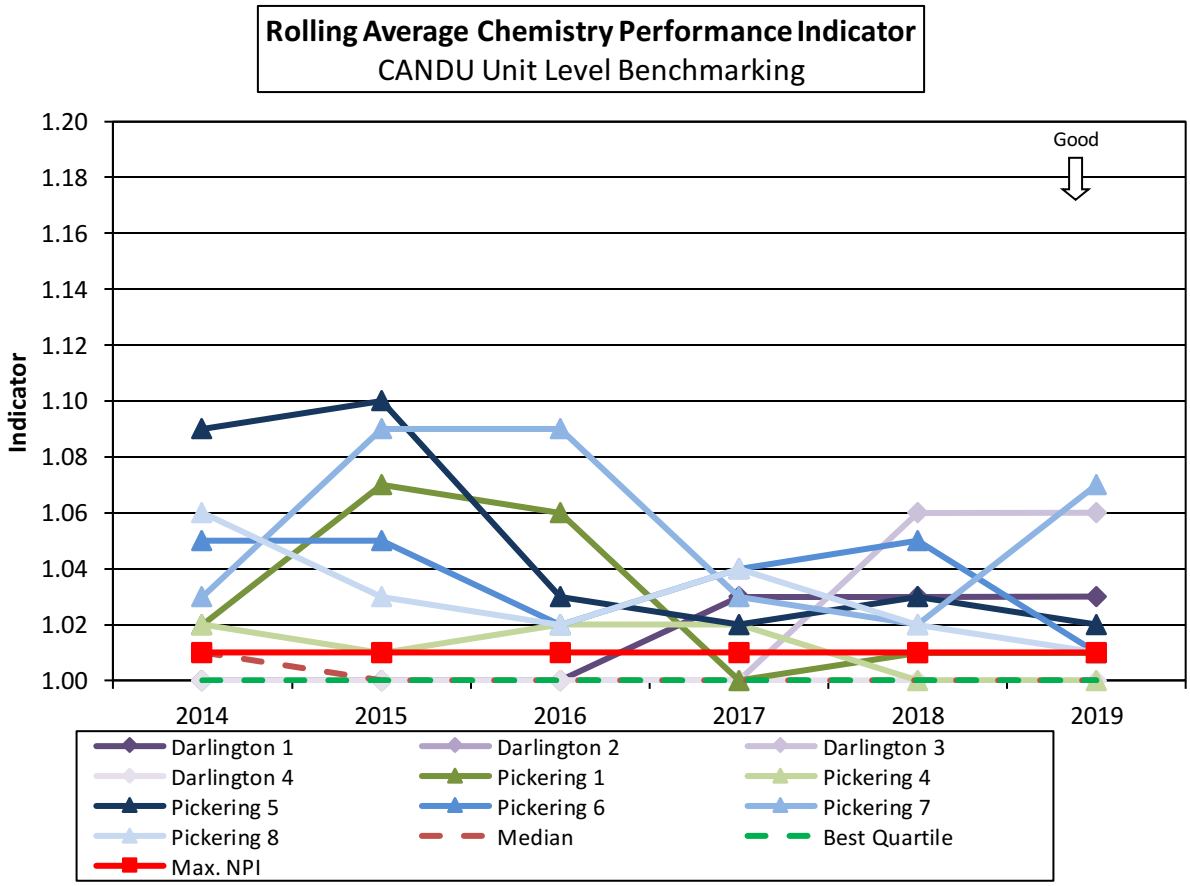
Rolling Average Chemistry Performance Indicator





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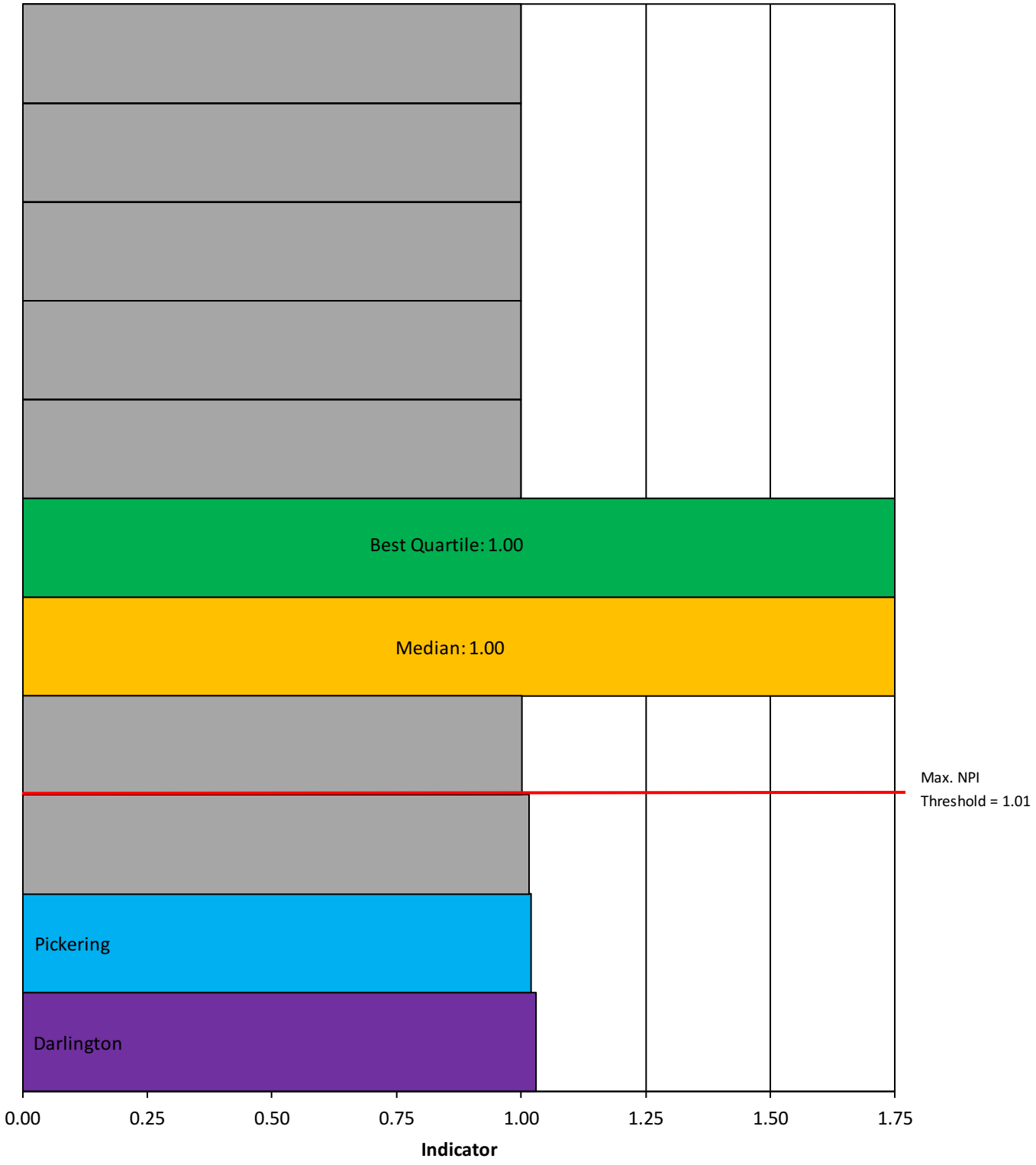
2019 Rolling Average Chemistry Performance Indicator
CANDU Plant Level Benchmarking



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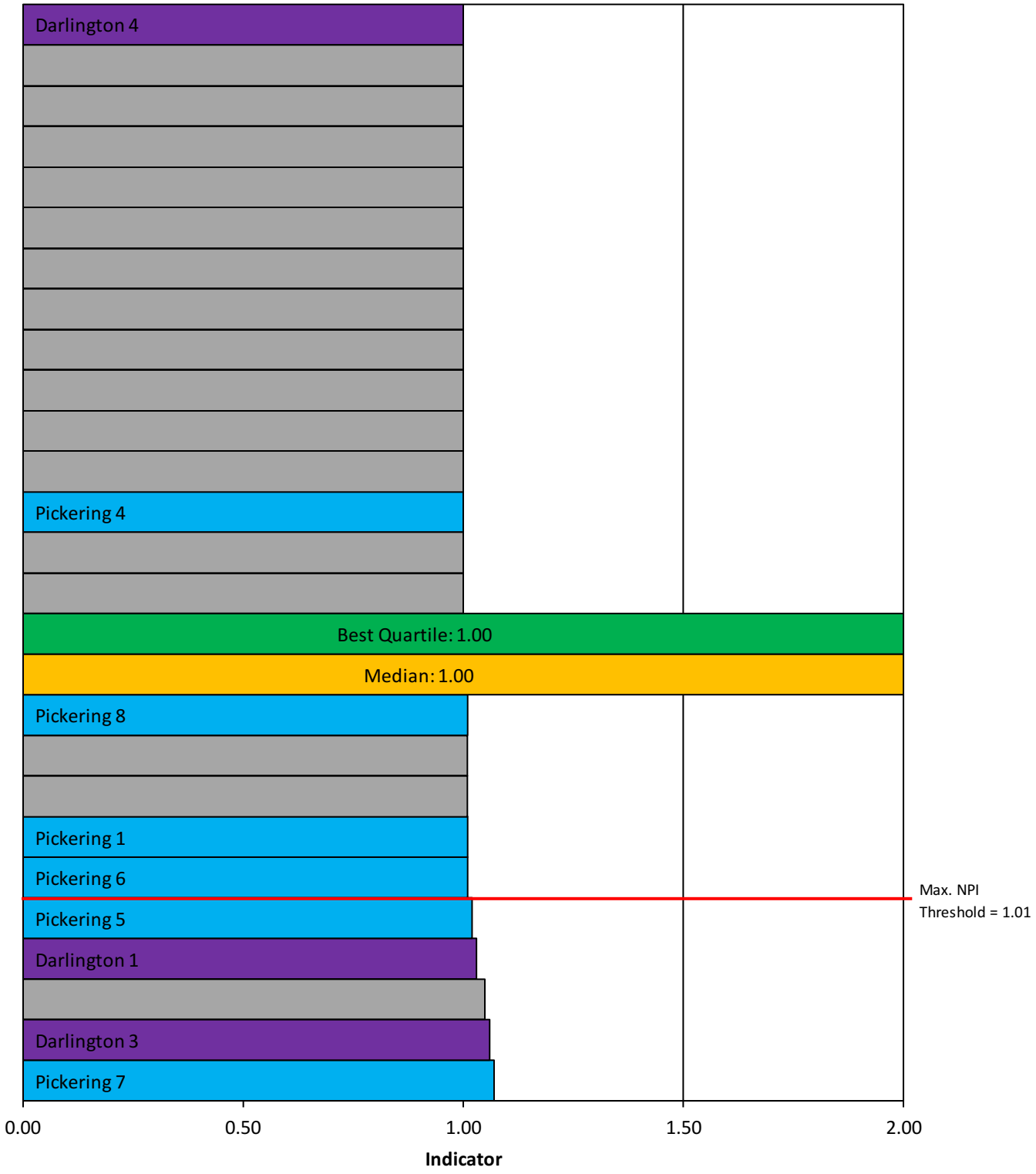
2019 Rolling Average Chemistry Performance Indicator
CANDU Unit Level Benchmarking



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Observations – Rolling Average Chemistry Performance Indicator (CANDU)

2019 (Rolling 2 Year Average Pickering, Rolling 3 Year Average Darlington)

- The CANDU plant median and best quartile values are both 1.00.
- PNGS CPI performance has remained unchanged from 2018 at 1.02.
- DNGS CPI performance has remained unchanged from 2018 at 1.03.

Trend

- Overall industry performance has remained stable, with the best quartile holding at 1.00 over the last five years.
- The overall performance trend for PNGS has been positive over the last 5 years, with CPI performance improving year-over-year from 1.06 and to 1.02.
- DNGS has exhibited a declining trend in the last three years, increasing from a CPI of 1.00 to the current CPI value of 1.03.

Factors Contributing to Performance

- In 2019, challenges were experienced with boiler chemistry start-up on Pickering Unit 5.
- In 2019, Pickering experienced high sodium levels following outage start-up on Unit 7 and elevated chloride levels on Units 5 and 8 due to ingress from the Water Treatment Plant.
- The 2019 performance at Darlington can be attributed to Unit 3 condenser tube leaks, which caused an increase in boiler conductivity and feedwater iron levels during start-ups following the unit outages. As the CPI is a 3-year rolling average, the event from 2018 continues to impact 2019 performance.
- Work practices that are being implemented to improve performance include:
    - Development of component cleanliness requirements.
    - Improvements in condenser tube leak detection at Darlington.
    - Chemistry data trending review meetings to share operating experience, lessons learned, and improvement plans.

- **Chemistry initiatives to further improve CPI to best quartile:**
    - Procurement of filtration skid to mitigate corrosions products following restart from Refurbishment.

    - Implementing new innovations for improved chemistry control, reliability and safety, including:
        - Hydrazine-in-air scrubber use / new PPE for hydrazine vapour hazards at Pickering;
        - Hydrazine neutralization agent feasibility assessments at Pickering;
        - Film Forming Amine at Darlington (first successful application on Darlington Unit 3 in March 2020); and
        - EPRI Smart Chemistry online analyzer application at Darlington.

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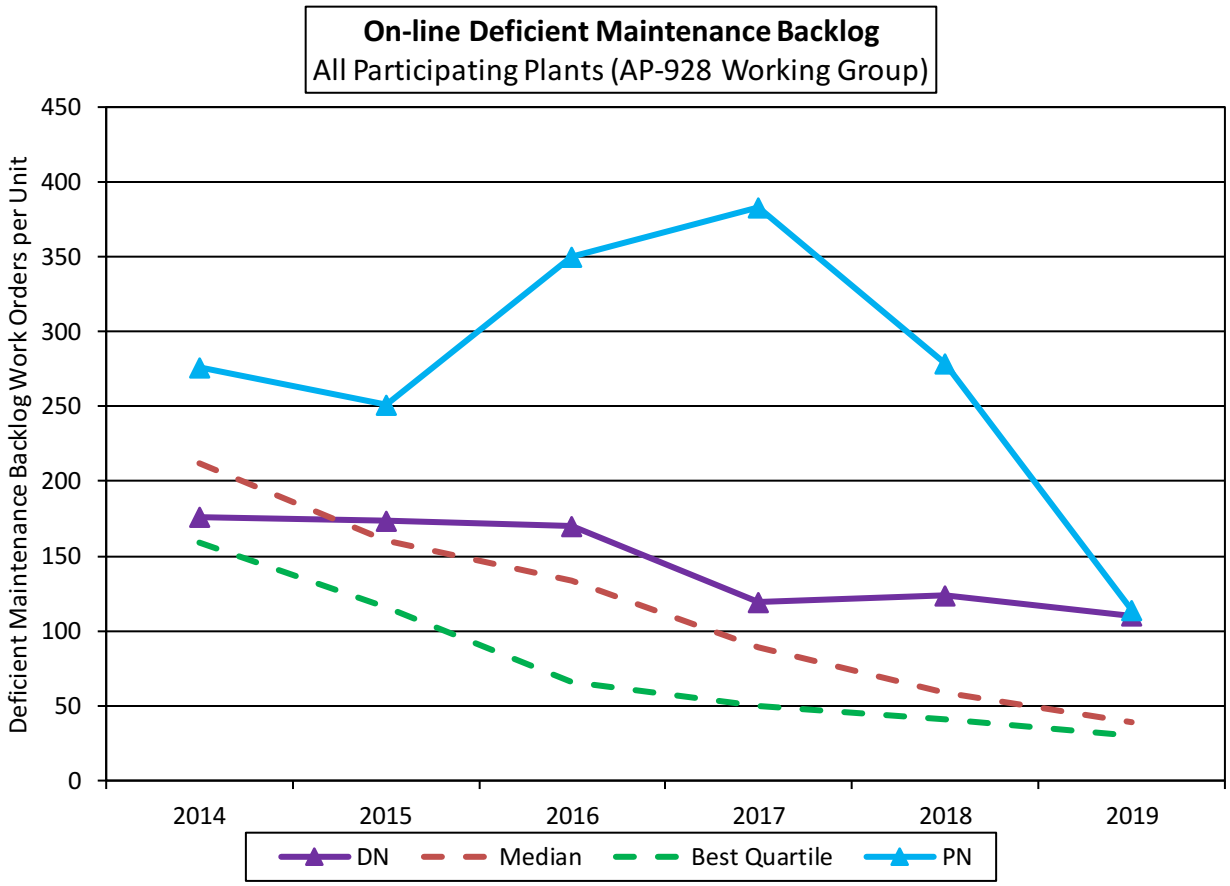
On-Line Deficient Maintenance Backlog



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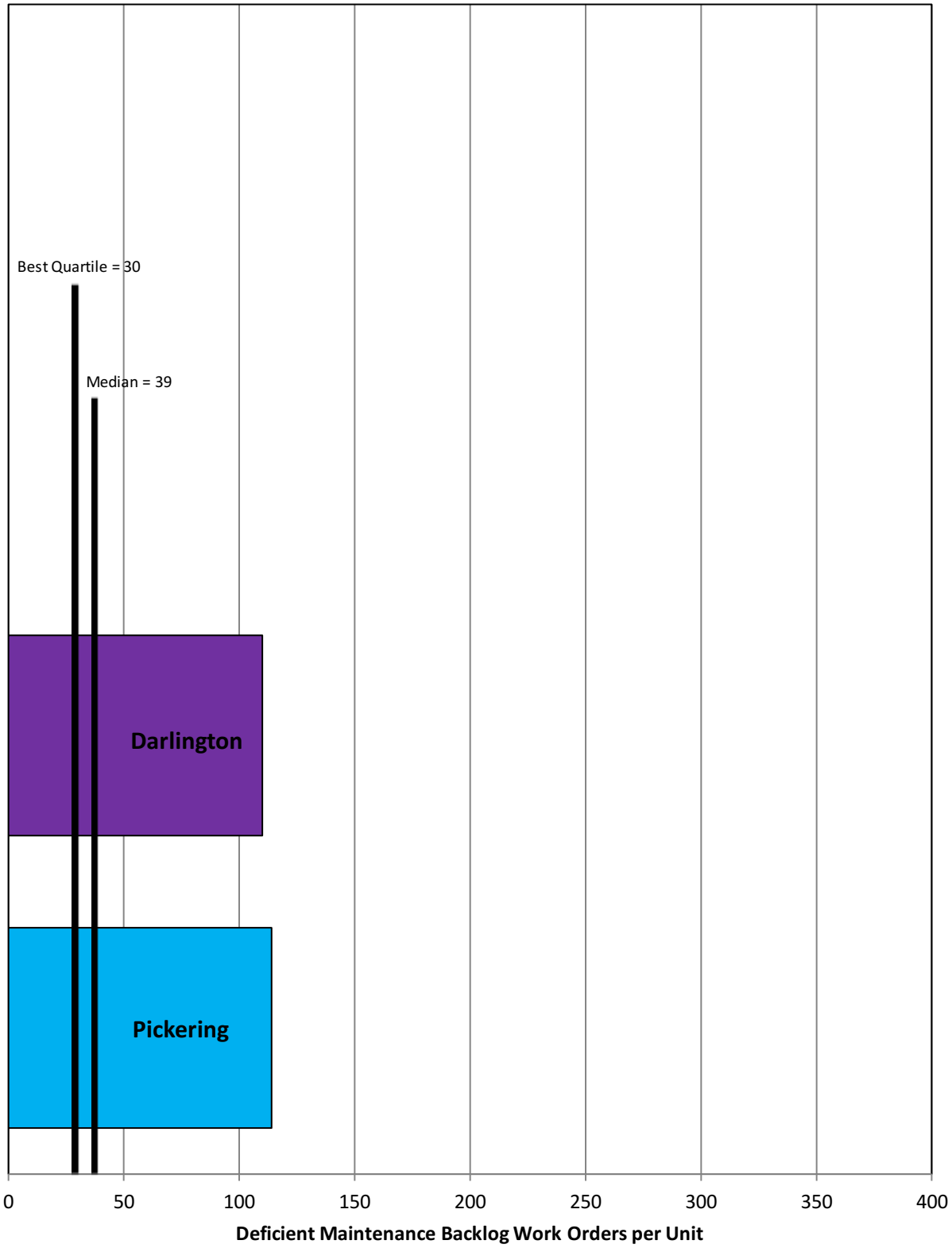
1-Year 2019 On-line Deficient Maintenance Backlog
All Participating Plants (AP-928 Working Group)



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Observations – On-Line Deficient Maintenance Backlog (AP-928 Working Group)

2019 (Annual Value)

- The industry Best Quartile and Median Thresholds were 30 and 39 work orders/unit, respectively for On-Line Deficient Maintenance (DM) backlog.
- Darlington DM backlogs were at 110 work orders/unit and Deficient Critical (DC) backlogs were at 3 work orders/unit.
- Pickering DM backlogs were at 114 work orders/ unit and DC backlogs were at 5 work orders/unit.

Trend

- Both DNGS and PNGS exhibited backlog improvements in the last year and over the trend period.
- In comparison to the 2018 data:
    - Darlington DM performance in 2019 improved from 124 to 110 work orders/unit.
        - Darlington DC performance improved from 9 to 3 work orders/unit.
    - Pickering DM performance in 2019 improved significantly from 279 to 114 work orders/unit and showed significant improvement since 2017.
        - Pickering DC performance improved from 9 to 5 work orders/unit.
    - Median backlog improved from 59 to 39 work orders/unit.

Factors Contributing to Performance

- At PNGS and DNGS, the focus continues on the reduction of on-line deficient critical backlogs, which has resulted in the improvement of critical DC backlogs for both sites.
- To improve performance, initiatives focus on:
    - Efficiencies and Optimizing existing maintenance resources.
    - Value Based Maintenance:
        - Move to a condition based maintenance program versus time based to better leverage resources and increase efficiencies.
        - Leverage technology to support value based and condition based maintenance strategies.

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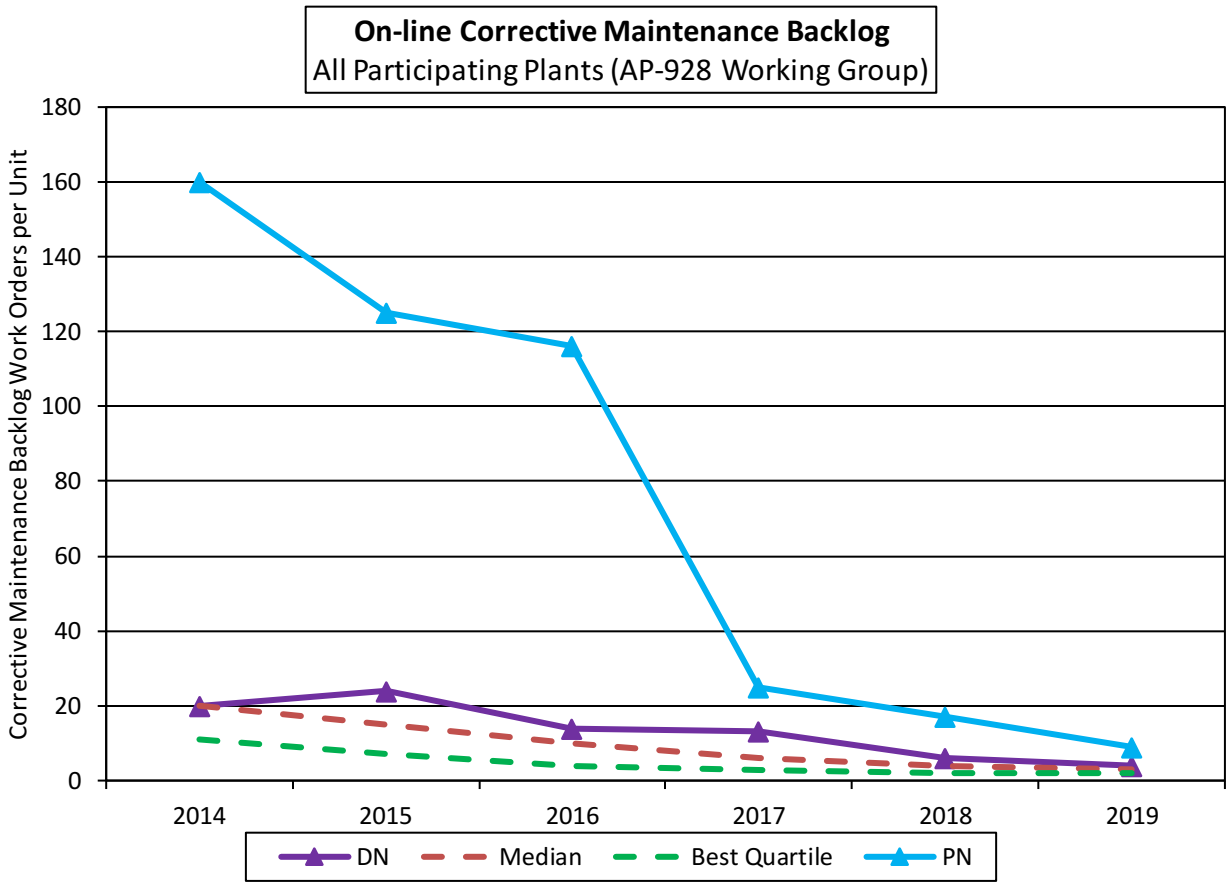
On-Line Corrective Maintenance Backlog



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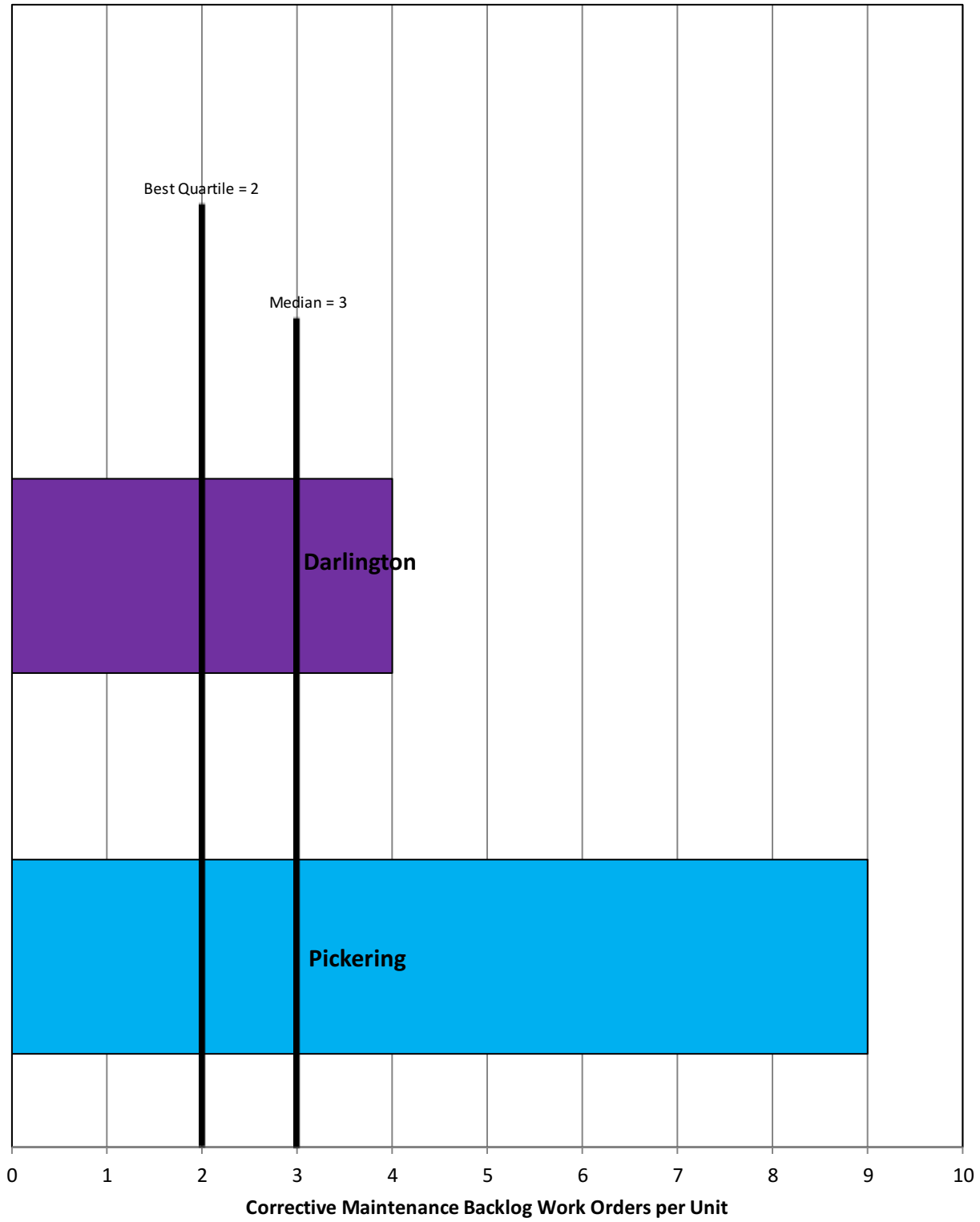
1 Year 2019 On-line Corrective Maintenance Backlog
All Participating Plants (AP-928 Working Group)



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Observations – On-Line Corrective Maintenance Backlog (AP-928 Working Group)

2019 (Annual Value)

- The industry Best Quartile and Median Thresholds were 2 and 3 work orders/unit respectively for On-Line Corrective Maintenance (CM) backlog.
  - Darlington CM backlogs were at 4 work orders/ unit and corrective critical backlogs were at 0.3 work order/unit.
  - Pickering CM backlogs were at 9 work orders/unit and corrective critical backlogs were at 0.5 work orders/unit.

Trend

- In comparison to the 2018 data:
  - Darlington performance in 2019 has improved from 6 to 4 work orders/unit.
  - Pickering performance in 2019 improved from 17 to 9 work orders/ unit.
  - Median backlog improved from 4 to 3 work orders per unit.

- Darlington has shown backlog improvement from 2014 through 2019.
- Pickering has shown significant backlog improvement in each of the last five years.

Factors Contributing to Performance

- At the end of 2019, PNGS On-line Corrective Critical Backlog declined to fourth quartile due to the standby generator and fuelling machine repair work orders, which were completed in January of 2020. Priority is placed on corrective critical backlogs and equipment is restored as expeditiously as possible.
- To improve performance, initiatives focus on:
  - Efficiencies and Optimizing existing maintenance resources.
  - Value Based Maintenance:
    - Move to a condition based maintenance program versus time based to better leverage resources and increase efficiencies.
    - Leverage technology to support value based and condition based maintenance strategies.

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4.0 VALUE FOR MONEY

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 covering the period from 2014-2019. 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 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. For that reason, some of the gaps in performance are associated with technology differences rather than comparable performance. As a result, beginning with 2017 results, Pickering and Darlington's 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[4]. The combined normalization allows for a more comparable assessment of performance between peers.

The relationship underlying certain value for money metrics is shown in the illustration below.

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.

[4] 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*

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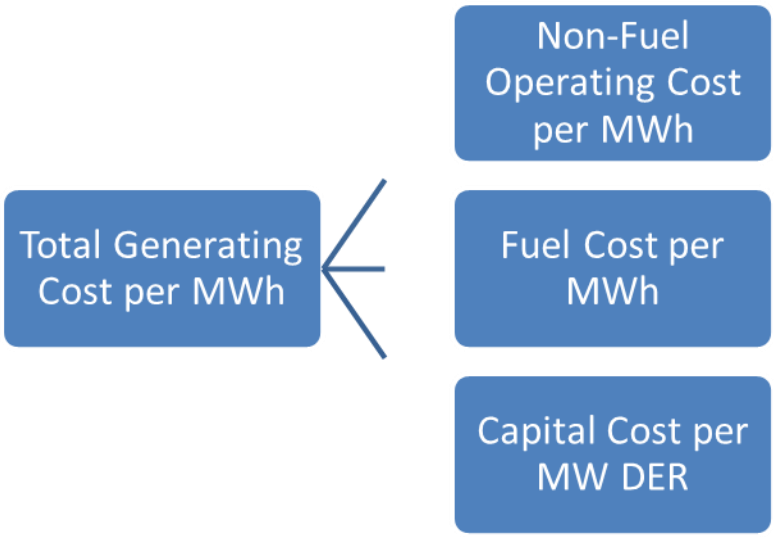
Given the differences between OPG's nuclear generating stations and most North American plants with respect to non-fuel, fuel and capital costs, it is difficult to compare plants by using non-fuel operating cost, fuel cost or capital cost metrics separately.

Summary Relationship of Value for Money Metrics



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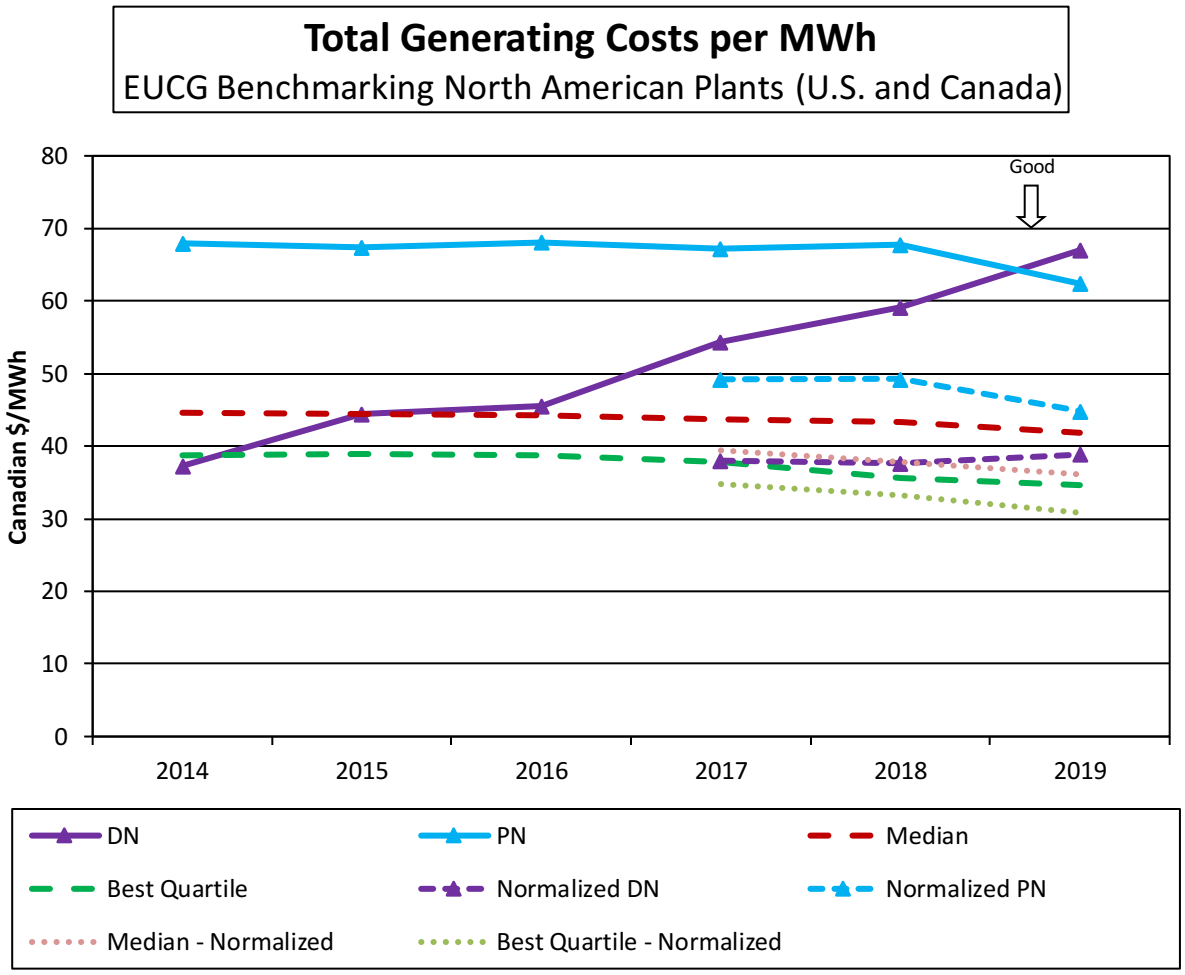
3-Year Total Generating Cost per MWh



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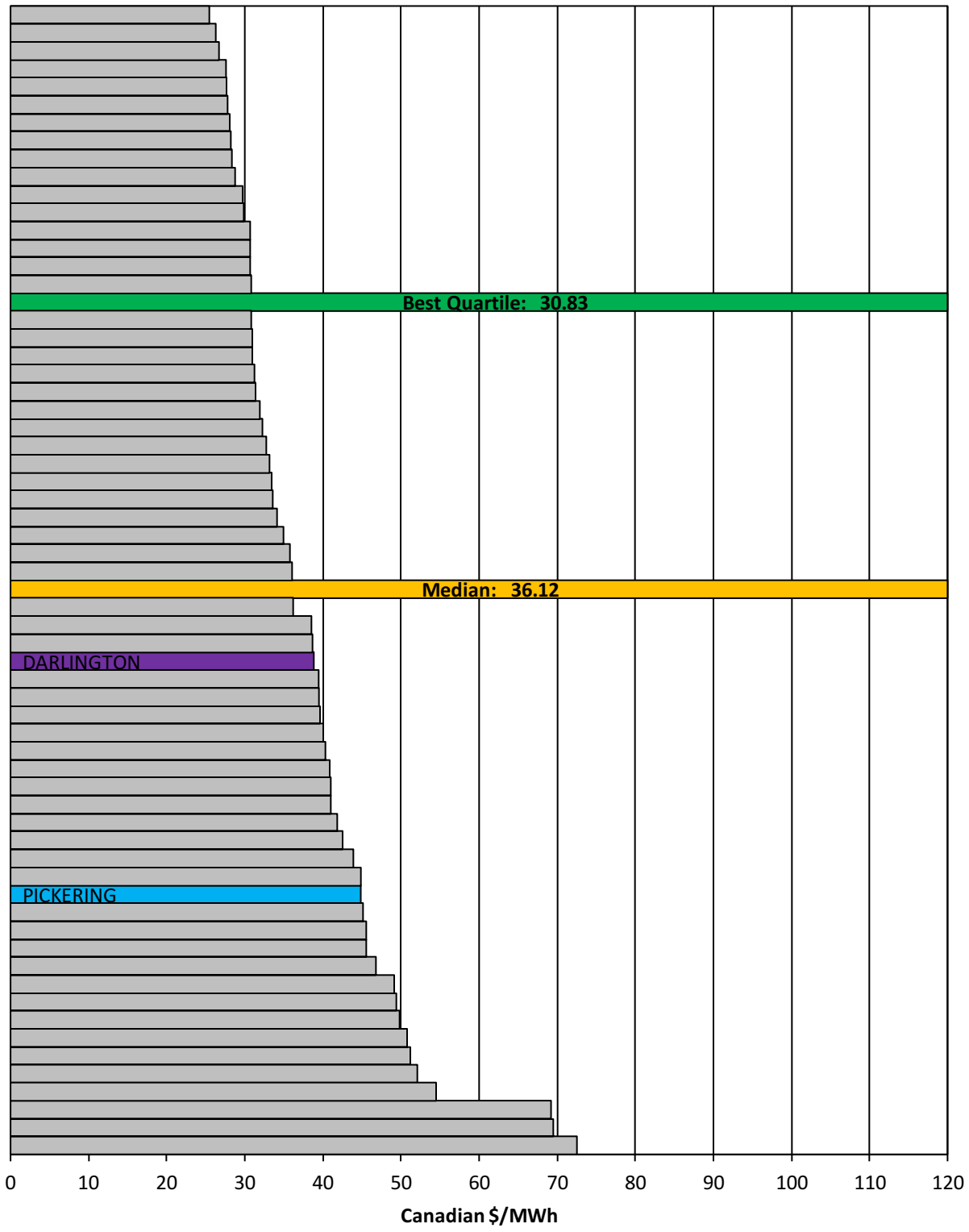
2019 Normalized 3-Year Total Generating Costs per MWh
EUCG Benchmarking North American Plants (U.S. and Canada)



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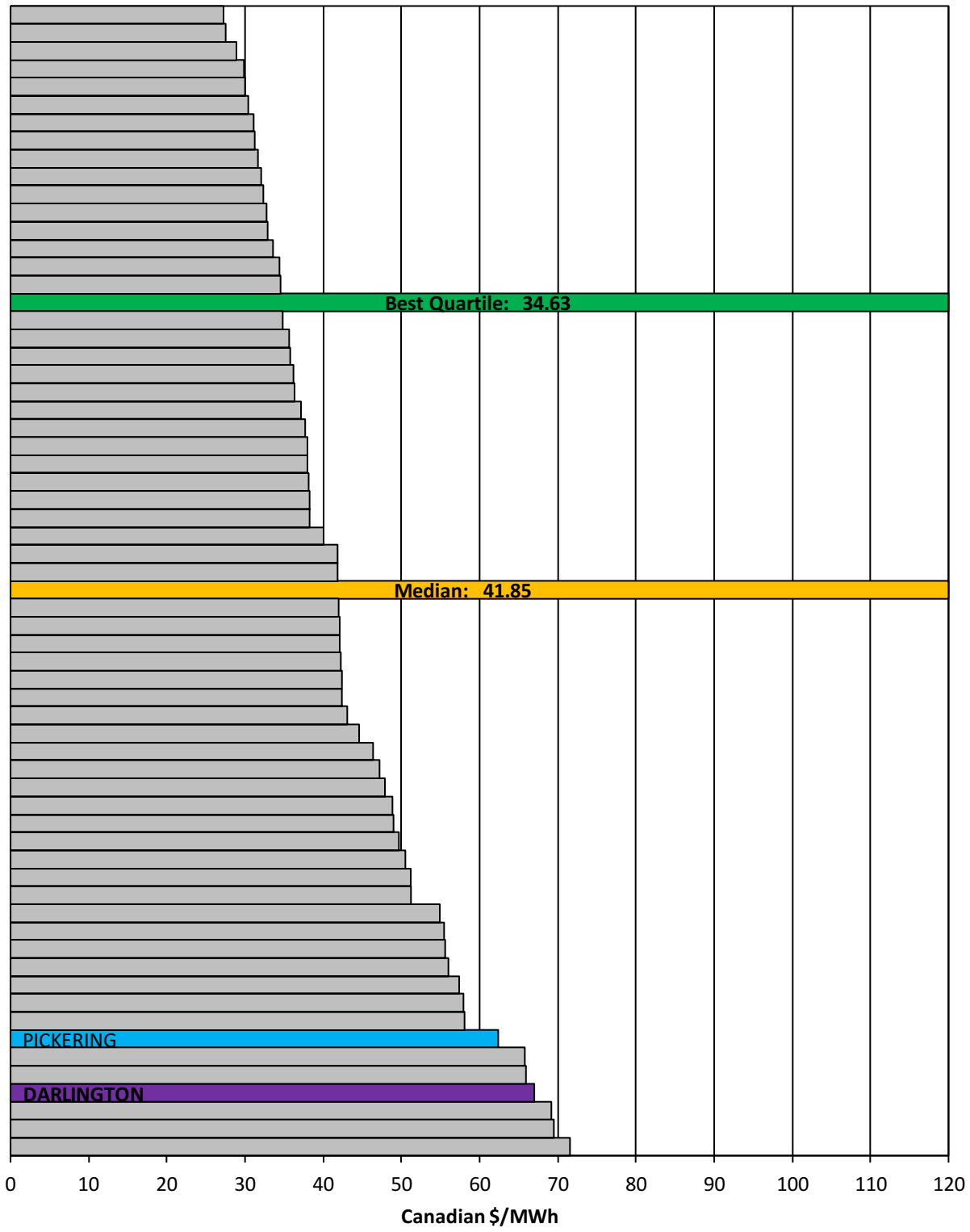
2019 Non-Normalized 3-Year Total Generating Costs per MWh
EUCG Benchmarking North American Plants (U.S. and Canada)



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Observations – 3-Year Total Generating Cost per MWh (All North American Plants)

2019 (3-Year Rolling Average)

- Best quartile level for normalized Total Generating Cost/MWh (TGC/MWh) was $30.83 (non-normalized $34.63/MWh) while the normalized median level was $36.12 (non-normalized $41.85/MWh).
- DNGS normalized result– achieved 3rd Quartile: $38.84/MWh (non-normalized $67.00/MWh).
- PNGS normalized – achieved 4th Quartile: $44.85/MWh (non-normalized $62.39/MWh).

Trend

- Since 2017, the normalized[1] best quartile cost decreased, reflecting a $3.95/MWh improvement, (non-normalized improved by $3.15/MWh for the same time period and by $4.07/MWh since 2014).
- The normalized median cost also decreased since 2017, showing an improvement of $3.30/MWh (non-normalized improved by $1.81/MWh for the same time period and by $2.76/MWh since 2014).
- DNGS normalized TGC/MWh increased by $0.90/MWh since 2017 (non-normalized increased by $12.60/MWh and by $29.72/MWh since 2014).
- PNGS normalized TGC/MWh performance was essentially the same in 2017 and 2018, with a marked improvement in 2019. Since 2017, the favourable trend shows a reduction of $4.42/MWh (non-normalized improved by $4.83/MWh for the same time period and by $5.61/MWh since 2014).
- Best and median normalized quartile levels had a decreasing Compound Annual Growth Rate (CAGR) of -2.38% and -1.73% respectively. Darlington's normalized CAGR increased over the review period by 0.47% (non-normalized increased by 12.44%). Pickering normalized had a decreasing CAGR over the review period of -1.86% (non-normalized had a decreasing rate of -1.71%).

Factors Contributing to Performance

- DNGS changes from 2019 to 2018 included lower generation due to the refurbishment activities (in 2017-2019 compared to 2016-2018) and increased capital investment from 2016 - 2019 that will serve the station in its life post-refurbishment.

[1] Normalization for Refurbishment and CANDU Technology applied from 2017 onwards in accordance with methodologies provided by ScottMadden.

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Pickering

- Pickering's improvement in performance from 2018 includes higher generation and associated outage OM&A cost reduction due to fewer outage days, as well as decreased capital investment, and improved Fuel Costs/MWh.

- Site capacity (reflecting unit size) as well as outage durations required to extend operations continued to contribute to Pickering's TGC/MWh. Pickering units are the smallest in the peer group with total unit capacity of 540 MW compared to the peer group average of 1,026 MW. The majority of the generating units in the peer group fall within the 900 to 1,299 MW range.

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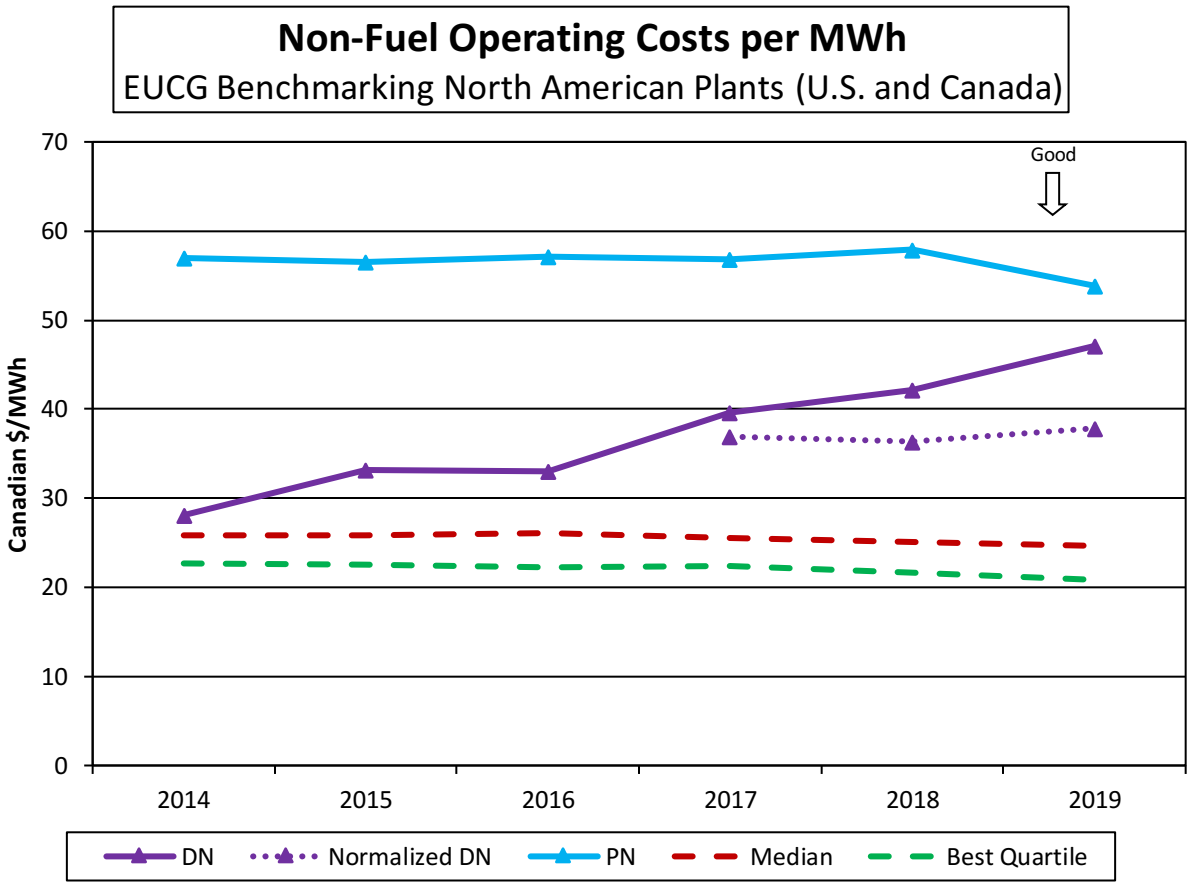
3-Year Non-Fuel Operating Cost per MWh



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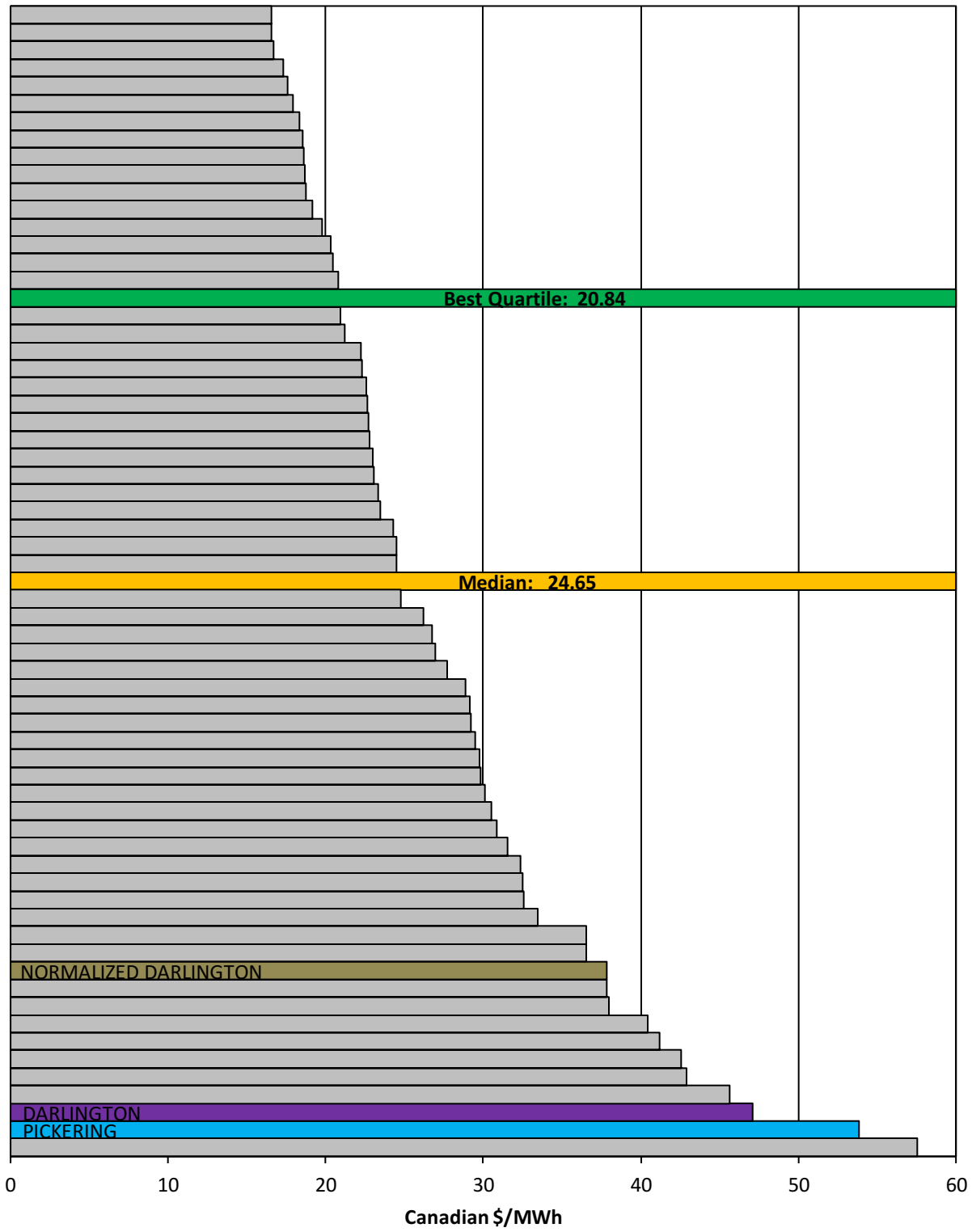
2019 /3-Year Non-Fuel Operating Costs per MWh
EUCG Benchmarking North American Plants (U.S. and Canada)



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Observations – 3-Year Non-Fuel Operating Cost per MWh (All North American Plants)

2019 (3-Year Rolling Average)

- Best quartile level Non-Fuel Operating Costs per MWh (NFOC/MWh) was $20.84 while the median level was $24.65/MWh.
- Darlington normalized[1] (for Refurbishment only) – 4th Quartile: $37.85/MWh (non-normalized $47.10/MWh)
- Pickering non-normalized – 4th Quartile: $53.85/MWh

Trend

- Best quartile cost has decreased, reflecting a $1.84/MWh improvement over the trend period, and the median cost also declined, improving by $1.18/MWh.
- Darlington normalized (for Refurbishment only) increased by $0.95/MWh since 2017 (non-normalized rose by $19.00/MWh since 2014).
- Pickering non-normalized decreased, improving by $3.16/MWh over the trend period.

Factors Contributing to Performance

- DNGS normalized (for Refurbishment only) 3-Year rolling average increased $1.47/MWh (non-normalized rose by $4.96/MWh) compared to 2018. The primary driver for the change from 2018 and over the trend period was lower generation associated with Darlington Refurbishment in years 2017 to 2019 compared to previous 3-year rolling averages.
- Pickering's non-normalized 3-Year rolling average decreased by $4.07/MWh compared to 2018, mainly as a result of higher generation.

[1] Normalization for Refurbishment applied from 2017 onwards in accordance with the methodology provided by ScottMadden.

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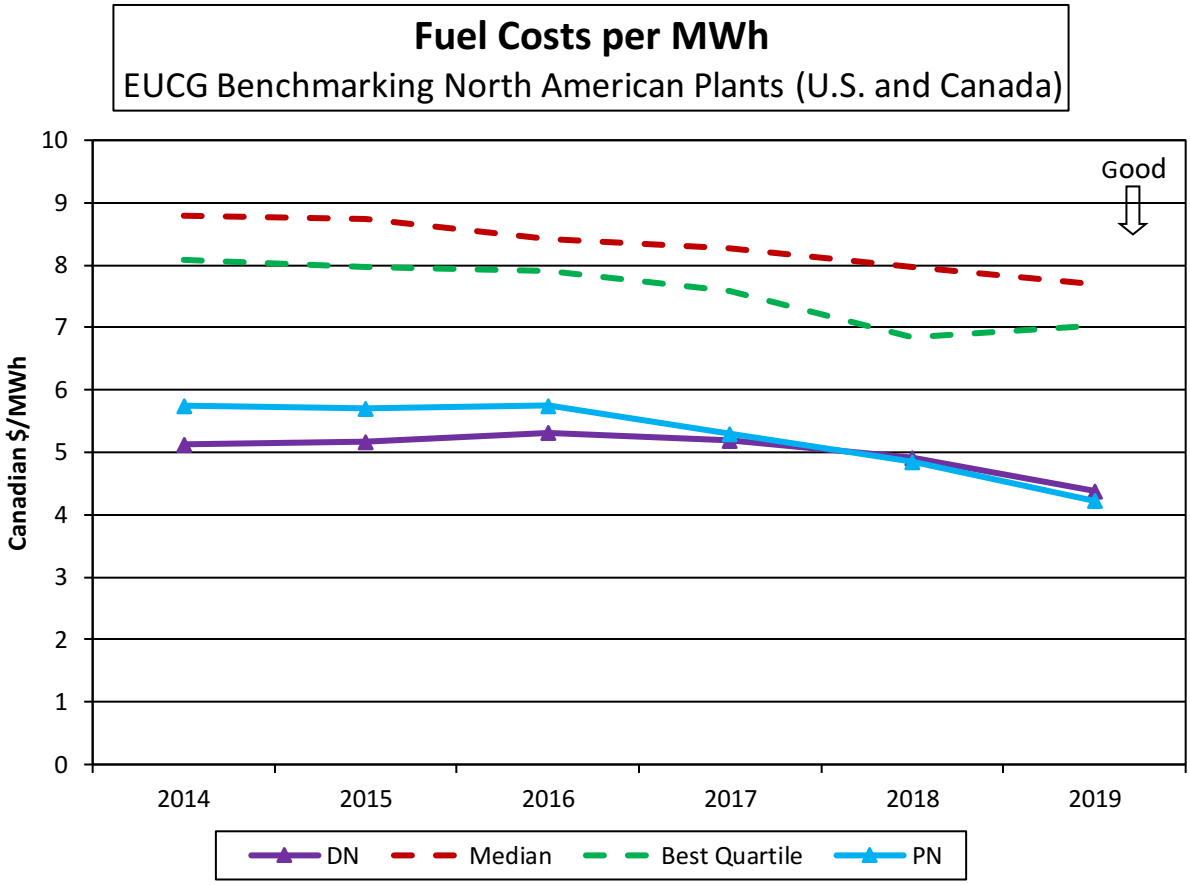
3-Year Fuel Cost per MWh



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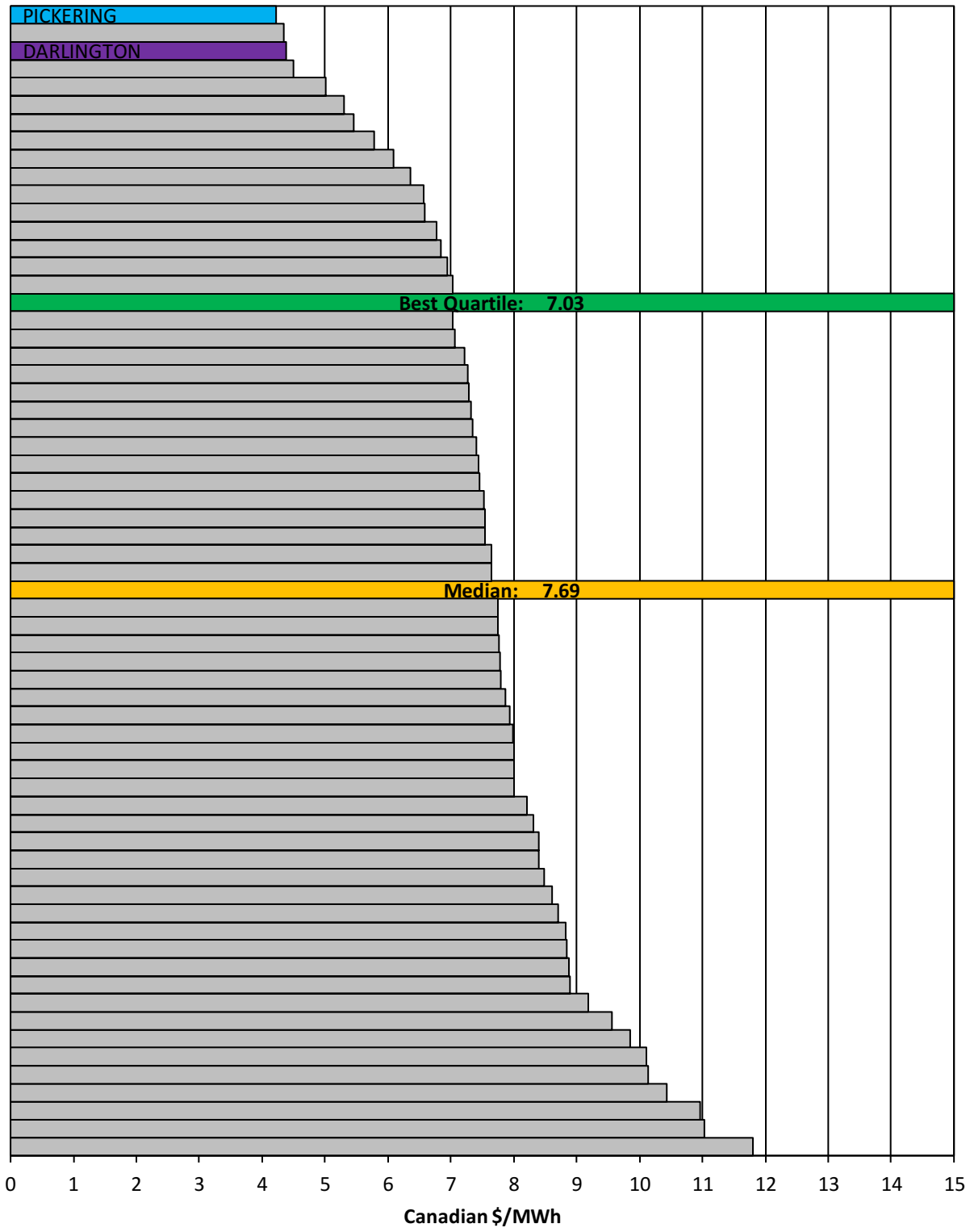
2019 3-Year Fuel Costs per MWh
EUCG Benchmarking North American Plants (U.S. and Canada)



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Observations – 3-Year Fuel Cost per MWh (All North American Plants)

2019 (3-Year Rolling Average)

- Best quartile was $7.03/MWh for the panel of North American EUCG plants.
- PNGS ranked at the top for the lowest fuel cost/MWh in the North American panel at $4.22/MWh and DNGS was ranked third at $4.38/MWh.

Trend

- The best quartile Fuel Cost/MWh improved by $1/MWh from 2014 to 2019.
- DNGS and PNGS performed consistently better than the best quartile during the review period.
- Fuel Cost/MWh for all OPG plants improved in 2019, as the improving trend continued since 2016.

Factors Contributing to Performance

- Fuel costs, primarily driven by the technological differences in CANDU technology, are lower for OPG than North American Pressurized Water Reactors or Boiling Water Reactors (PWR/BWR) as CANDUs do not require enriched uranium like BWRs and PWRs. This provides a significant advantage for OPG and other CANDUs in this cost category.
- The downward trend in the Fuel Cost per MWh for both PNGS and DNGS is due to a combination of lower input uranium costs, offset by general escalation in the fuel conversion and fuel fabrication costs.
- OPG's best quartile fuel cost performance is also due to the fact that CANDU is the most efficient of all reactors in using uranium, requiring about 15% less uranium than PWRs for each megawatt hour of electricity.

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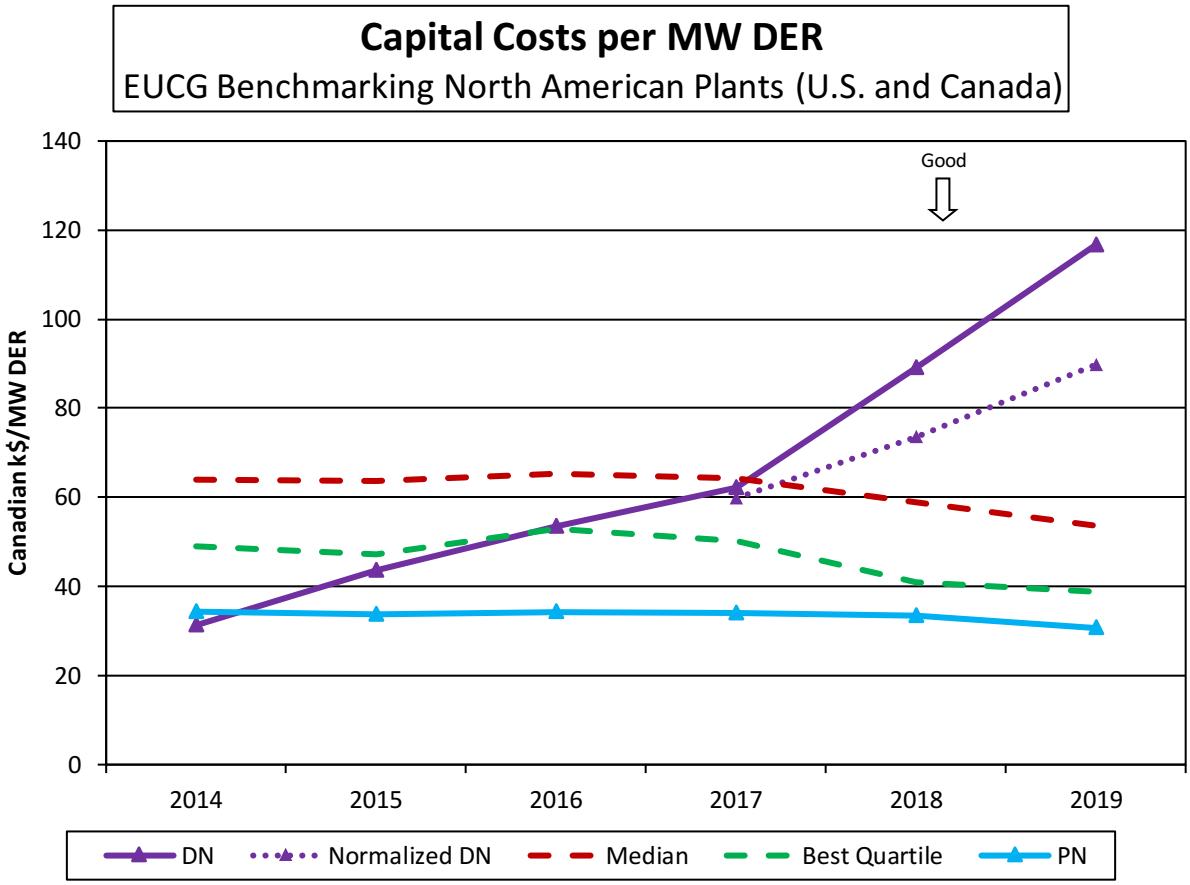
3-Year Capital Cost per MW DER (Design Electrical Rating)



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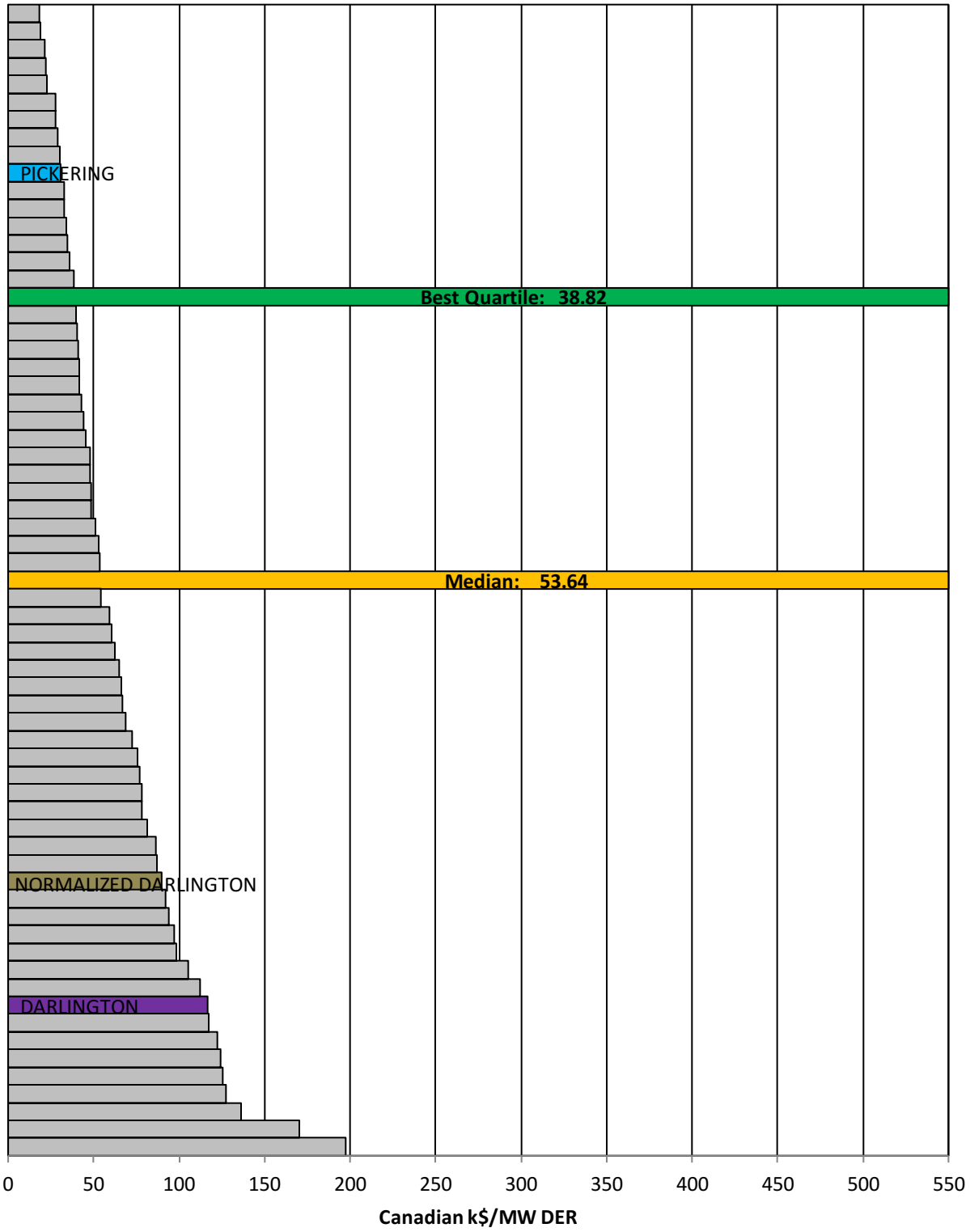
2019 3-Year Capital Costs per MW DER
EUCG Benchmarking North American Plants (U.S. and Canada)



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Observations – 3-Year Capital Cost per MW DER (All North American Plants)

2019 (3-Year Rolling Average)

- The best quartile threshold for Capital Cost per MW DER across US and Canadian EUCG peer plants was $38.82 k/MW DER.
- Median cost for the panel was $53.64 k/MW DER.
- PNGS was in the first quartile at $30.66 k/MW DER.
- DNGS was in the fourth quartile at $89.78 k/MW DER normalized and $116.67 k/MW DER non-normalized.

Trend

- Both best and median quartile thresholds decreased in 2019 due primarily to regulatory spending on Fukushima response ending. That reduction was partly offset by increased spending on reliability improvements. Spending on information technology and capital spares increased marginally with other categories being essentially flat over the trend period.
- Pickering's Capital Cost/MW DER improved in 2019 compared to previous years, due to reduced regulatory spending on Fukushima response, as well as reduced capital requirements as Pickering approaches end of commercial operations.
- Darlington's Capital Cost/MW DER rose year-over-year due to increased spending on life extension, performance improvements, sustaining investments, information technology and capital spares. This was partially offset by a reduction in Fukushima response spending.

Factors Contributing to Performance

- PNGS is performing in the first quartile and showed improvement in 2019 by $2.73 k/MW DER. This change from 2018, and over the trend period, reflects reductions in spending while maintaining reliable operations in the period leading up to the end of commercial operations. This is consistent with spending trends observed at other nuclear facilities approaching their end of commercial operations.
- DNGS is performing in the fourth quartile in 2019 and increased by $16.32 k/MW DER on a normalized basis compared to 2018. This change from 2018 and over the trend period reflects increased spending on life extension, sustaining investments, information technology and capital spares to support operations before, during and after refurbishment.
- Historically, Darlington's 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.

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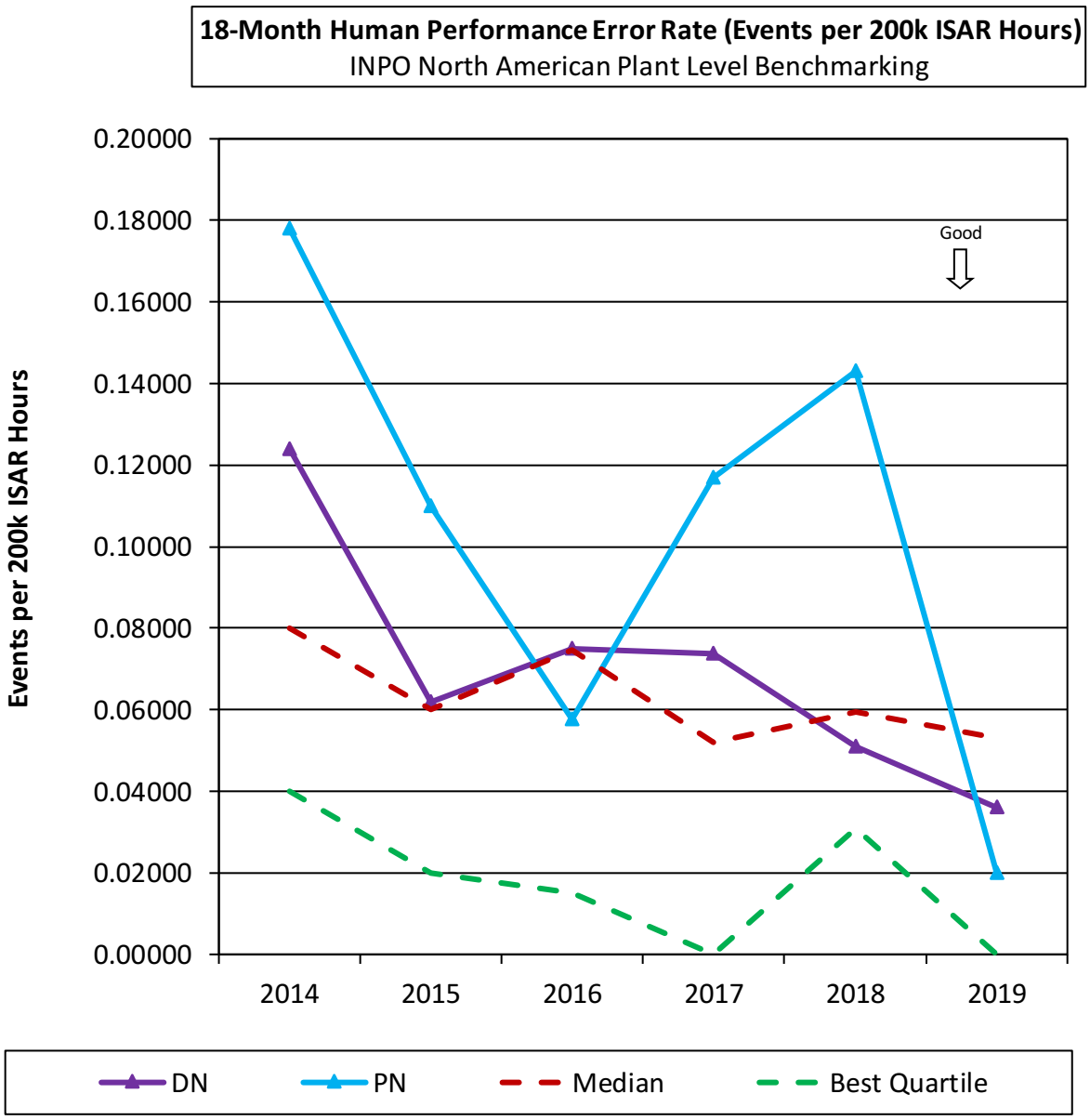
5.0 HUMAN PERFORMANCE

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. This will ensure a continued focus on improving Human Performance.

18-Month Human Performance Error Rate



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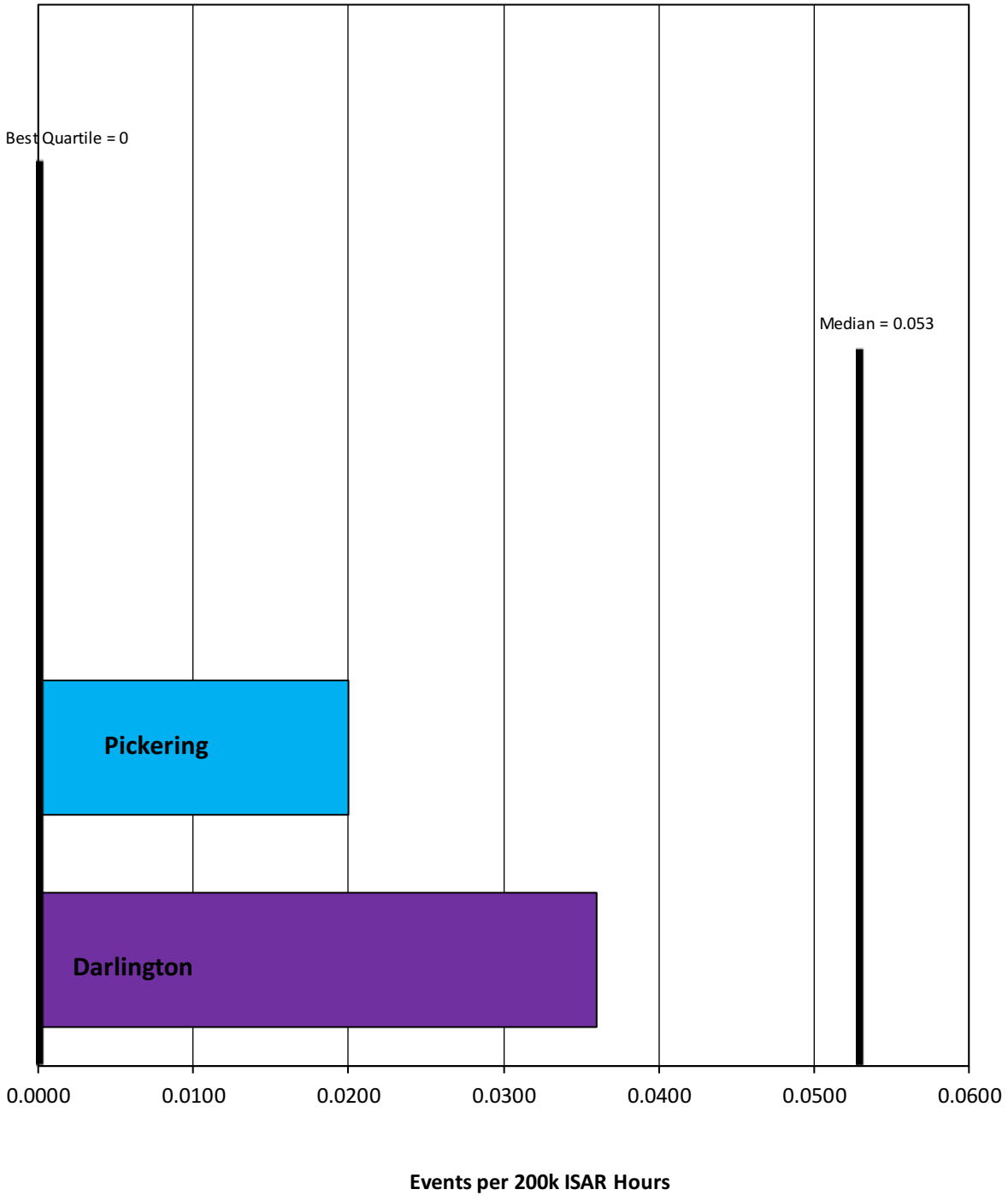
2019 18-Month Human Performance Error Rate

INPO North American Plant Level Benchmarking



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Observations – 18 Month Human Performance Error Rate (INPO North American Plants)

2019 (18 Month Rolling Average)

- The best quartile is 0 for the Human Performance (Hu) error rate for INPO plants. The median is 0.053. These rates reflect industry performance over an 18-month period.
- Pickering Hu Error Rate is 0.02, and Darlington is 0.036, which reflect second quartile performance at both stations. Darlington Unit 2 began a long-term refurbishment outage on October 15, 2016 and has been excluded from benchmarking results.
- Three site event free day resets (S-EFDRs) occurred in the 18-month period ending in 2019, with two at DNGS and one at PNGS.

Trend

- PNGS and DNGS performance has improved significantly over the trend period.
- The overall industry also improved steadily over the review period with best quartile at the end of 2019 being 0.00, improved from 0.04 in 2014.

Factors Contributing to Performance

- There are many successes in Human Performance that have contributed to Pickering and Darlington's low error rates in 2019 and improvement over the trend period. Industry-leading Human Performance practices have been built through innovation including:
  - the "iConnect" Mobile Observation & Coaching Application,
  - analysis tools for early detection of signs of decline in Hu performance,
  - associated Microsoft Power BI Dashboards to support data analytics and reporting, and
  - specialized training with the use of a simulator to teach Hu concepts and behaviours.

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6.0 MAJOR OPERATOR SUMMARY

Purpose

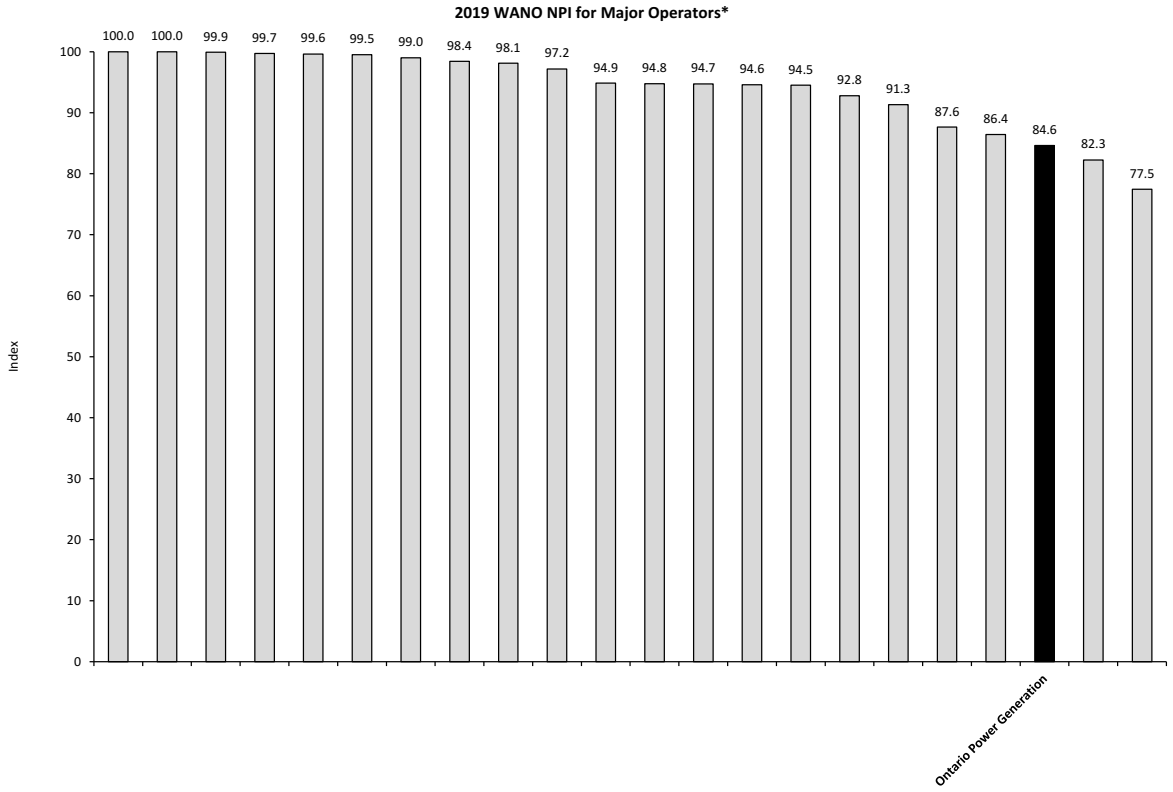
This section provides a more detailed comparison of the major operators of nuclear plants for three key metrics: WANO Nuclear Performance Index (NPI), Unit Capability Factor (UCF), and Total Generating Cost (TGC) per MWh.

Operator level summary results are the average (mean) of the results across all plants managed by the given operator. These comparisons provide additional context, but the detailed data in the previous sections provide a more complete picture of plant by plant performance. This view is consistent with ScottMadden's Evaluation of 2019 OPG Nuclear Benchmarking, in which ScottMadden recommended that OPG focus on site-level comparisons of performance for Pickering and Darlington rather than operator-level comparisons.

The WANO NPI and UCF are calculated as the mean of all unit performance for a specific operator. The TGC per MWh is the mean of plant level data.

WANO Nuclear Performance Index Analysis

The WANO NPI results for the operators in 2019 are illustrated in the graph below. OPG Nuclear performance ranking improved from 2018 by three rankings as shown in Table 2.



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*See Table 7 in the Appendix for listing of operators and plants.

**OPG Nuclear unit values averaging to a WANO NPI of 84.6 in 2019 are shown below:

Unit	2019 WANO NPI
Pickering 1	93.9
Pickering 4	78.2
Pickering 5	85.1
Pickering 6	76.5
Pickering 7	87.0
Pickering 8	74.1
Darlington 1	90.8
Darlington 2	N/A
Darlington 3	87.8
Darlington 4	87.9

OPG ranked 20th, with an NPI of 84.6. OPG's NPI performance increased by 4.5 compared to the 2018 ranking.

The NPI rankings of the major operators from 2014 to 2019 are listed in Table 2. The list and ranking of operators has been updated to reflect any applicable industry developments.

Table 2: Average WANO NPI Rankings

Operator	2014	2015	2016	2017	2018	2019
	2	4	13	2	2	1
	18	21	15	6	3	2
	5	5	3	1	1	3
	13	9	9	9	6	4
	8	3	1	16	18	5
	7	10	7	5	5	6
	19	7	11	14	7	7
	10	8	10	8	8	8
	20	20	12	10	12	9
	4	6	6	7	4	10
	12	16	14	3	9	11
	9	2	2	4	10	12
	17	19	22	22	14	13
	6	17	17	11	15	14
	16	1	8	13	13	15
	15	12	4	15	16	16
	3	15	16	12	11	17
	24	24	23	18	17	18
	1	14	18	21	20	19
Ontario Power Generation	22	23	21	23	23	20
	11	11	20	17	21	21
	21	22	19	19	19	22
	14	13	5	20	22	NA
	23	18	NA	NA	NA	NA

Note: The following operators are no longer ranked in 2019 (reason for 24 ranked operators in 2014 vs. 22 in 2019):

- Omaha Public Power District was removed from the WANO data set as of October 2016 (Fort Calhoun no longer in service).
- South Carolina Electric & Gas Co. is now a subsidiary of Dominion Generation since 2019.
- All 2014-2018 rankings are carried over from previous Benchmarking reports.

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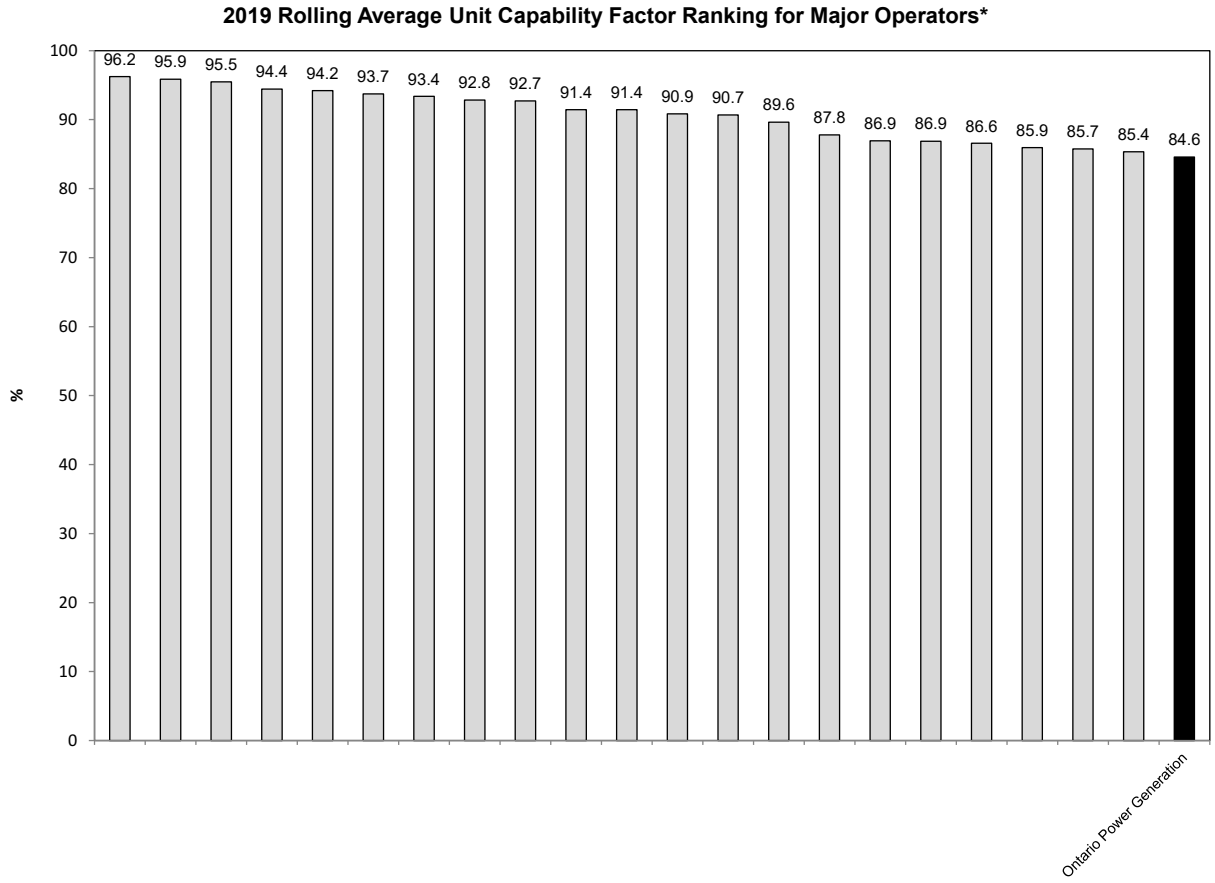
Unit Capability Factor Analysis

A comparison of UCF values for major nuclear operators is presented in the graph below. The list and ranking of operators has been updated to reflect any applicable industry developments.

UCF is expressed as a two-year average for all operators except for OPG Nuclear, which includes a three-year average for the Darlington station and a two-year average for Pickering to reflect each plant's respective historical outage cycle. OPG Nuclear experienced a rolling average UCF of 84.6% and ranked 22 out of 22 operators in the WANO data set.



* See Table 7 in the Appendix for listing of operators and plants.
**OPG unit values averaging to a rolling average UCF of 84.6% in 2019 are shown below:

Unit	2019 Rolling Average UCF
Pickering 1	95.1
Pickering 4	80.8
Pickering 5	82.1
Pickering 6	79.9
Pickering 7	83.5
Pickering 8	78.4

Unit	2019 Rolling Average UCF
Darlington 1	86.4
Darlington 2	N/A
Darlington 3	87.8
Darlington 4	87.0

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Rankings for the major operators for UCF over the past six years are provided in Table 3 below.

Table 3: Rolling Average Unit Capability Factor Rankings

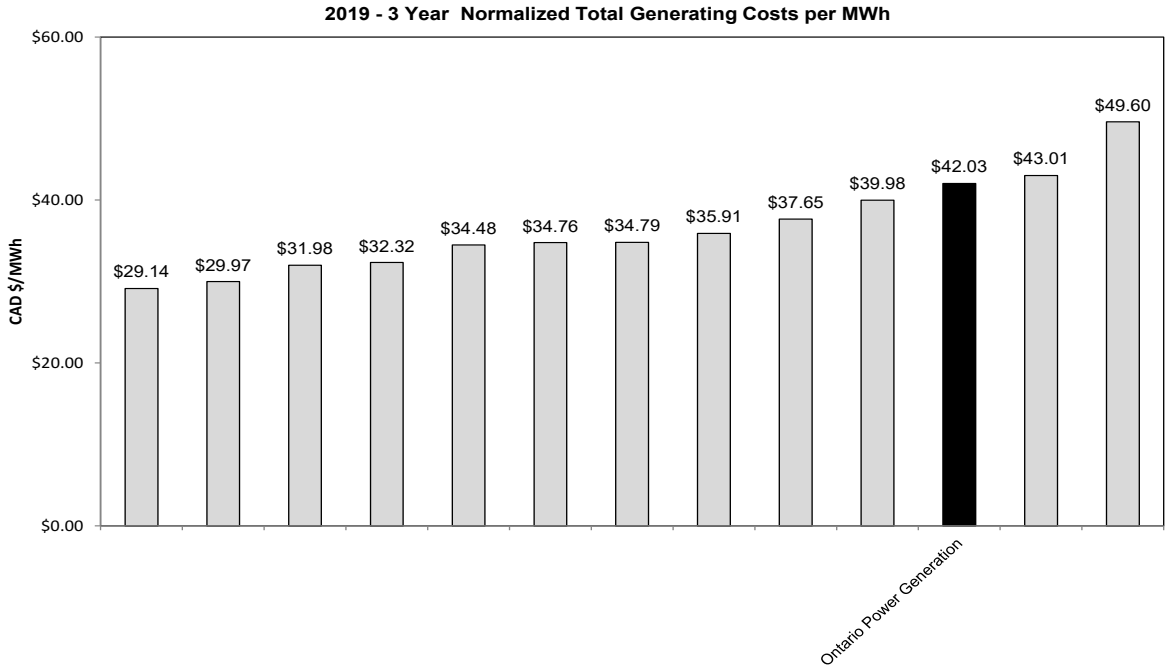
Operator	2014	2015	2016	2017	2018	2019
	1	1	1	1	1	1
	2	7	2	3	5	2
	18	20	20	13	4	3
	10	14	10	7	3	4
	5	10	3	14	17	5
	6	5	8	5	2	6
	8	6	5	2	7	7
	20	17	14	4	10	8
	19	4	6	20	15	9
	4	9	11	6	8	10
	14	19	19	21	13	11
	16	15	13	10	11	12
	7	2	7	9	12	13
	3	13	16	23	21	14
	13	12	4	8	9	15
	11	11	15	16	20	16
	17	3	12	18	19	17
	23	22	21	12	6	18
	9	8	18	15	14	19
	22	24	23	19	18	20
	15	18	17	17	16	21
Ontario Power Generation	21	23	22	22	23	22
	12	21	9	11	22	NA
	24	16	NA	NA	NA	NA

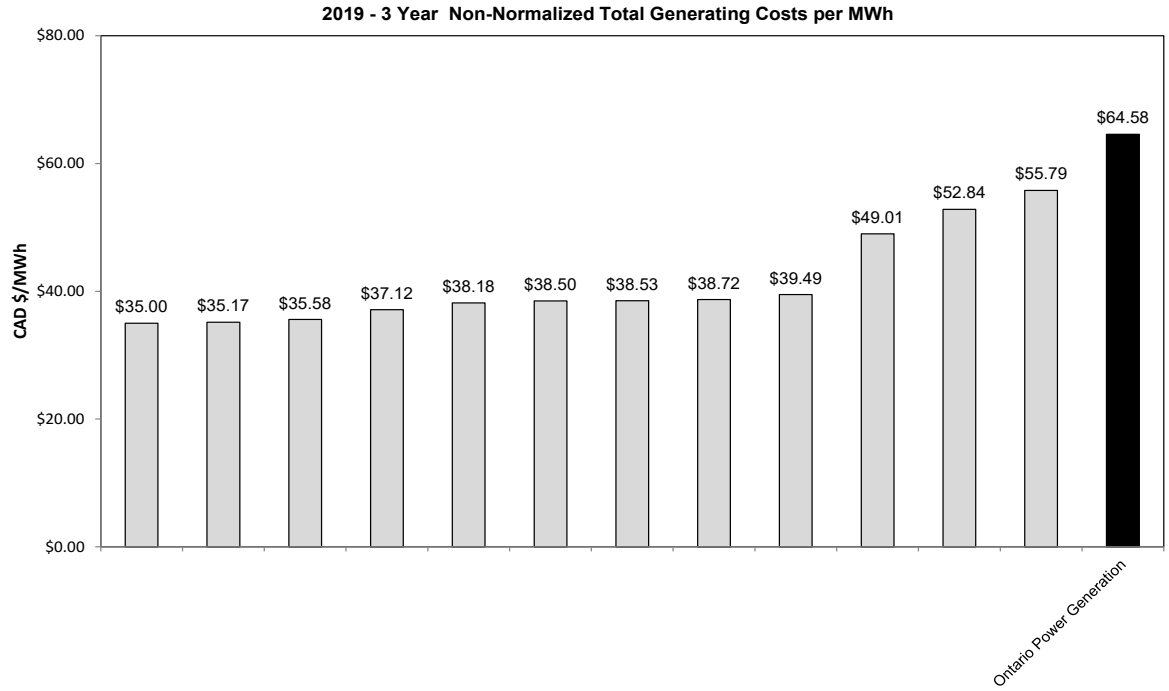
Note: The following operators are no longer ranked in 2019 (reason for 24 ranked operators in 2014 vs. 22 in 2019):

- Omaha Public Power District was removed from the WANO data set as of October 2016 (Fort Calhoun no longer in service).
- South Carolina Electric & Gas Co. is now a subsidiary of Dominion Generation since 2019.
- All 2014-2018 rankings are carried over from previous Benchmarking reports.

Total Generating Cost/MWh Analysis

The 3-year average Total Generating Cost (TGC)/MWh results for the major operators in 2019 are displayed in the graphs below. On a normalized basis, OPG Nuclear ranked 11th, with a 3-year Total Generation Cost of $42.03 per MWh (non-normalized, ranked 13th with $64.58/MWh).





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OPG plant values of 3-year rolling average TGC per MWh are shown below:

2019 3-Year TGC/MWh		
Station	Normalized	Non-Normalized
Darlington	$38.84/MWh	$67.00/MWh
Pickering	$44.85/MWh	$62.39/MWh

Table 4: Three Year TGC/MWh Rankings

	2014	2015	2016	2017	2018	2019
	11	11	9	3	1	1
	4	2	1	2	2	2
	7	7	6	6	6	3
	12	8	7	8	5	4
	8	9	10	9	9	5
	5	3	3	5	8	6
	3	5	4	7	7	7
	2	4	5	4	4	8
	1	1	2	1	3	9
	6	6	8	10	10	10
	13	13	13	13	12	11
	9	10	11	11	11	12
Ontario Power Generation	10	12	12	12	13	13
Ontario Power Generation - Normalized	-	-	-	11	11	11

Table 5 shows the relative contribution of Non-Fuel Operating Costs, Fuel Costs and Capital Costs to Total Generating Cost/MWh and compares OPG's non-normalized costs to those of all EUCG operators.

Table 5: EUCG Indicator Results Summary (Operator Level)

EUCG Indicator Results Summary	OPG Average	EUCG Major Operators*		Unit of Measure
		Median	Best Quartile	
Value for Money Performance				
3-Yr. Non-Fuel Operating Costs per MWh (non-normalized)	$50.65	$23.43	$22.48	CAD $/MWh
3-Yr. Fuel Costs per MWh (non-normalized)	$4.30	$7.73	$7.17	CAD $/MWh
3-Yr. Capital Costs per MWh (non-normalized)	$9.63	$9.02	$6.16	CAD $/MWh
3-Yr. Total Generating Costs per MWh (non-normalized)	$64.58	$38.53	$37.12	CAD $/MWh
3-Yr. Total Generating Costs per MWh - Normalized	$42.03	$34.79	$32.32	CAD $/MWh

**See Table 8 in the appendix for list of operators included.*

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7.0 APPENDIX

Acronyms

Acronym	Meaning
ALARA	As Low As Reasonably Achievable
BWR	Boiling Water Reactor
CANDU	CANada Deuterium Uranium (type of PHWR)
CEA	Canadian Electricity Association
COG	CANDU Owners Group
DER	Design Electrical Rating
EPRI	Electric Power Research Institute
EUCG	Electric Utility Cost Group
INPO	Institute of Nuclear Power Operators
OPG	Ontario Power Generation
PHWR	Pressurized Heavy Water Reactor
PWR	Pressurized Water Reactor
WANO	World Association of Nuclear Operators

Safety and Reliability Definitions

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

Total Recordable Injury Frequency is the average number of fatalities, lost time injuries, medical treatment injuries and restricted work injuries per 200,000 hours worked.

Industrial Safety Accident Rate is defined as the 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, for purposes of this indicator, is the total external and internal whole body exposure determined by primary dosimeter (thermoluminescent dosimeter (TLD) or film badge), 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.

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Airborne Tritium Emissions per Unit: Tritium emissions to air.

Fuel Reliability Index is 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) is defined as the 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_{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.

The **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).

The **Nuclear Performance Index** Method 4 is an INPO sponsored performance measure, and is a weighted composite of ten WANO Performance Indicators related to safety and production performance reliability.

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The **Forced Loss Rate (FLR)** is defined as the 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 are 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 is 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 is 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 energy losses are those 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 is the 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 is defined as the 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 is the 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 is the energy that could be produced if the unit were operated continuously at full power under reference ambient conditions.

Reference ambient conditions are environmental conditions representative of the annual mean (or typical) ambient conditions for the unit.

The **Chemistry Performance Indicator** 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 Backlog is the 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 Backlog is the 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 is maintenance that will be performed with the main generator connected to the grid.

Value for Money Definitions

The following definition summaries are taken from the *January 2020 EUCG Nuclear Committee Nuclear Database Instructions*.

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).

Fuel ($)
The total cost associated with a load of fuel in the reactor which is burned up in a given year.

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Net Generation (Gigawatt Hours)
The 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). Negative quantities should not be used.

Design Electrical Rating (DER)
The 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 ($)
All relevant costs to operate and maintain nuclear operations. It includes the cost of labour, materials, purchased services and other costs, including administration and general.

Total Generating Costs ($)
The sum of operating costs, fuel costs and capital costs.

Note: Total Generating Costs are divided by net generation to obtain per MWh results. Capital costs are also divided by MW DER to obtain per MW results.

<u>Human Performance Definitions</u>

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

Human Performance Error Rate (# per ISAR and Contractor Hours)
The Human Performance Error Rate metric represents the number of site level human performance events in an 18-month period per 200,000 ISAR hours worked (including on site supplemental personnel). The formula used is:

{(# of S-EFDRs) / (Total ISAR Hours + Total Contractor Hours)} x 200,000 Hours (Calculated as an 18-month rolling average)

INPO guidelines define non-utility personnel to include 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.

INPO defines an event to occur as a result of the following:
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.

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Table 6: Industry Peer Groups

	WANO/COG CANDUs	All North American PWR and PHWRs (WANO)	INPO AP-928 Workgroup	INPO	CEA	EUCG North American Plants (US and Canada)
Safety						
Total Recordable Injury Frequency					X	
Rolling Average Industrial Safety Accident Rate*		X				
Rolling Average Collective Radiation Exposure*	X					
Airborne Tritium Emissions 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					
Reliability						
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 Corrective Maintenance Backlog			X			
Value for Money						
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
Human Performance						
Human Performance Error Rate				X		

* Sub-indicator of WANO NPI

Data provided by the World Association of Nuclear Operators (WANO) is the primary source of benchmarking data for operational performance (Safety and Reliability) indicators. Eleven out of the twenty benchmarking metrics have been compared to the WANO/COG CANDU panel. All WANO performance indicators are presented at the unit and plant levels except the Industrial Safety Accident Rate and Emergency AC Power Unavailability which are only measured at the plant level.

Different peer groups were used for a few of the specialized operating metrics which are not tracked through WANO. For maintenance work order backlogs, the peer group consisted of all plants participating in the Institute of Nuclear Power Operations (INPO) AP-928 working group. For human performance comparisons, data was obtained from INPO. For the Total Recordable Injury Frequency metric, the Canadian Electricity Association (CEA) panel was used.

For financial performance comparisons, data compiled by the Electric Utility Cost Group (EUCG) was used. 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 Nuclear 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.

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All data provided by the peer groups (WANO, INPO, CEA, 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.

Panels

Table 7: WANO Panel

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

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Table 8: EUCG Panel

Major Operator	Plant
Bruce Power	Bruce A Bruce B
Dominion Generation	Millstone North Anna Surry V.C. Summer
Duke Energy	Brunswick Catawba Harris Mcguire Oconee Robinson
Entergy Nuclear	Arkansas Nuclear One Grand Gulf Indian Point Palisades Pilgrim River Bend Waterford
Exelon Generation Co.	Braidwood Byron Calvert Cliffs Clinton Dresden Fitzpatrick Lasalle Limerick Nine Mile Oyster Creek Peach Bottom Quad Cities Ginna Three Mile Island
FirstEnergy Nuclear Operating Co.	Beaver Valley David-Besse Perry
Florida Power & Light Co.	St Lucie Turkey Point
NextEra Energy Resources	Duane Arnold Point Beach Seabrook
Northern States Power Company	Monticello Prairie Island
Ontario Power Generation	Darlington Pickering
Public Service Enterprise Group Nuclear	Hope Creek Salem
Southern Nuclear Operating Co.	Farley Hatch Vogtle
Tennessee Valley Authority	Browns Ferry Sequoyah Watts Bar

Remaining EUCG Members

Operator	Plant	Operator	Plant
AmerenUE	Callaway	Nebraska Public Power District	Cooper
American Electric Power Co. Inc.	Cook	Pacific Gas & Co.	Diablo Canyon
Arizona Public Service Co.	Palo Verde	Talen Energy	Susquehanna
DTE Energy	Fermi	STP Nuclear Operating Co.	South Texas
Energy Northwest	Columbia	Wolf Creek Nuclear Operations Corp.	Wolf Creek
Luminant Generation	Comanche Peak		

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Table 9: COG CANDUs

Operator	Plant
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 10: CEA Members

Companies
Alectra Inc.
Algonquin Power & Utilities Corp.
AltaLink
ATCO Electric
ATCO Power
BC Hydro and Power Smart
Brookfield Renewable Energy Group
Capital Power Corporation
City of Medicine Hat, Electric Utility
City of Red Deer
Elexicon Energy
Emera Power
ENMAX
EPCOR
Evolugen
FortisAlberta Inc.
FortisBC Inc.
FortisOntario
Heartland Generation
Hydro One
Hydro Ottawa
Hydro Quebec

Companies
Hydro Quebec
IESO
London Hydro
Manitoba Hydro
Maritime Electric Company
Nalcor Energy
New Brunswick Power
Newfoundland Power
Northwest Territories Power Corp.
OEC
Ontario Power Generation
Qulliq Energy Corporation
Rio Tinto
Saint John Energy
Saskatoon Light & Power
SaskPower
TC Energy
Toronto Hydro Corp.
TransAlta
Utilities Kingston
Yukon Energy Corp.

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Table 11: INPO Members for Human Performance Error Rate

Plant	
Arkansas Nuclear One (ANO)	Monticello
Beaver Valley	Nine Mile Point
Braidwood	North Anna
Browns Ferry	Oconee
Brunswick	Oyster Creek
Byron	Palisades
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	Three Mile Island
Hatch	Turkey Point
Hope Creek	Vermont Yankee
Indian Point	Vogtle
LaSalle	Waterford
Limerick	Watts Bar
McGuire	Wolf Creek
Millstone	

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Table 12: INPO Members for On-Line Maintenance Backlogs

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

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Table 13: NPI Plant Level Performance Summary (North American Panel)

	2019 Actuals				
Indicator	**NPI Max**	**Best Quartile**	**Median**	**Pickering**	**Darlington**
Rolling Average Industrial Safety Accident Rate (#/200k hours worked)	0.20	0.00	0.01	0.02	0.04
Rolling Average Collective Radiation Exposure (person-rem per unit)	80.00	23.40	32.00	70.32	83.23
Fuel Reliability Index (microcuries per gram)	0.000500	0.000001	0.000005	0.000187	0.000295
2-Year Reactor Trip Rate (# per 7,000 hours)	0.50	0.00	0.00	0.24	0.00
3-Year Auxiliary Feedwater System Unavailability (#)	0.0200	0.0020	0.0036	0.0039	0.0000
3-Year Emergency AC Power Unavailability (#)	0.0250	0.0076	0.0122	0.0003	0.0026
3-Year High Pressure Safety Injection Unavailability (#)	0.0200	0.0017	0.0024	0.0001	0.0000
Rolling Average Forced Loss Rate (%)	1.00	0.31	0.98	3.39	2.56
Rolling Average Unit Capability Factor (%)	92.00	95.10	91.43	83.31	87.06
Rolling Average Chemistry Performance Indicator (Index)	1.01	1.00	1.00	1.02	1.03
WANO NPI (Index)	Not Applicable	100.0	98.1	82.5	88.9