ONTARIO POWER GENERATION

ONTARIO POWER GENERATION NUCLEAR

2018 NUCLEAR BENCHMARKING REPORT

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Nuclear Finance – Business Planning and Benchmarking

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1.0 EXECUTIVE SUMMARY

Key Highlights

OPG benchmarked favourably relative to its peers in 2017 in a number of key nuclear cornerstone areas. OPG's benchmarking results continue to demonstrate strong safety performance and show a commitment to continuous improvement in Human Performance trends. Management efforts to reduce critical maintenance backlogs have been successful. However, other reliability metrics were impacted by plant life extension activities (i.e., Pickering Extended Operations and Darlington Refurbishment). While cost pressures and lower production associated with such life extension requirements also influenced the performance of certain value for money benchmarking metrics, TGC/MWh performance improved at Pickering and TGC per unit performance was favourable.

Safety

Under the Safety cornerstone, OPG's nuclear generating stations continued to achieve strong performance in a majority of the safety performance metrics. Darlington and Pickering continued to demonstrate first quartile performance in All Injury Rate.

OPG Nuclear Stations continue to lead in Safety

Darlington 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 continued to show maximum WANO NPI results or top quartile performance for five NPI sub-metrics under the Safety cornerstone.

Pickering's Collective Radiation Exposure (CRE) improved from the prior year and remained in third quartile. Darlington's CRE declined to the fourth quartile, driven largely by planned scope associated with Single Fuel Channel Replacement, Shutdown Cooling Heat Exchanger Replacements and Shield Tank Over-pressure Protection modifications work. Darlington's CRE is expected to improve to achieve max NPI points going forward.

Airborne Tritium Emissions at Pickering remained in the third quarter largely due to an increase in heavy water-related emissions. As a result, management continues to focus on improving vapour recovery dryer performance to reduce emissions. Darlington tritium emissions reflect top quartile and sustained performance through vault ACU leaks and dryer systems repairs.

Pickering's Fuel Reliability Index (FRI) declined resulting from two fuel defects. Management continues to focus on a number of corrective actions to improve FRI performance. Darlington's FRI performance was in top quartile and as a result achieved maximum NPI points.

Reliability

OPG's nuclear facilities are transitioning through a major refurbishment and life extension which impacted OPG's performance under the Reliability cornerstone. To facilitate extended operations, OPG is experiencing a greater number of planned outage days than in prior years.

Despite the higher planned outages, the majority of Pickering's performance metrics improved compared to 2016 such as the WANO NPI, Unit Capability Factor (UCF), Chemistry Performance Indicator (CPI), and On-line Corrective Maintenance backlogs. At Pickering, the most significant improvement was the On-line Corrective Maintenance backlogs performing better by a 78% reduction compared to 2016, which was largely attributed to a deliberate focus on scheduling corrective maintenance.

OPG Nuclear Stations have significantly improved in reducing maintenance backlogs. Corrective Critical backlogs are at or near 0 at Darlington and Pickering

Pickering's NPI performance and FLR have improved considerably since 2012 due to better outage Foreign Materials Exclusion practices, Water Treatment Plant output quality, and blowdown frequency adherence.

Certain Darlington reliability metrics showed sustained or improved performance (e.g., On-line Corrective and Deficient Maintenance backlogs). Darlington improved their On-line Deficient Maintenance Backlogs and On-line Corrective Maintenance Backlogs by reducing the number of work orders per unit relative to 2016 as a result of continued station focus, overall maintenance efficiency and improved schedule quality.

NPI performance at Darlington declined to the third quartile largely driven by lower UCF from impacts of fuel channel inspections required to reach the unit refurbishment date and scheduled nuclear refurbishment project impacts (i.e. refurb bulkhead installation). Darlington's NPI is expected to improve to top quartile over the next few years.

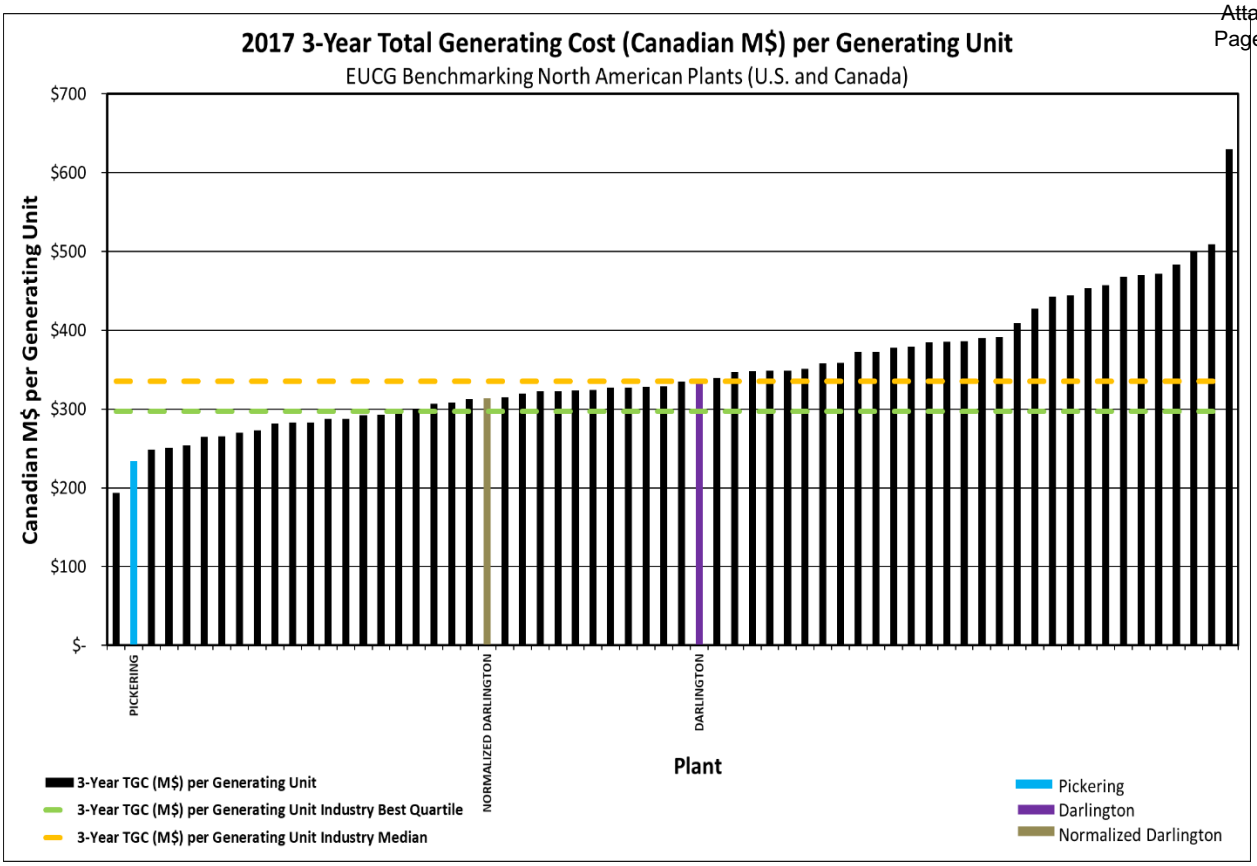
Value for Money

Under the Value for Money cornerstone, Pickering's Total Generating Cost (TGC) per MWh improved in 2017. Moreover, Pickering's TGC per MWh remained relatively flat over the 2012-2017 period with a compound growth rate of 0.02% whereas the best quartile and median levels increased by 0.81% and 0.12% respectively. Pickering remained in the fourth quartile for performance in TGC per MWh despite maintaining best quartile performance in Fuel Cost per MWh and Capital Cost per MW DER. Unit size and outage durations required to extend operations to 2024 continued to contribute to fourth quartile results.

TGC/MWh improved at Pickering while Darlington was impacted by life extension and refurbishment.

Pickering units are the smallest in the peer group with total unit capacity of 540 MW compared to the peer group average of 1,024 MW. The majority of the generating units in the peer group fall within the 900 to 1,299 MW range.

The following chart is the 3-year Total Generating Costs per unit.



However, Pickering's TGC per generating unit demonstrated strong performance with Pickering placing among the best in the peer group as illustrated in the graph above. Darlington's TGC per generating unit placed in the median level.

Darlington's TGC per MWh performance (before normalization) was in the fourth quartile in 2017 driven largely by cost impacts and reduced generation associated with life extension and refurbishment work. After normalizing[1] for refurbishment, TGC per MWh performance moved to the third quartile. Darlington was able to sustain top quartile performance in Fuel Cost per MWh and median quartile performance in Capital Cost per MW.

Human Performance

In the area of Human Performance, Darlington improved their human performance error rate and remained in the median quartile. However Pickering declined to the third quartile in 2017, resulting from five station event free day resets. The Human Performance Fleet Excellence plan is intended to enhance Human Performance and reinforces the need to remain focused on setting, communicating and reinforcing standards and expectations through effective coaching in the field and recognize risks to ensure human performance shortfalls are addressed.

[1] See section 4.0 for a description of the TGC/MWh normalization methodology.

Benchmarking Results – Plant Level Summary

Table 2 provides a summary of OPG Nuclear's 2017 performance compared to benchmark results.

Table 2: Plant Level Performance Summary

Metric	NPI Max	2017 Actuals			
		Best Quartile	Median	Pickering	Darlington
Safety					
All Injury Rate (#/200k hours worked)		1.02	N/A[1]	0.06	0.40
Rolling Average[2] Industrial Safety Accident Rate (#/200k hours worked)	0.20	0.00	0.00	0.05	0.04
Rolling Average[2] Collective Radiation Exposure (Person-rem per unit)	80.00	42.77	63.16	83.96	91.80
Airborne Tritium Emissions (Curies) per Unit[3]		1,013	2,290	3,103	875
Fuel Reliability Index (microcuries per gram)	0.000500	0.000001	0.000027	0.000584	0.000179
2-Year Reactor Trip Rate (# per 7,000 hours)	0.50	0.00	0.21	0.26	0.29
3-Year Auxiliary Feedwater System Unavailability (#)	0.0200	0.0000	0.0001	0.0000	0.0000
3-Year Emergency AC Power Unavailability (#)	0.0250	0.0014	0.0030	0.0030	0.0000
3-Year High Pressure Safety Injection Unavailability (#)	0.0200	0.0000	0.0000	0.0000	0.0000
Reliability					
WANO NPI (Index)		86.7	85.0	76.7	82.0
Rolling Average[2] Forced Loss Rate (%)	1.00	1.43	2.46	5.01	3.47
Rolling Average[2] Unit Capability Factor (%)	92.00	86.80	83.83	77.36	82.17
Rolling Average[2] Chemistry Performance Indicator (Index)	1.01	1.00	1.01	1.02	1.01
1-Year On-line Deficient Maintenance Backlog (work orders per unit)		50	89	383	119
1-Year On-line Deficient Critical Maintenance Backlog (work orders per unit)		3	5	41	15
1-Year On-line Corrective Maintenance Backlog (work orders per unit)		3	6	25	13
1-Year On-line Corrective Critical Maintenance Backlog (work orders per unit)		0	0	0	1
Value for Money					
3-Year Total Generating Cost per MWh ($ per Net MWh)		37.78	43.66	67.22	54.40
Normalized 3-Year Total Generating Cost per MWh ($ per Net MWh)		37.78	43.66	N/A	50.54
3-Year Total Generating Cost per Unit (M $ per Unit)		296.76	335.04	233.75	337.56
Normalized 3-Year Total Generating Cost per Unit (M $ per Unit)		296.76	328.73	N/A	313.62
3-Year Non-Fuel Operating Cost per MWh ($ per Net MWh)		22.35	25.55	56.89	39.62
Normalized 3-Year Non-Fuel Operating Cost per MWh ($ per Net MWh)		22.35	25.55	N/A	36.89
3-Year Fuel Cost per MWh ($ per Net MWh)		7.59	8.27	5.31	5.19
3-Year Capital Cost per MW DER (k$ per MW)		50.21	64.36	33.91	62.11
Human Performance					
18-Month Human Performance Error Rate (# per 200k ISAR and contractor hours)		0.0000	0.0520	0.1160	0.0520

Notes
1. No median benchmark available.
2. Indicates a 2-Year Rolling Average for Pickering and a 3-Year Rolling Average for Darlington.
3. 2016 Industry data is used because 2017 results were unavailable at the time of benchmarking.

Green = maximum NPI results achieved or best quartile performance

White = 2nd quartile performance

Yellow = 3rd quartile performance

Red = 4th quartile performance

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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 listed in Table 7 of Section 7.0 and are divided into four categories aligned with OPG Nuclear's four cornerstones of safety, reliability, value for money, and human performance.

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 7 of Section 7.0 and panel members are detailed in Tables 8-13 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. Operations related (WANO NPI and UCF) results were averaged at the unit level and cost related (TGC per MWh) results were averaged at the plant level. 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. The detailed data in sections 2.0 to 5.0 of the report provide a more complete picture of plant by plant performance.

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. One plant has been excluded since it was taken offline since December 31, 2015 for refurbishment.

The All Injury Rate (AIR) 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 11).

Airborne Tritium Emissions per unit data were collected from the CANDU Owners Group (COG) for 2012 to 2017 as displayed in the historical trend line chart. The peer group for this metric is all CANDUs who are a member of COG.

Nine metrics are included in this benchmarking report to 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 All Injury Rate and the COG Airborne Tritium Emissions per unit are included in this section of the report.

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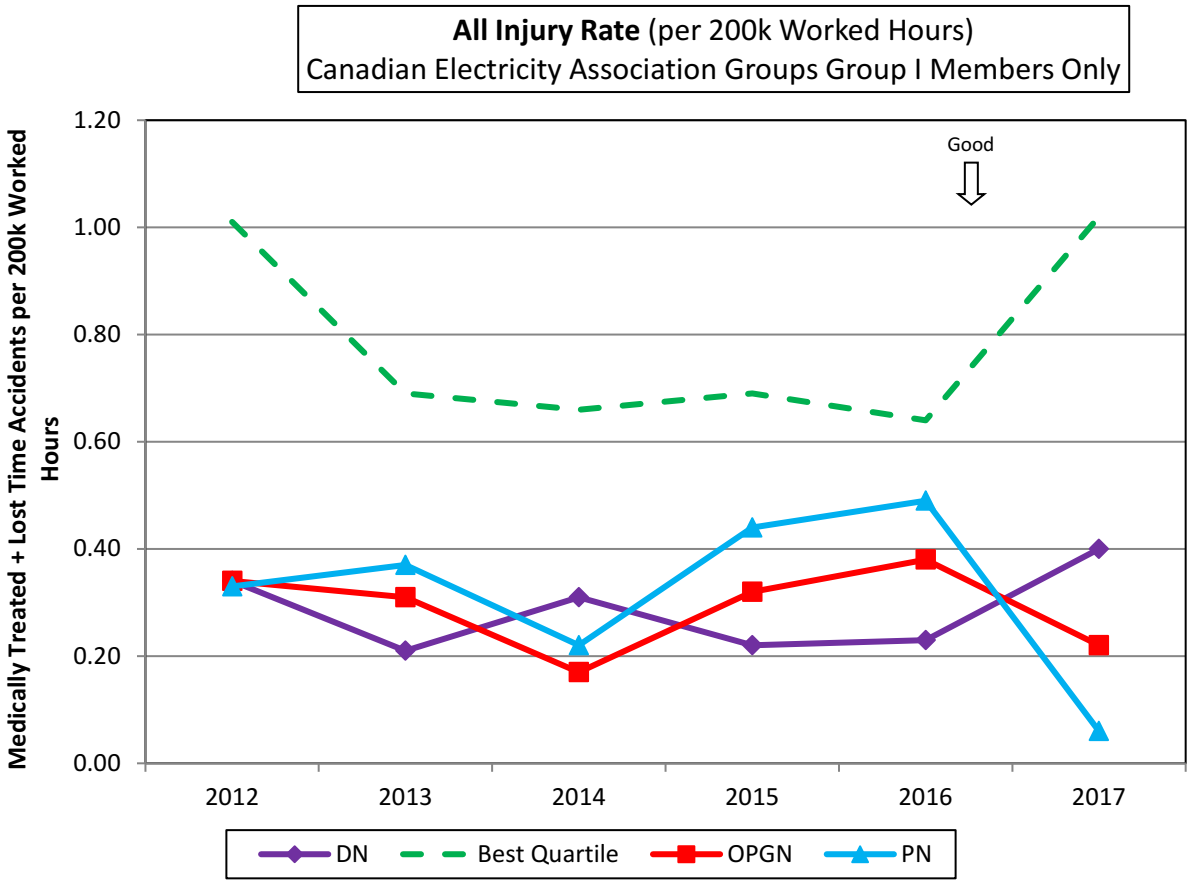
All Injury Rate



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Observations – All Injury Rate (AIR) (Canadian Electricity Association - CEA)

2017 (Annual Value)

- The All Injury Rate (AIR) incorporates all lost time and medically treated injuries incurred by OPG employees working on site.
- Pickering, Darlington, and OPG Nuclear as a fleet all performed better than the CEA top quartile value of 1.02.
- Darlington's AIR increased slightly compared to 2016 from 0.23 to 0.40 in 2017.
- Pickering's AIR improved significantly from 0.49 in 2016 to 0.06 in 2017.
- OPG benchmarks against CEA Group 1 (a sub-set of all CEA members), which incorporates approximately 10 organizations with more than 1500 employees, including most provincial utilities.
- In 2017, OPG was the top performer of all Group 1 members.

Trend

- Darlington, Pickering and OPG Nuclear have consistently performed significantly better than the benchmark value over the past five years.

Factors Contributing to Performance

- Conventional Safety performance trends are monitored such that action plans to support continuous improvement can be implemented. These actions 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 is expanding and enhancing the Safe Work Planning process in 2017 and 2018. The Safe Work Planning process supports supervisors and employees in identifying, planning and mitigating hazards prior to commencement of work, as well as monitoring ongoing work for conditions that could lead to unanticipated hazardous situations.
- Since 2014, OPG has been implementing the Total Health Program, which supports employees and their families in their efforts to achieve an optimal level of health and functioning, primarily through health education, health promotion, disease and injury prevention, and crisis intervention. Employee mental health is a key component of the Total Health Program. As of June 2018, over 2000 OPG employees have completed an intensive 2-day training course in mental health first aid.

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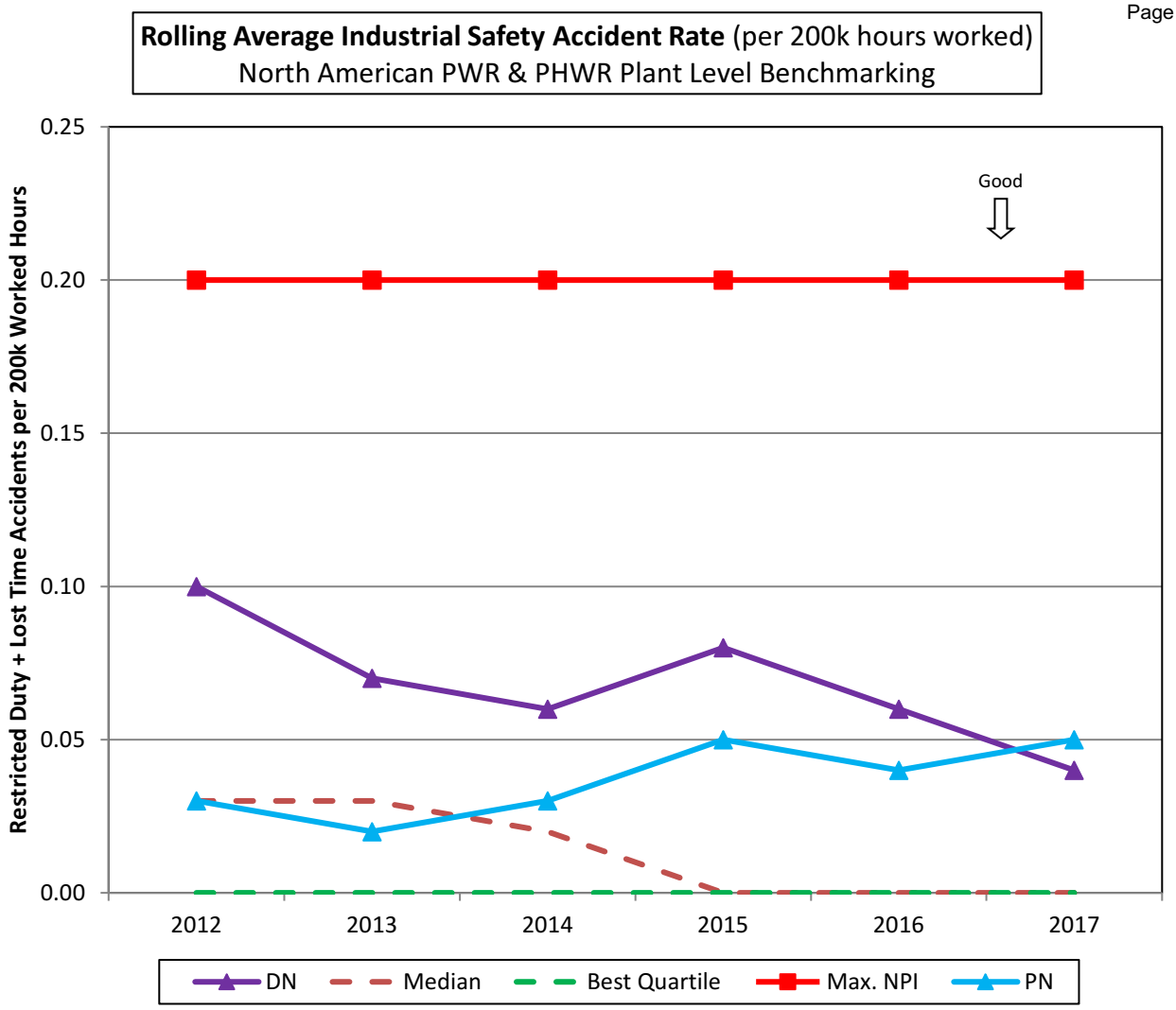
Rolling Average Industrial Safety Accident Rate



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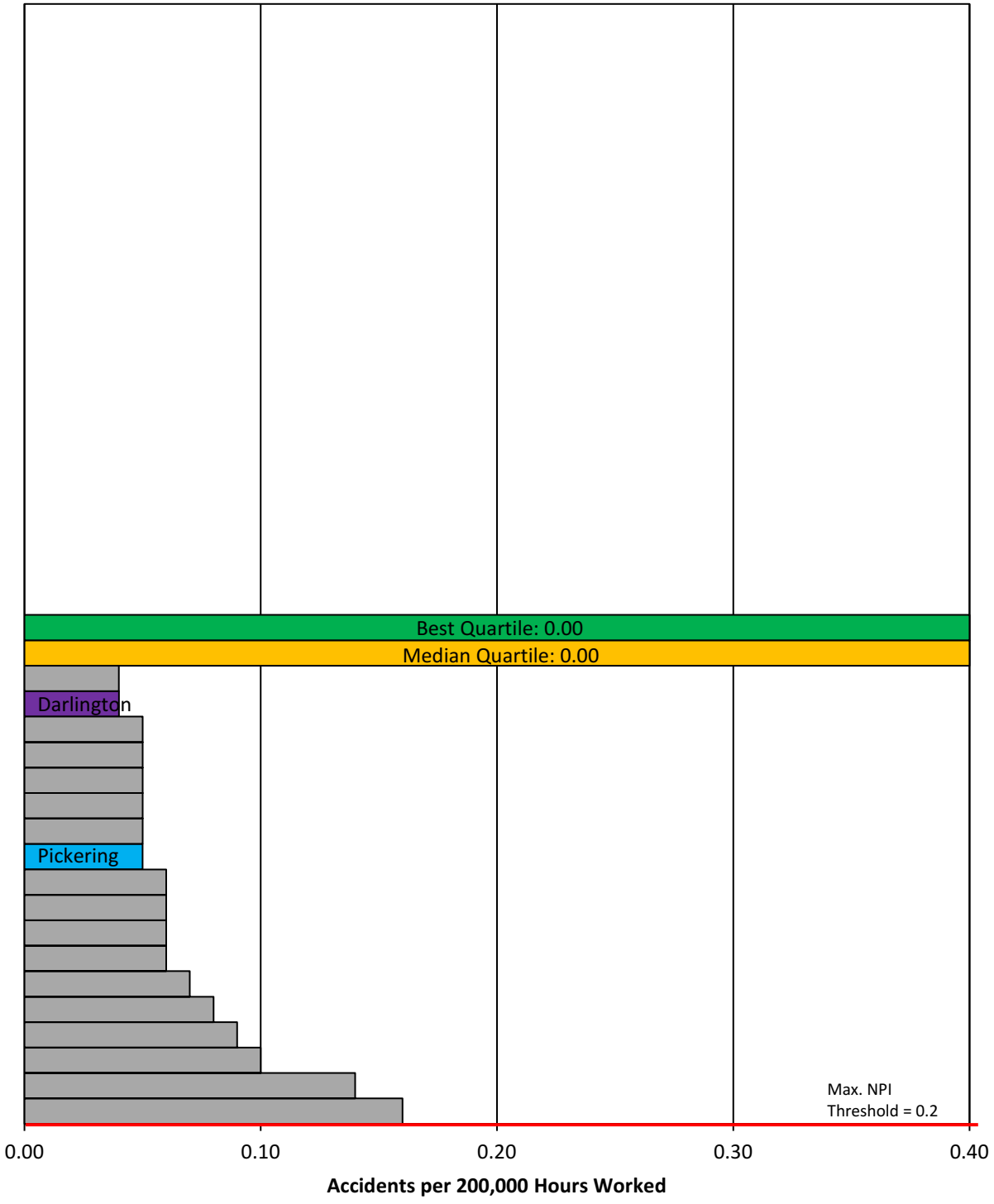
2017 Rolling Average Industrial Safety Accident Rate (per 200,000 hours worked)
North American PWR & PHWR Plant Level Benchmarking



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

2017 (Rolling 2 Year Average Pickering, Rolling 3 Year Average Darlington)

- The Industrial Safety Accident Rate (ISAR) incorporates all lost time injuries and restricted work injuries incurred by OPG employees working on the site.
- For reporting the ISAR, a 2-year rolling average was used for all panel members with the exception of the Darlington station which follows a 3-year outage cycle. This is consistent with the World Association of Nuclear Operators (WANO) Nuclear Performance Index (NPI) reporting guidelines.
- WANO top quartile in 2017 remained unchanged from 2016 at 0.00 (i.e. zero ISAR events). Median performance was 0.00, which was also unchanged from 2016.
- Both Pickering and Darlington achieved maximum NPI points for the ISAR in 2017.
- Pickering ISAR performance declined slightly from 2016 to 2017 (0.04 to 0.05). However, Pickering Nuclear had a successful WANO evaluation in 2017, resulting in zero areas for improvement in Industrial Safety.
- Darlington ISAR performance improved from 2016 to 2017 (0.06 to 0.04).

Trend

- Darlington's ISAR rolling average has improved slightly in 2017 to 0.04 and continues to show general improved performance over the past five years.
- Pickering's ISAR rolling average has shown a generally stable performance over the past five years.
- The ISAR median has steadily improved over the past five years, remaining at zero for the past two years. The industry best quartile has remained at zero for the past five 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 processes.
- One major focus area for OPG Nuclear in 2017 and 2018 is to expand and enhance the Safe Work Planning process, which supports supervisors and employees in identifying, planning and mitigating hazards prior to commencement of work, as well as monitoring ongoing work for conditions that could lead to unanticipated hazardous situations.

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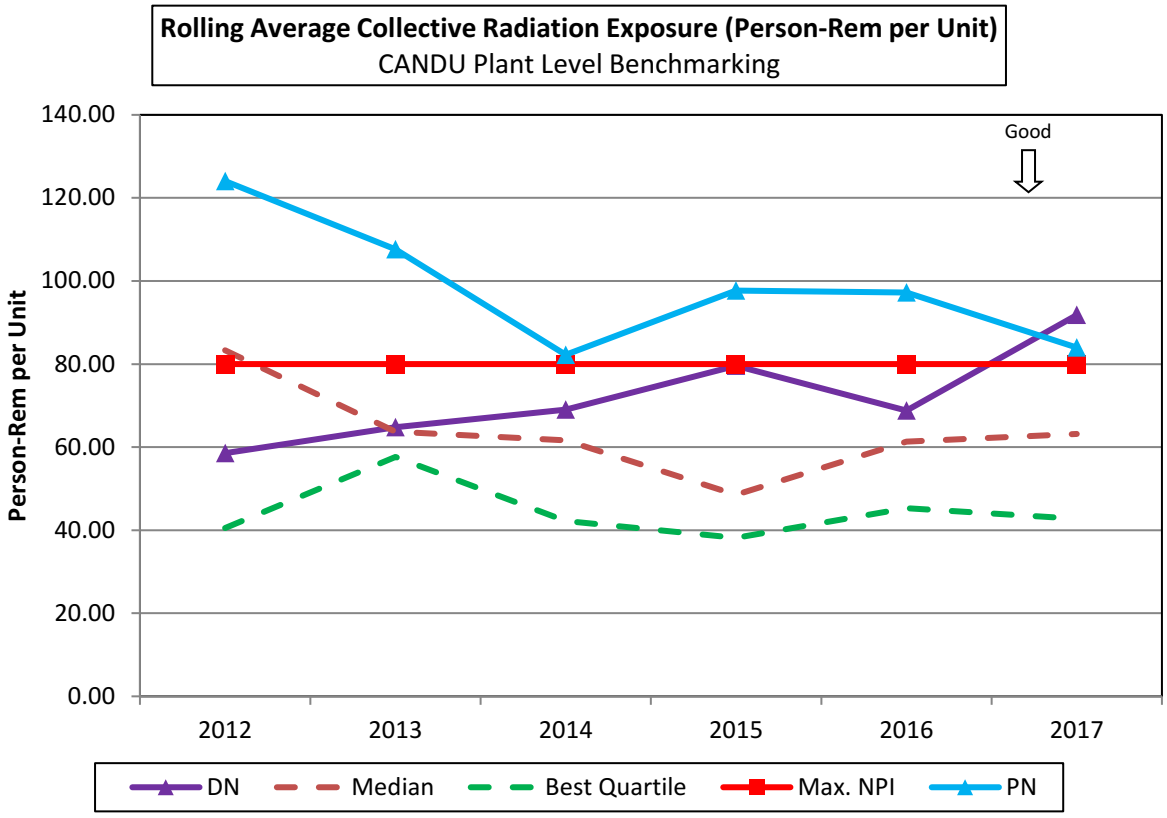
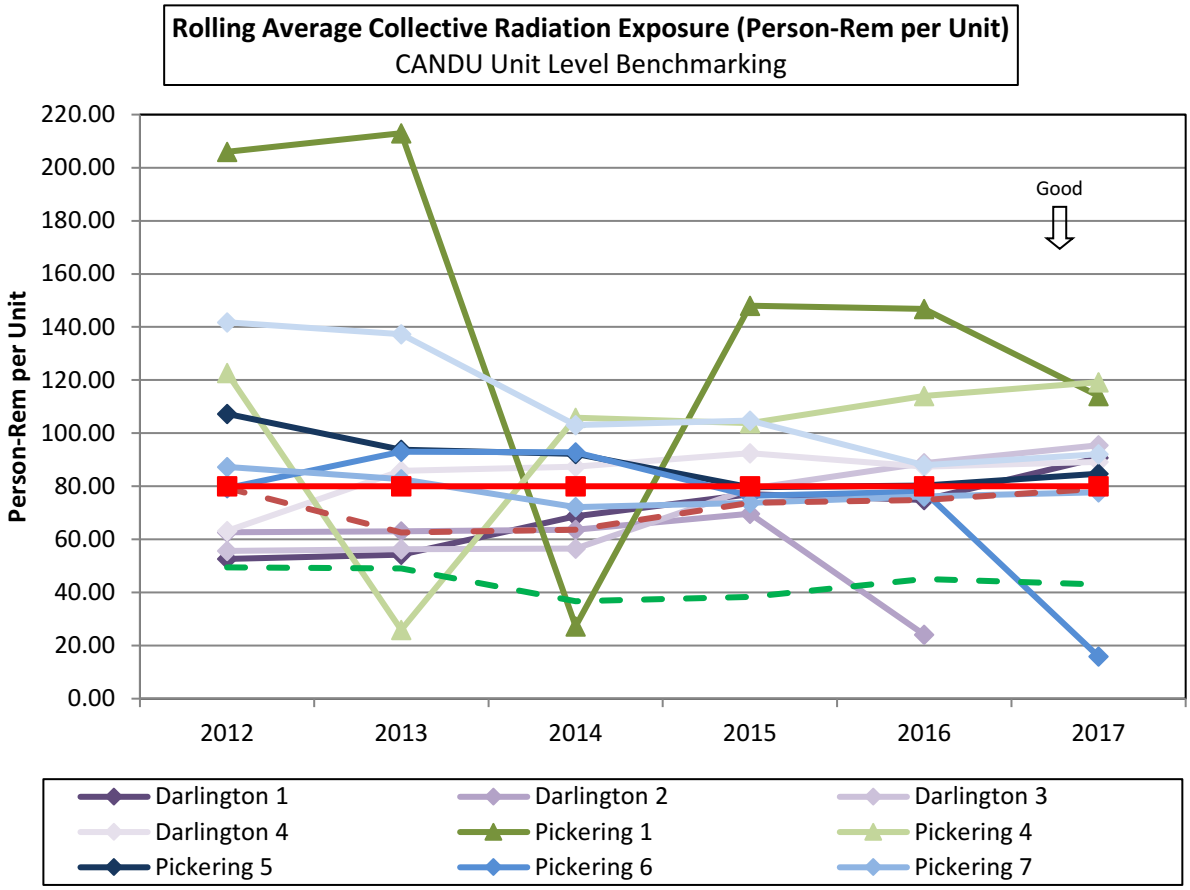
Rolling Average Collective Radiation Exposure





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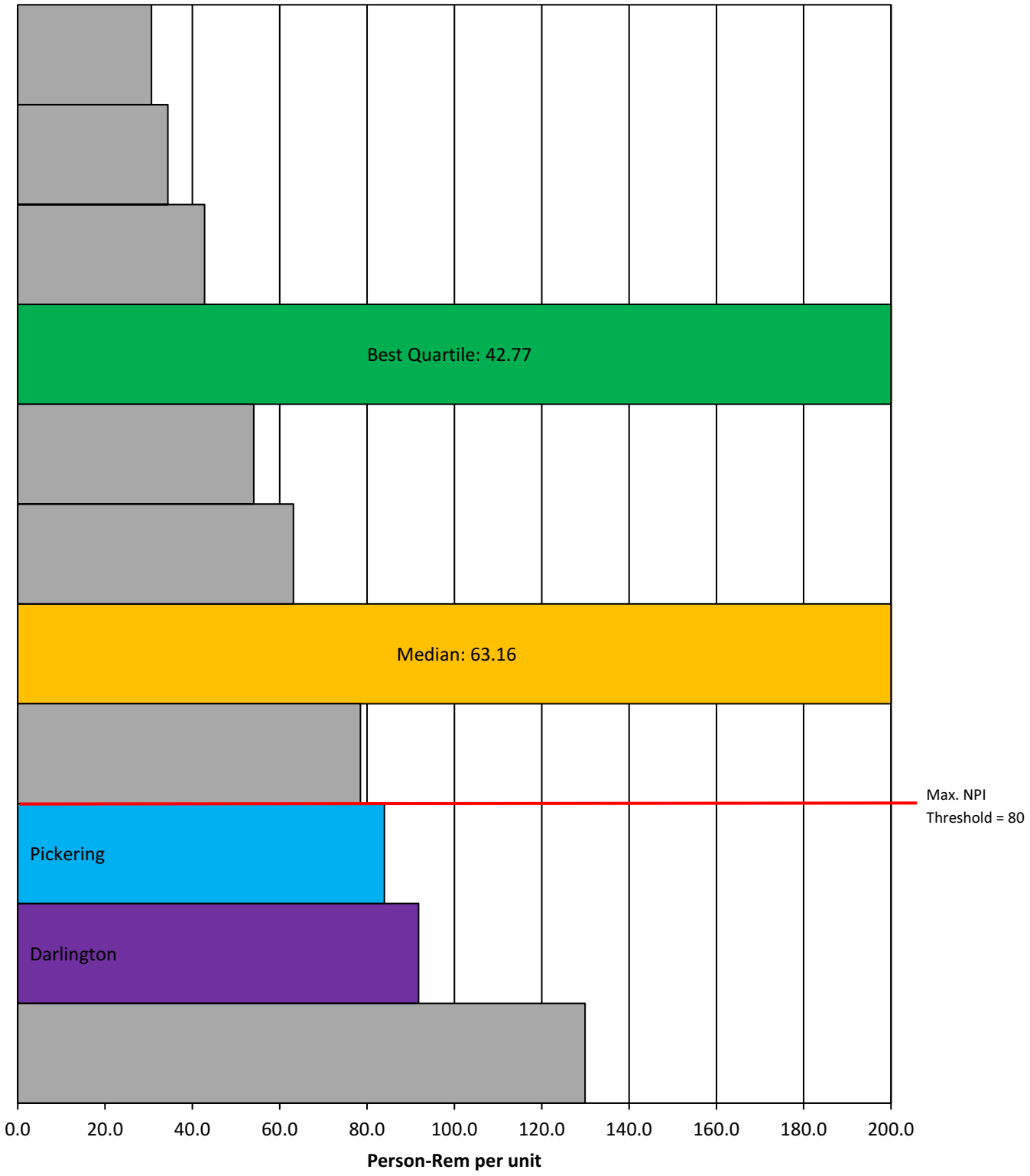
2017 Rolling Average Collective Radiation Exposure (Person-Rem per Unit) CANDU Plant Level Benchmarking



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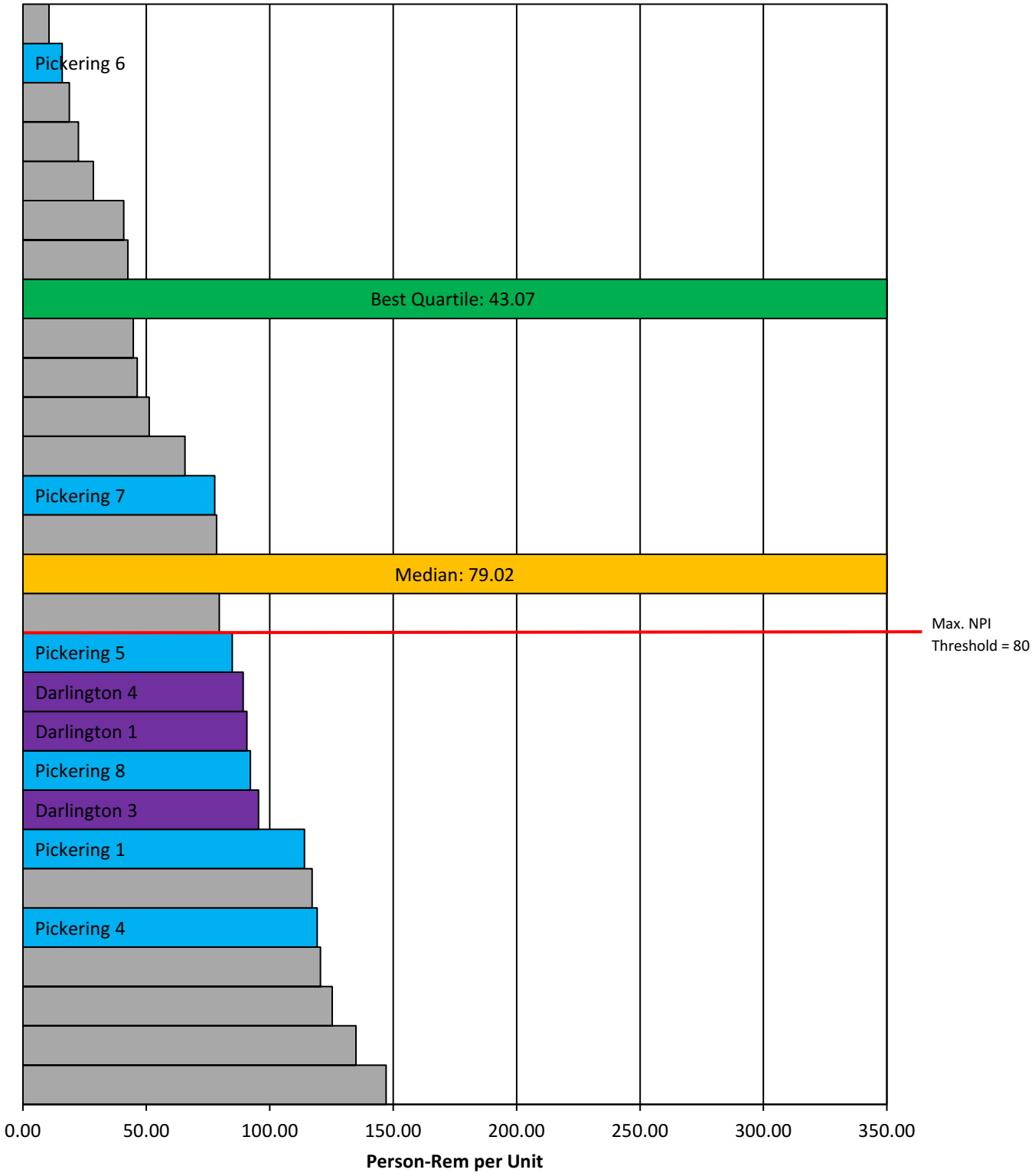
2017 Rolling Average Collective Radiation Exposure (Person-Rem per Unit) CANDU Unit Level Benchmarking



Observations – Rolling Average Collective Radiation Exposure (CANDU)

- Collective Radiation Exposure (CRE) is an industry composite indicator encompassing external and internal collective whole body radiation dose.
- The planned outage cycles for each unit at Pickering Nuclear Generating Station (PNGS) and Darlington Nuclear Generating Station (DNGS) are two-year and three-year, respectively. Rolling average CRE for each unit at both stations is derived based on these outage cycles.
- The number of planned outages, work scope and as well as outage duration significantly contributed to plant level and unit rolling average CRE performance. In general, Pickering has three major planned outages per year; Darlington averages 1.3 outages per year over the three year outage cycle.
- The CRE reflects total work scope performed during the year and it varies year by year. Therefore, the increase in the rolling average CRE may be attributable to larger work scope, not necessarily deficiencies in Radiation Protection program and dose reduction initiatives.
- Darlington Unit 2 began a long-term refurbishment outage on October 15, 2016. Dosage associated with Refurbishment activities has been excluded.
- The best quartile for CANDU Units in 2017 was lower than 2016, while the median value was higher than in 2016. The best quartile and median values (person-rem per unit) in 2017 vs. 2016 were 42.77 vs. 45.33 and 63.16 vs. 61.29, respectively. The benchmark value was 80 person-rem/unit. Full NPI Points were obtained at 80 person-rem/unit or less; no points were earned at 140 person-rem/unit or more.

2017 (Rolling 2 Year Average Pickering, Rolling 3 Year Average Darlington)

- At the plant level, PNGS dose performance value of 83.96 person-rem/unit was above the CANDU plant-level median value of 63.16 person-rem/unit.
- At the unit-level, dose performance for Units 6 and 7 were better than the maximum NPI points of 80.0 person-rem/unit as well as the median value. Unit 6 dose performance was also better than the best quartile value . The performance of other four units were worse than the maximum NPI points value of 80.0 person-rem/unit and the median value.
- In 2017, there were four planned outages (Units 1, 4, 5 and 8), four forced outages (one each on units 1 and 4, and two on Unit 7) and three sudden outages. In addition, Unit 7 planned outage was extended into 2017. It started in September 2016 and came back up on January 12, 2017.
- At the plant level, DNGS dose performance value of 91.8 person-rem/unit was above the CANDU plant-level median value of 63.16 person-rem/unit.
- At the unit-level, dose performance for units 1, 3 and 4 was above the maximum NPI points of 80.0 person-rem/unit, as well as the median value.

- In 2017, there was three planned outage and five forced outages at DNGS.

Trend

- Overall, Pickering plant-level performance has improved since 2012, approaching toward the maximum NPI value of 80 person-rem per unit. The rolling average is impacted by scope increases during outages and longer outage duration.

- Pickering unit-level performance has improved compared to last year, particularly Units 6 and 7. In 2016, both units were worse than the median value of 74.91 person-rem/unit. In 2017, their performances were better than the Median level.

- The Darlington plant-level dose has been increasing since 2012 due to plant aging, increased outage scope, including both planned and unplanned outages.

Factors Contributing to Performance Rolling Average Collective Radiation Exposure (CANDU)

- The following factors play a significant role in the CANDU reactors' CRE performance: planned outage scope and outage duration, tritiated ambient air in accessible and access controlled areas, effectiveness of mitigation measures and initiatives being implemented to reduce identified sources of radiological hazards, and human performance during execution of radiological tasks.

Best Practices

- The following list represents common practices that demonstrate continuous improvement and help maintain good CRE performance for CANDU type reactors:
    - Robust Site As Low as Reasonably Achievable (ALARA) Committee, chaired by Facility Senior Vice President.

- Reactor face shielding to reduce dose rates.
- Use of custom vault platforms to improve workflow.
- Teledosimetry.
- Process fluid detritiation.
- Use of Munters driers to enhance existing measures to minimize ambient airborne tritium levels.
- Optimization of Fuelling Machine purification using Ion Exchange with annual resin replacement and/or sub-micron filters.
- Sub-micron filtration in the Primary Heat Transport system.
- Use of independent radiological oversight for higher risk work to improve human performance during execution of radiological tasks.
- Daily accounting of dose, and work group focus on Radiation Protection Fundamentals.

- OPG establishes internal administrative dose limits to ensure that dose to each exposed individual is managed and maintained well below individual regulatory limits.
- Implementation of Dose Goal Reporting and Monitoring where individuals take ownership of their dose and strive to maintain ALARA exposure.

Initiatives

- OPG Nuclear fleet-wide and site specific initiatives have been implemented to incorporate the industry best practices noted above.
- Specific key initiatives are described below.

Pickering

- Implementation of Lanxess Dose Reducing Resin in Units 1 and 4, contributing to a 20% reduction in reactor face dose rates.
- Leveraging technology to avert dose using robotic equipment and remote monitoring of systems
- Deployment of CZT (Cadmium Zinc Telluride) Gamma Cameras and Gamma Spectrometers for enhanced source term monitoring.
- Source term reduction, including improvements to process fluid filtration and detritiation.
- Source term mitigation, including optimization of shielding for reactor face work, improvements to the shielding canopy for reactor face work, and dryer system health management for improved performance and reliability.
- Human performance involvement and oversight by Radiation Protection (RP) staff in respect of work with elevated radiation risk.
- Focus on dose to the individual through implementation of daily dose goals.
- Improving RP worker practices by driving individual accountability.
- Work Group specific dose reduction plans are being developed and implemented.

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- Use of Dynamic Learning Activities for focused program areas to permit mentoring of 'what excellence looks like' in realistic work environments with simulated radiological conditions.
- Implementation of an extensive network of remote reading radiation instrumentation and other tools to provide real-time information on radiological conditions and minimize time and therefore dose in radioactive work areas.
- Use of portable gamma spectrometers to improve source term characterization.

Darlington

- A reduction of coolant pH factors from 10.8 to 10.1 minimized crud migration from boilers to inlet feeders. The installation of sub micron heat transport filters effectively reduced the dose rates in the heat transport system and has contributed to the success of Darlington's external dose.
- Developed and implemented a reactor face shielding strategy to reduce dose while at the same time minimize the risks of personnel injury during shielding installation.
- Implemented an improved feeder ice jacket including the application of long handled tools for jacket installation and remote data acquisition.
- Effectively utilized Teledosimetry to reduce Radiation Protection Coordinator dose. Utilized Teledosimetry as a coaching tool to improve worker radiation protection practices and reduce dose.
- Tritium mitigation strategies have been developed and implemented to reduce airborne tritium concentrations inside containment and confinement rooms.
- Developed and implemented X-ray Fluorescence (XRF) spectroscopy to identify cobalt residues in an effort to reduce cobalt deposits in the moderator system during valve overhaul activities thus reducing overall radiation dose.
- Work Group specific dose reduction initiatives have been developed and implemented.

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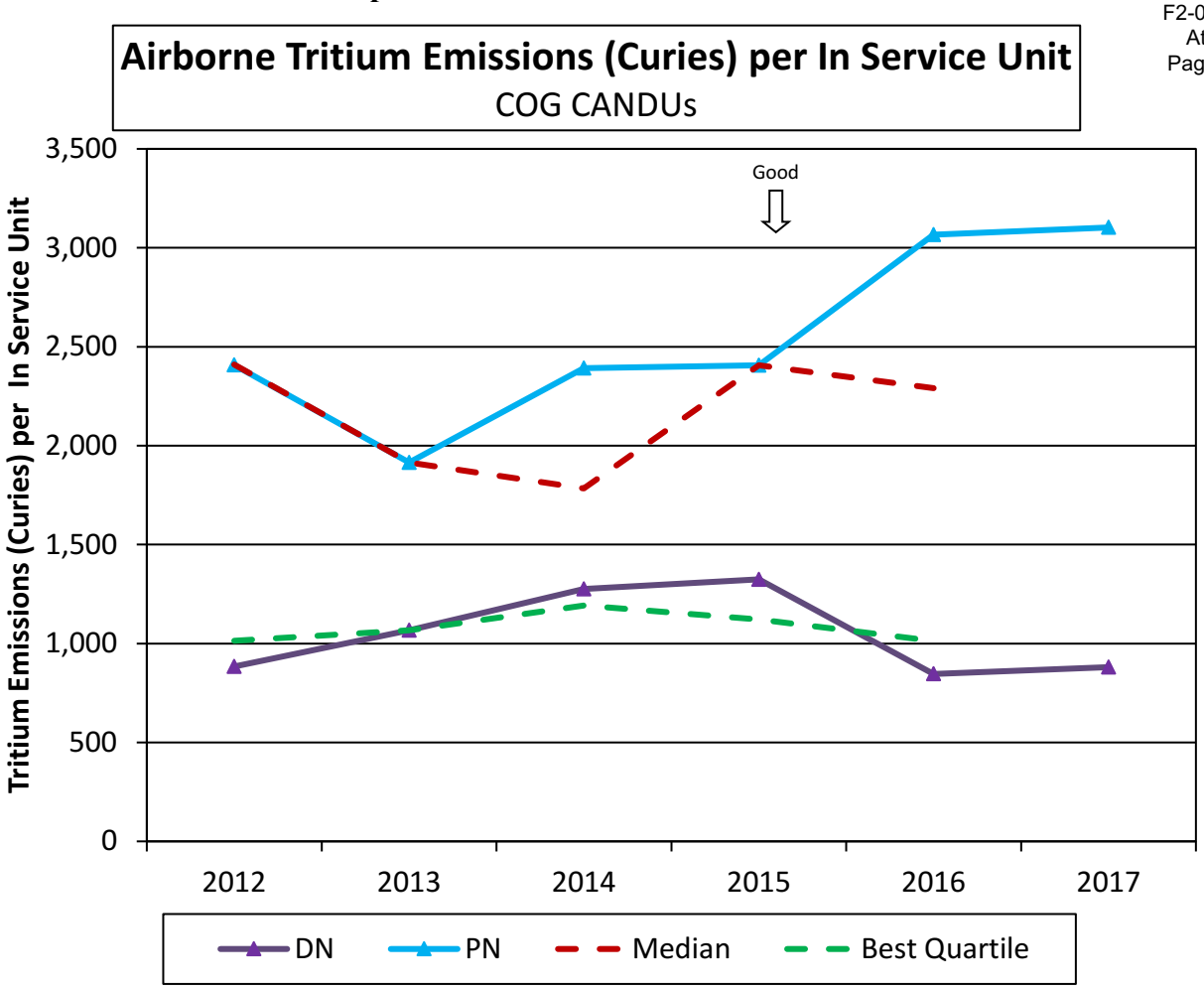
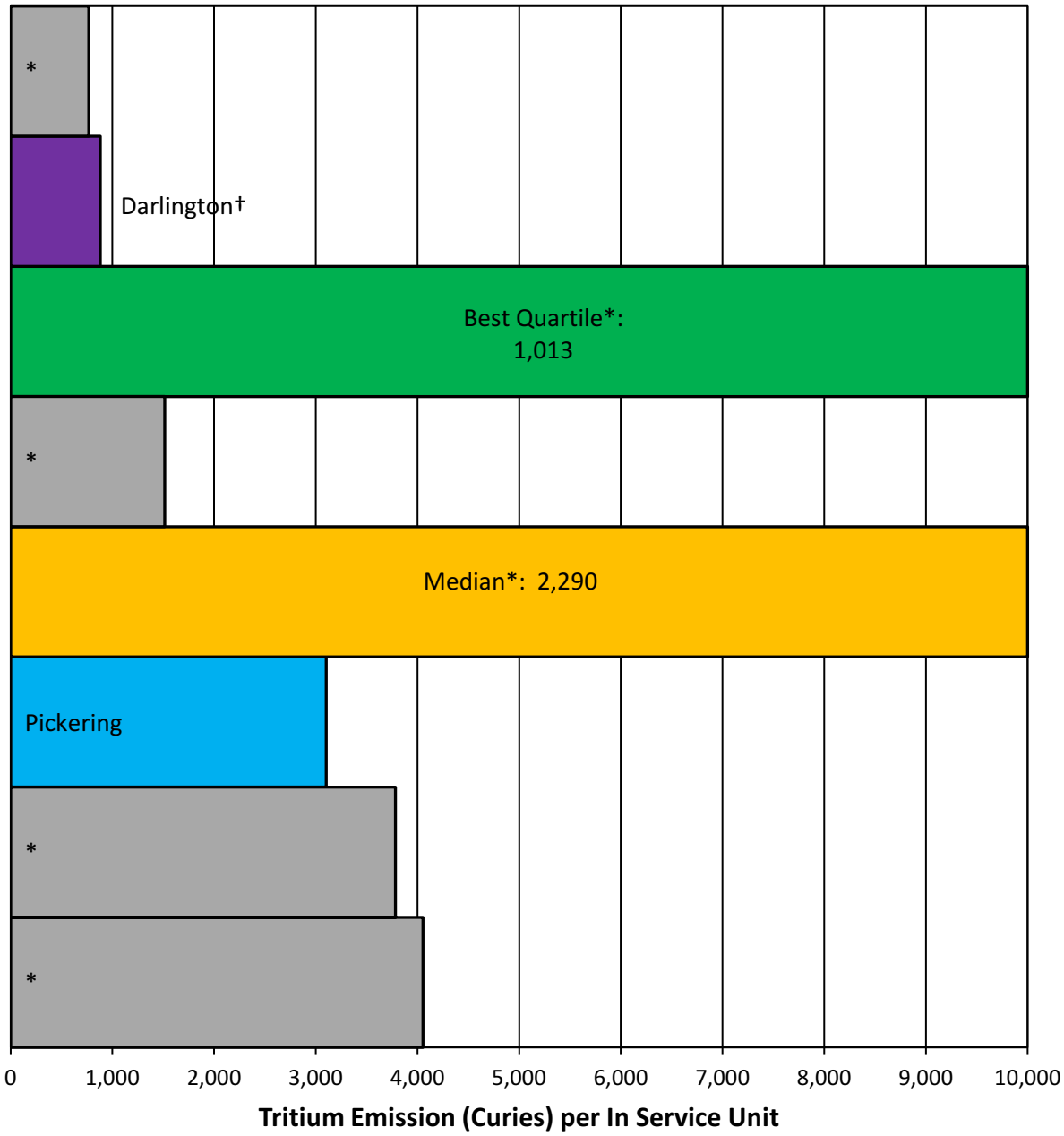
Airborne Tritium Emissions per In Service Unit



Notes:

- Median and Best Quartiles are plotted till 2016 as the 2017 results were unavailable at the time of benchmarking.
- Darlington values have retroactively modified as of 2013 to exclude Tritium Removal Facilities emissions consistent with COG benchmarking results.

2017 Airborne Tritium Emissions (Curies) per In Service Unit
COG CANDUs



* Industry data based on 2016 as it is the best available information at the time. Pickering and Darlington results are 2017.
†Excludes emissions from Tritium Removal Facility.
Notes:

- Two plants are excluded as one plant's 2016 data is unavailable and another plant was taken offline since December 31, 2015 for refurbishment.

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

2017 (Annual Value)

- The 2016 industry results collected by the CANDU Owners Group (COG) are included in this report as the most up-to-date figures available for benchmarking performance. As of 2013, tritium emissions from Tritium Removal Facility (TRF) are no longer included in COG benchmarking results.
- Airborne tritium emissions from OPG facilities for 2017 are compared per in service reactor unit. As such, emissions from Darlington Unit 2 are not included in this benchmarking report due to the shutdown of Unit 2 in October 2016 for refurbishment.
- Curies per in service unit at top quartile CANDU plants was 1,013 or lower.
- Darlington performed well at 875 Curies per in service unit placing in the best quartile of the in service units. Performance improved from second quartile in 2014 and 2015 to best quartile performance in 2016 and 2017.
- Pickering performance remained in the third quartile with 3,103 Ci per in service unit, higher than the industry median threshold of 2,290 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.
- Performance at Pickering has declined from 2013 to 2017. Increased emissions in 2016 and 2017 are primarily due to tritiated water in the Fuel Transfer Conveyor Tunnel being vented to monitored stacks, leaks and dryer performance issues. Management continues to focus on improving vapour recovery dryer performance to reduce emissions at Darlington.
- Performance at Darlington in 2017 is comparable to the improved performance in 2016, mainly due to increased focus on dryers and leaks repairs throughout the station.
- The industry trend line graph shows that industry best quartile performance for 2016 is essentially the same as it was in 2015, and has been relatively stable over the past six years.

Factors Contributing to Performance

- Key factors affecting performance at Darlington and Pickering include the following:
    - The presence of tritiated water in Pickering Fuel Transfer Conveyor Tunnel being vented to monitored stacks,
    - Leaks from various equipment or systems,
    - Less than adequate vapour recovery dryer performance,
    - Increased unit source term (e.g., higher moderator tritium concentrations),
    - Repair of coil leaks from Darlington Vault Air Conditioning Units (ACU) help to reduce humidification loadings, and dryer regeneration cycle time,
    - Start up of TRF after a planned outage help to reduce unit source term which subsequently reduced moderator curie concentration by 60% in 2017.

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

- Station 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 environmental benchmarking of participating CANDU stations to determine best environmental practices.

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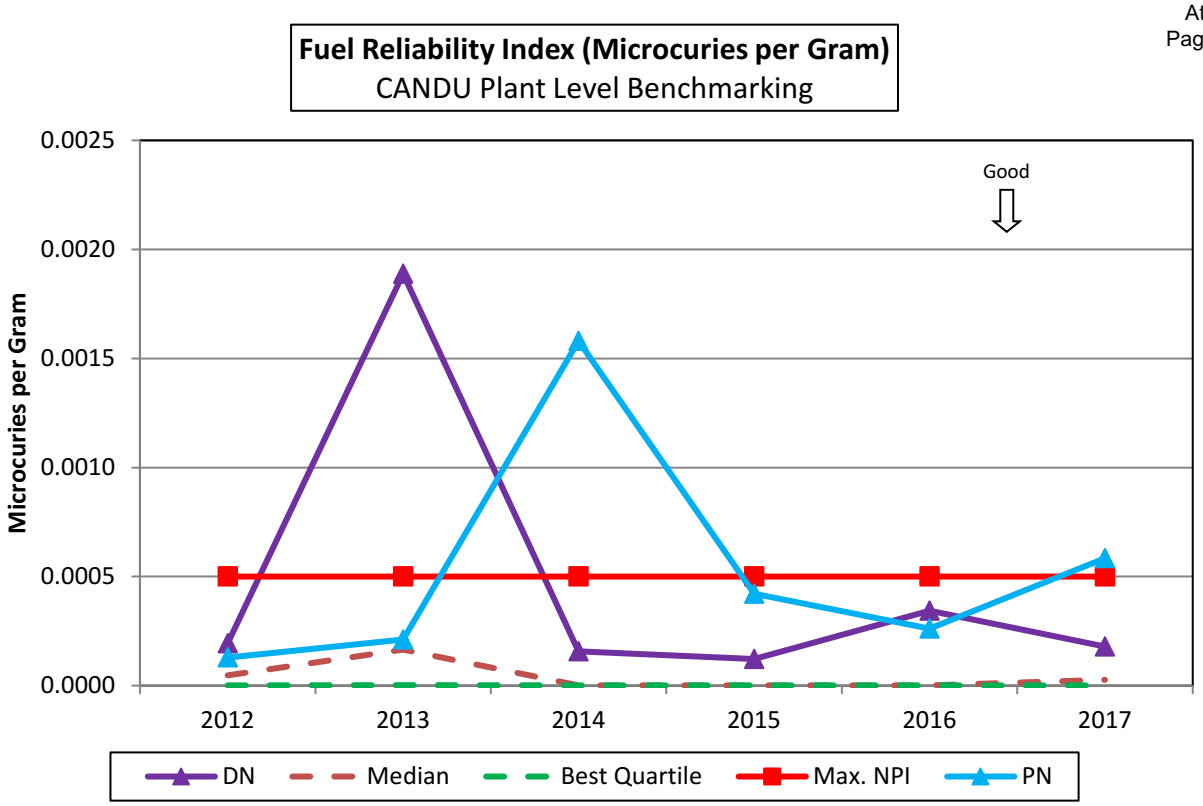
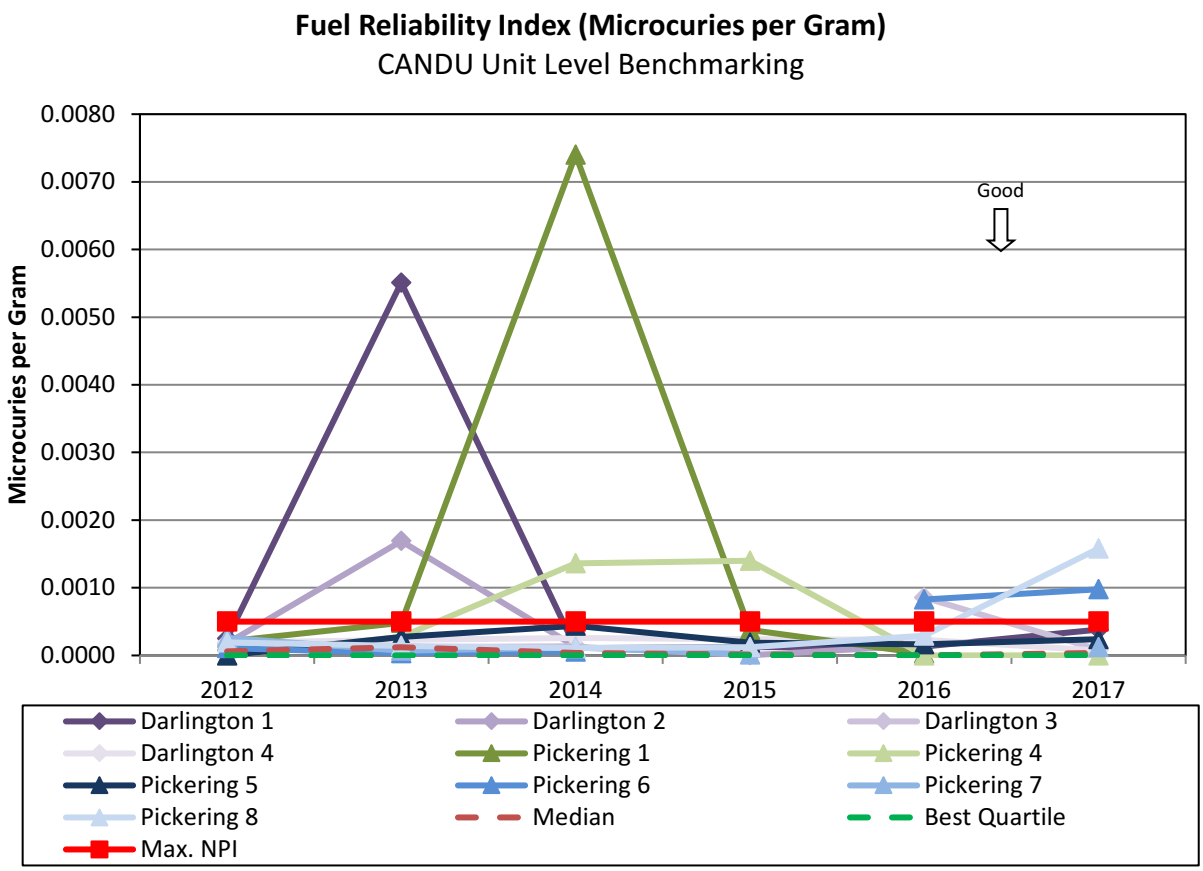
Fuel Reliability Index





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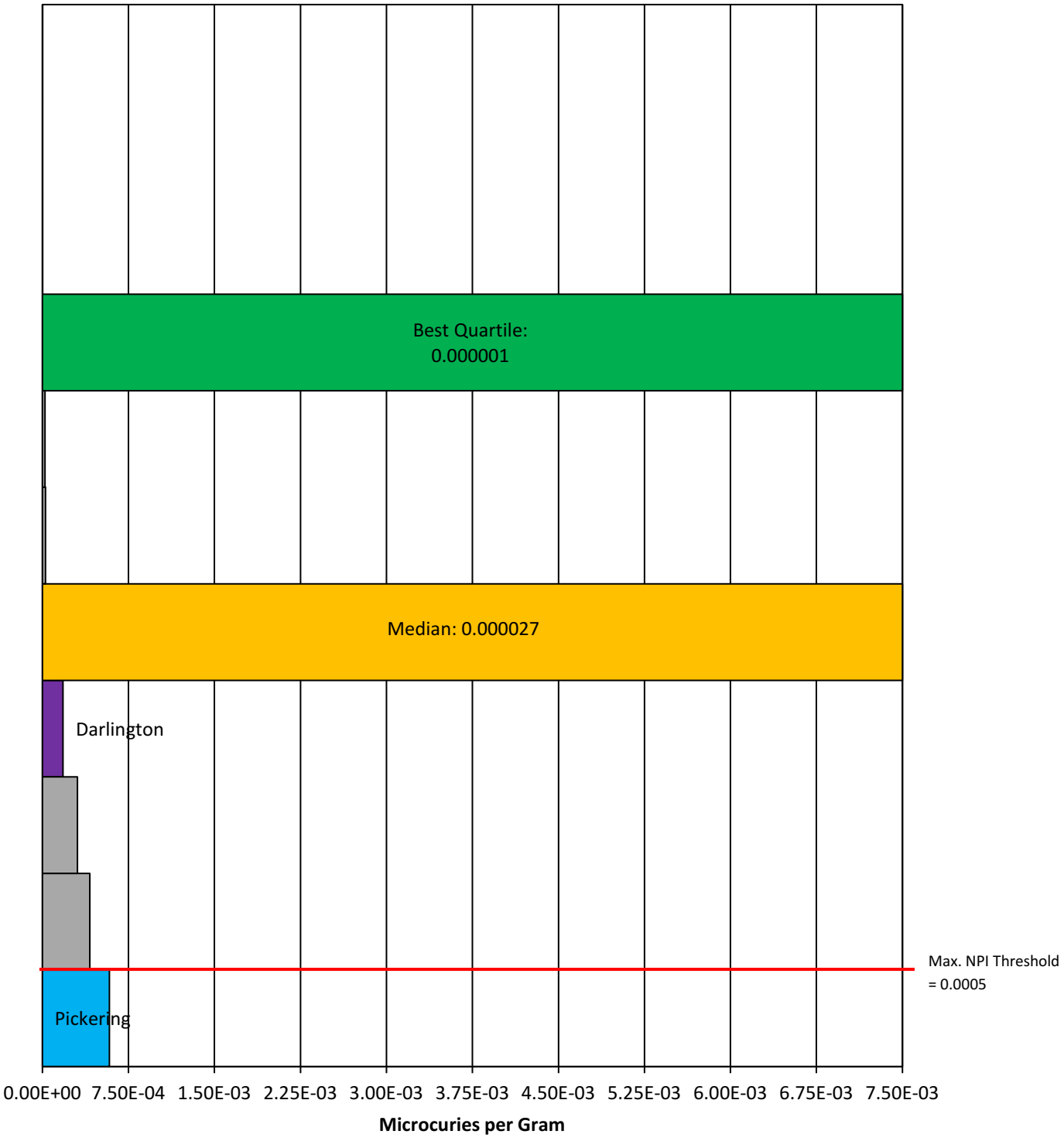
2017 Fuel Reliability Index (Microcuries per Gram)
CANDU Plant Level Benchmarking



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Observations – Fuel Reliability Index (CANDU - FRI)

2017 (Most Recent Operating Quarter)

- The best quartile and median values for Fuel Reliability Index (FRI) performance for CANDU plants were 0.000001 µCi/g and 0.000027 µCi/g, respectively. For individual CANDU units, the best quartile was 0.000001 µCi/g and the median value was 0.000036 µCi/g.
- The Pickering plant level FRI performance at 0.000584 µCi/g in 2017 was worse than the median value threshold.
- Darlington achieved maximum NPI points in 2017 and its performance improved from 2016 (0.00179 µCi/g vs 0.000343 µCi/g) however, it was below the median value threshold.
- Post-discharge fuel inspections for Pickering indicated that the overall condition of fuel inspected was acceptable and consistent with previous years. Fuel inspections for Pickering confirmed two fuel defects in 2017. No fuel issues of significance arose at Pickering in 2017.
  Post-discharge fuel inspections for Darlington indicated that the overall condition of fuel inspected was acceptable and consistent with previous years. Fuel inspections for Darlington confirmed one fuel defect that occurred in 2016 and was inspected in 2017. One suspect fuel defect occurred in Unit 3 in DNGS in 2017.

Trend

- The best quartile for CANDU plants remained consistent at 0.000001 from 2012. The median values for CANDU plants has generally improved from 2010 and remained at 0.000001 since 2014 with an increase to 0.000027 in 2017.
- The Pickering station FRI performance has improved compared to 2014 due to the reduction in fuel defect incidents.
- The Darlington station FRI performance has improved compared to 2013. The Unit 3 reactor had one suspect fuel defect in 2017. The other units were defect free for 2017.

Factors Contributing to Performance

Actions that have been taken at Pickering to improve FRI performance include:

- Developing a fuel defect guideline,
- Increasing scope of Heat Transport System (HTS) grab sampling and analysis,
- Assessing and comparing Units 1, 4 and 5 to 8 power ramps,
- Assessing impact of adjuster burn-out during operation,
- Assessing impact of pressure tube creep on fuel performance,
- Improving the methods of surveillance and elimination of the possibility of foreign materials entrance into the HTS due to Fuel Handling and Outage practices,

- Fuel bundle manufacturing assessment,
- 3rd party examinations of unirradiated Pickering fuel bundles,
- Irradiated fuel inspections and examinations,
- Improving capability of detecting the defected fuel bundles during the discharge from the fuelling machines, and
- Improving the capability of the in-bay inspection of the suspected fuel bundles to be defected.

Darlington had only one suspect fuel defect in 2017. The steps taken that have led to improved FRI performance and prevent the potential of fuel defects are the following:

- New fuel with tighter tolerances for mass is currently being used,
- Completed inspections in East Fuelling Facility Auxiliary Area,
- 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, and
- Projects in progress on Gaseous Fission Products (GFP) and feeder scanners to improve ability to locate defects on power and during outages.

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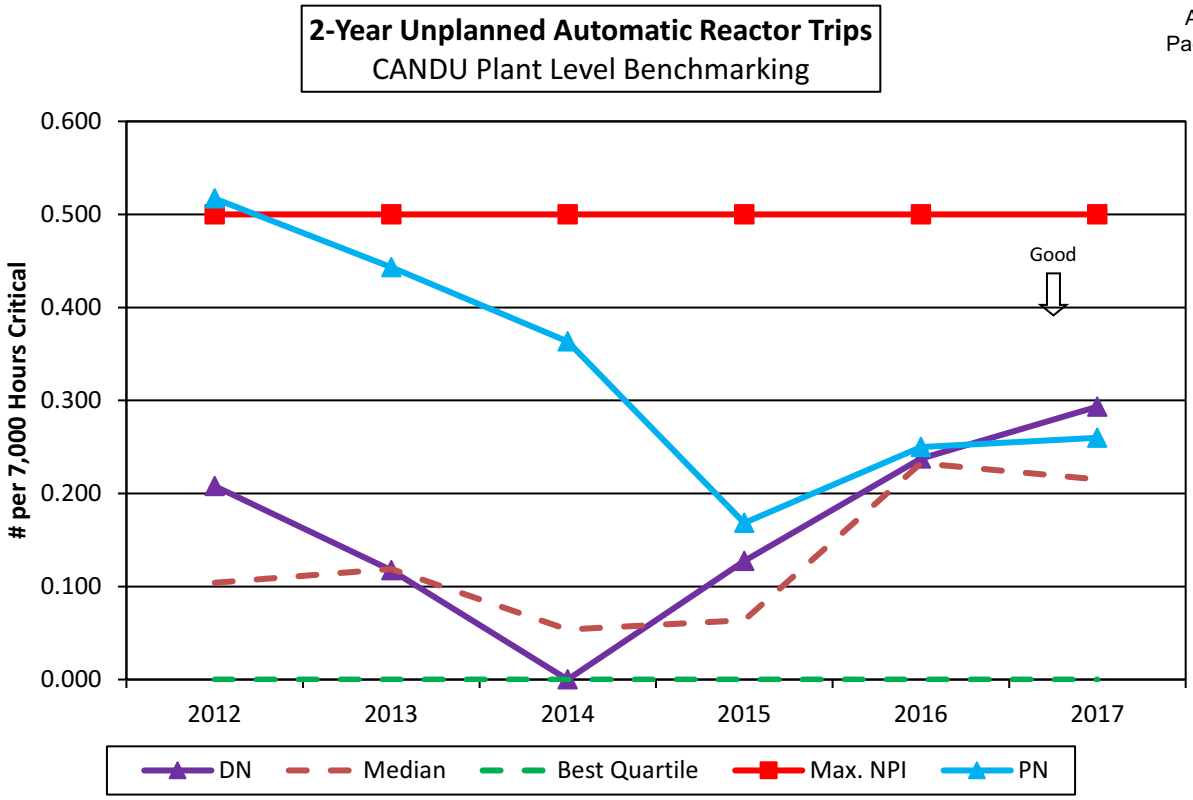
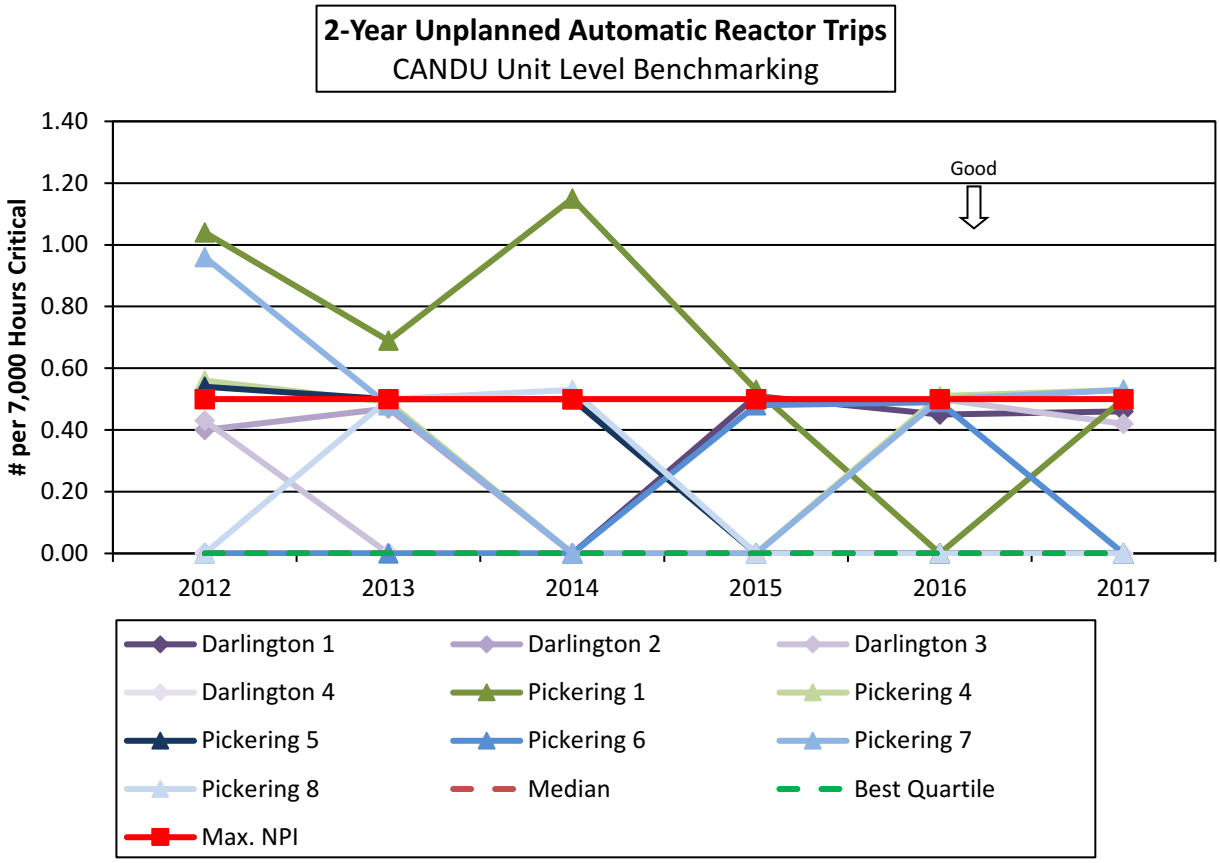
2-Year Unplanned Automatic Reactor Trips





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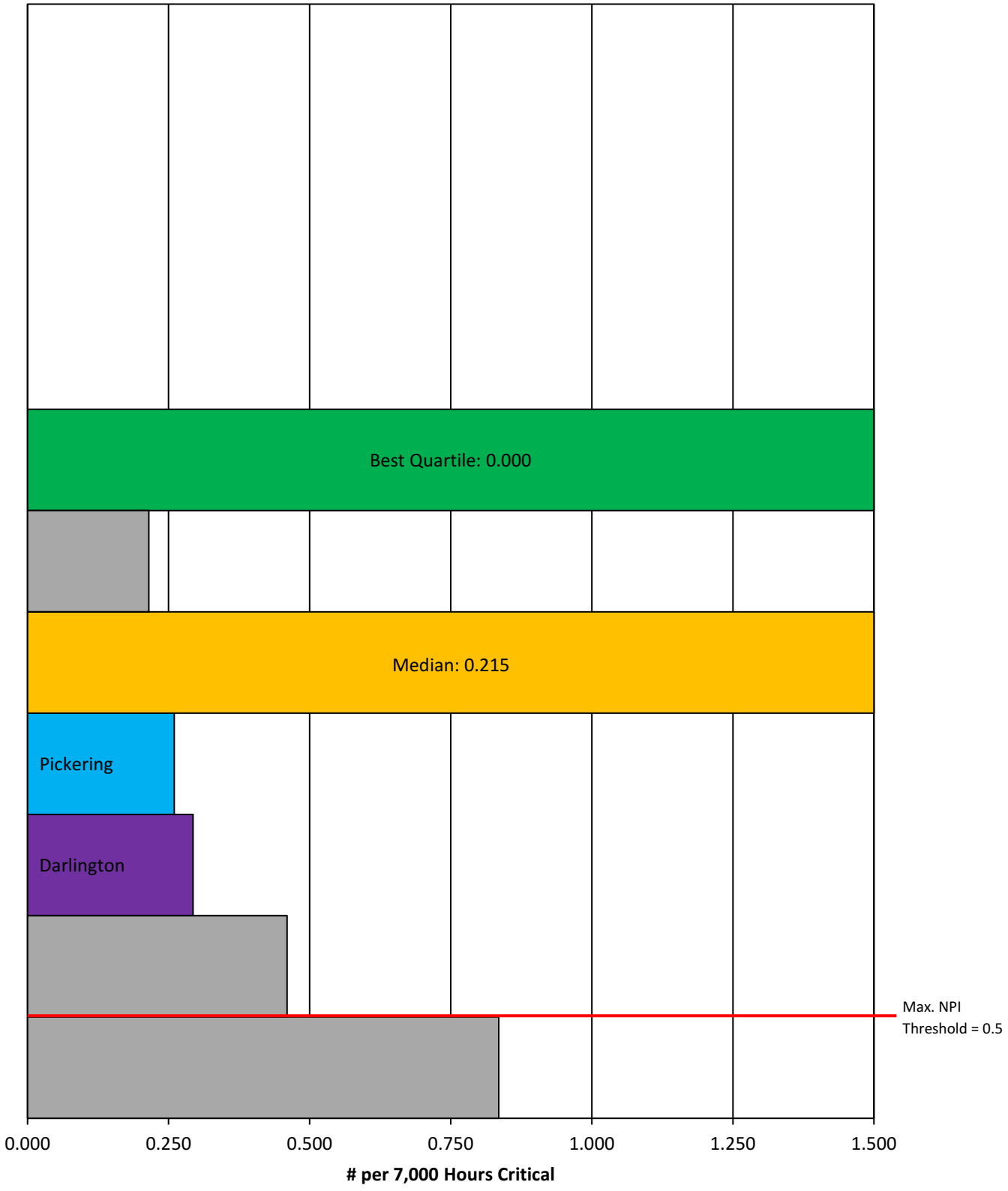
2017 2-Year Unplanned Automatic Reactor Trips
CANDU Plant Level Benchmarking



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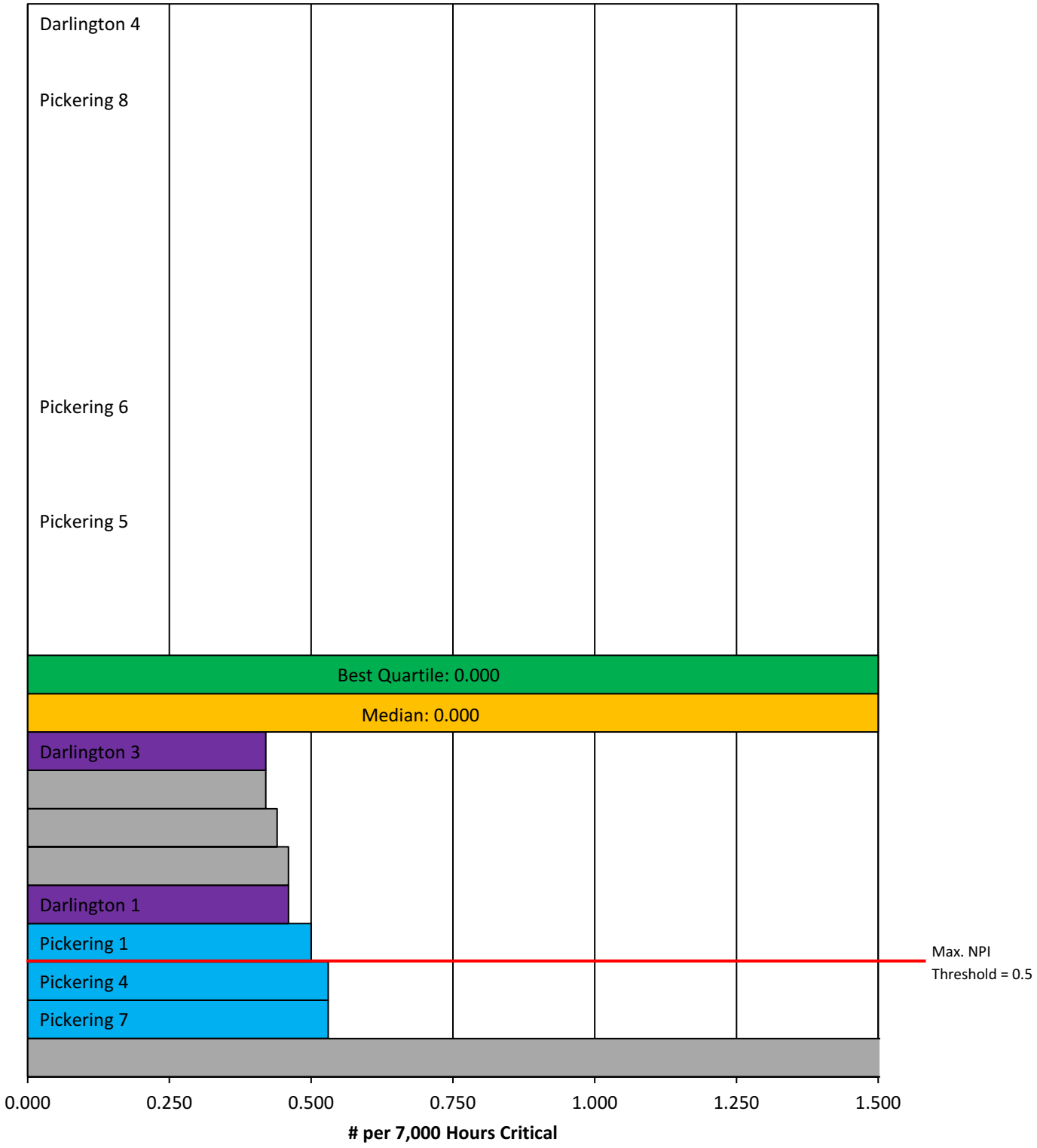
2017 2-Year Unplanned Automatic Reactor Trips
CANDU Unit Level Benchmarking



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

2017 (2-Year Rolling Average)

- The 2-year rolling average unplanned automatic reactor trip best quartile for CANDU plants was zero with a median of 0.22. For individual CANDU units, the best quartile and median values for unplanned reactor trip were zero.
- At the plant level, Pickering's trip rate of 0.26 was better than the maximum NPI threshold value of 0.50. On an individual unit basis, Units 5, 6, and 8 with trip rate of zero, were at best quartile. Unit 1 with rate of 0.50, Unit 4 and Unit 7 with trip rate of 0.53 each, were worse than the third quartile threshold of 0.44 and significantly better than the maximum value of 1.67.
- At the plant level Darlington's trip rate of 0.29 was below the maximum NPI threshold value of 0.50. On an individual unit basis, Unit 4, with a trip rate of zero, performed at the best quartile level. Unit 1, with a trip rate of 0.46, was worse than the third quartile threshold of 0.44, but significantly better than the maximum value of 1.67. Unit 3, with trip rate of 0.42, which was slightly better than the third quartile threshold of 0.44, is significantly better than the maximum value of 1.67. Unit 2 performance is excluded due to refurbishment.

Trend

- The unplanned automatic reactor trip best quartile for CANDU plants has been zero since 2012. The median value declined in 2013, improved in 2014, and then declined in 2015 and 2016. The median value slightly improved in 2017 compared to 2016. On an individual unit basis, the industry best quartile and median has remained at zero since 2012.
- At the plant level, Pickering station performance improved each year from 2012, but declined in 2016 and 2017.
- At the plant level, Darlington station performance improved from 2012, achieving the best result of a zero trip rate in 2014, but decreased each year from 2015 to 2017.

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Factors Contributing to Performance

- Key performance drivers for this metric include: general equipment reliability, material condition, and human performance.
- In 2017, Pickering had 1 unplanned automatic reactor trip (1 on Unit 1).
- In 2017, Darlington had 1 unplanned automatic reactor trip (1 on Unit 1).
- On-going due diligence is undertaken by Station Operations, Engineering, and Maintenance organizations. Operating Experience (OPEX) from each event has been shared at Pickering, Darlington and at external meetings. Where necessary, training material has been revised based on OPEX. To improve human performance, technical procedures have been revised. To improve equipment reliability, where possible, like-for-like parts replacement has taken place. System health teams are involved in obsolescence issues.

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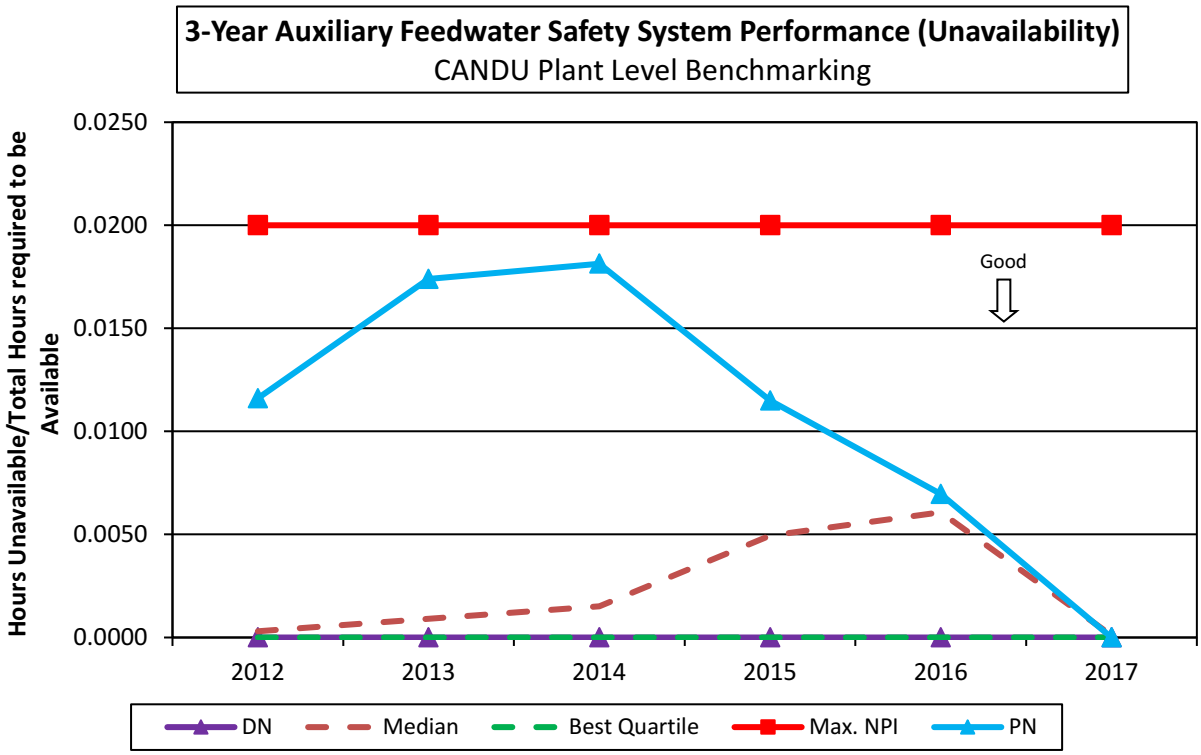
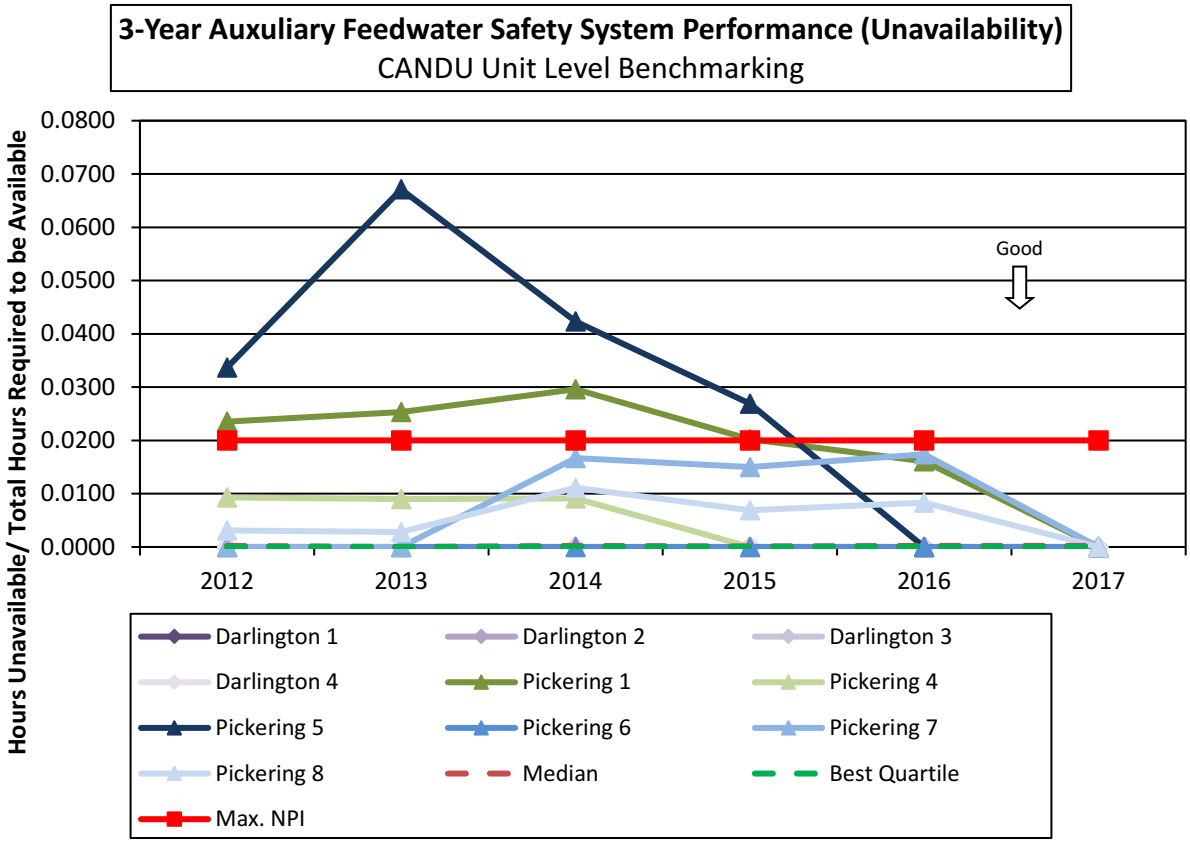
3-Year Auxiliary Feedwater Safety System Unavailability





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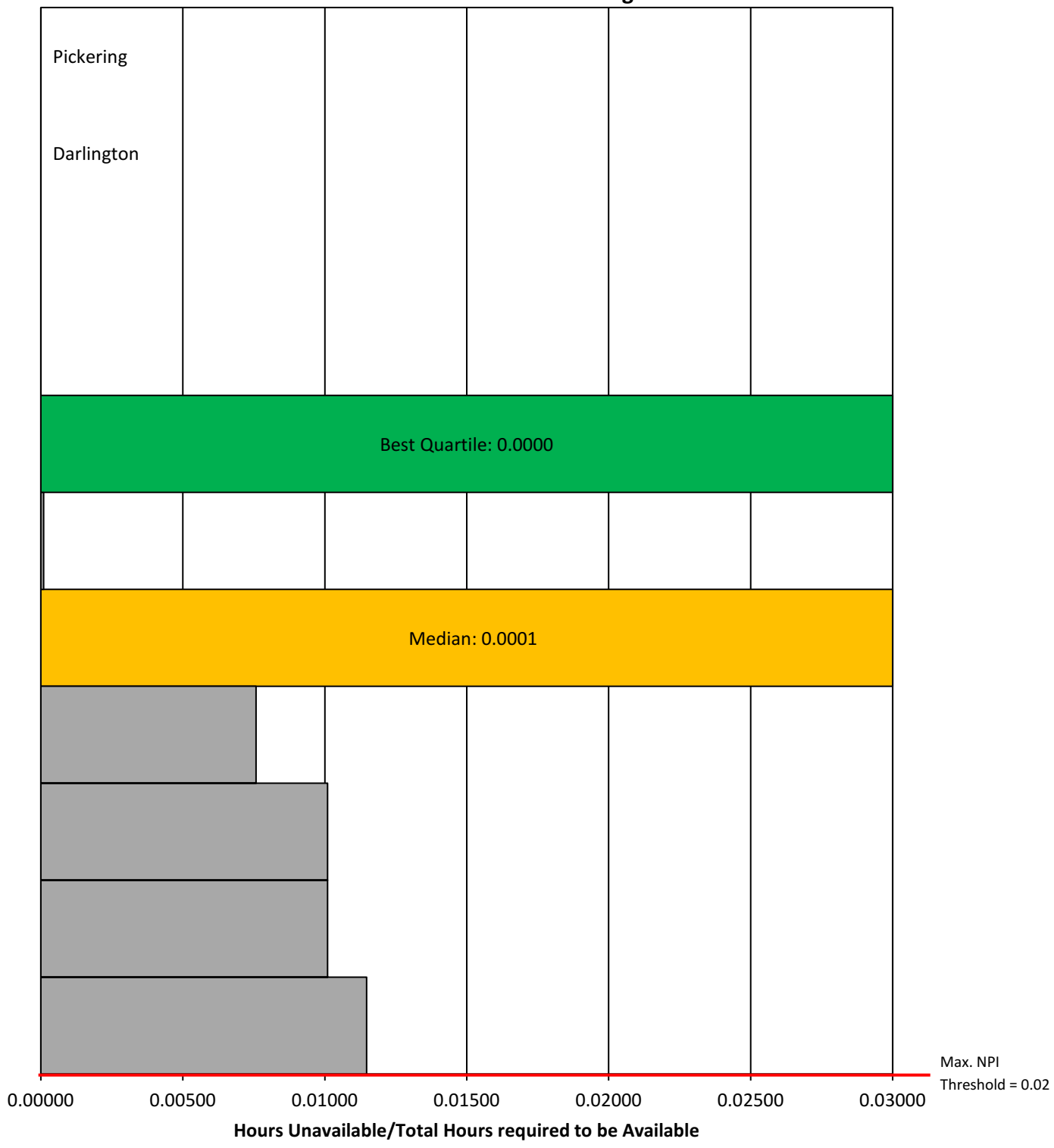
2017 3-Year Auxiliary Feedwater Safety System Performance (Unavailability) CANDU PlantLevel Benchmarking



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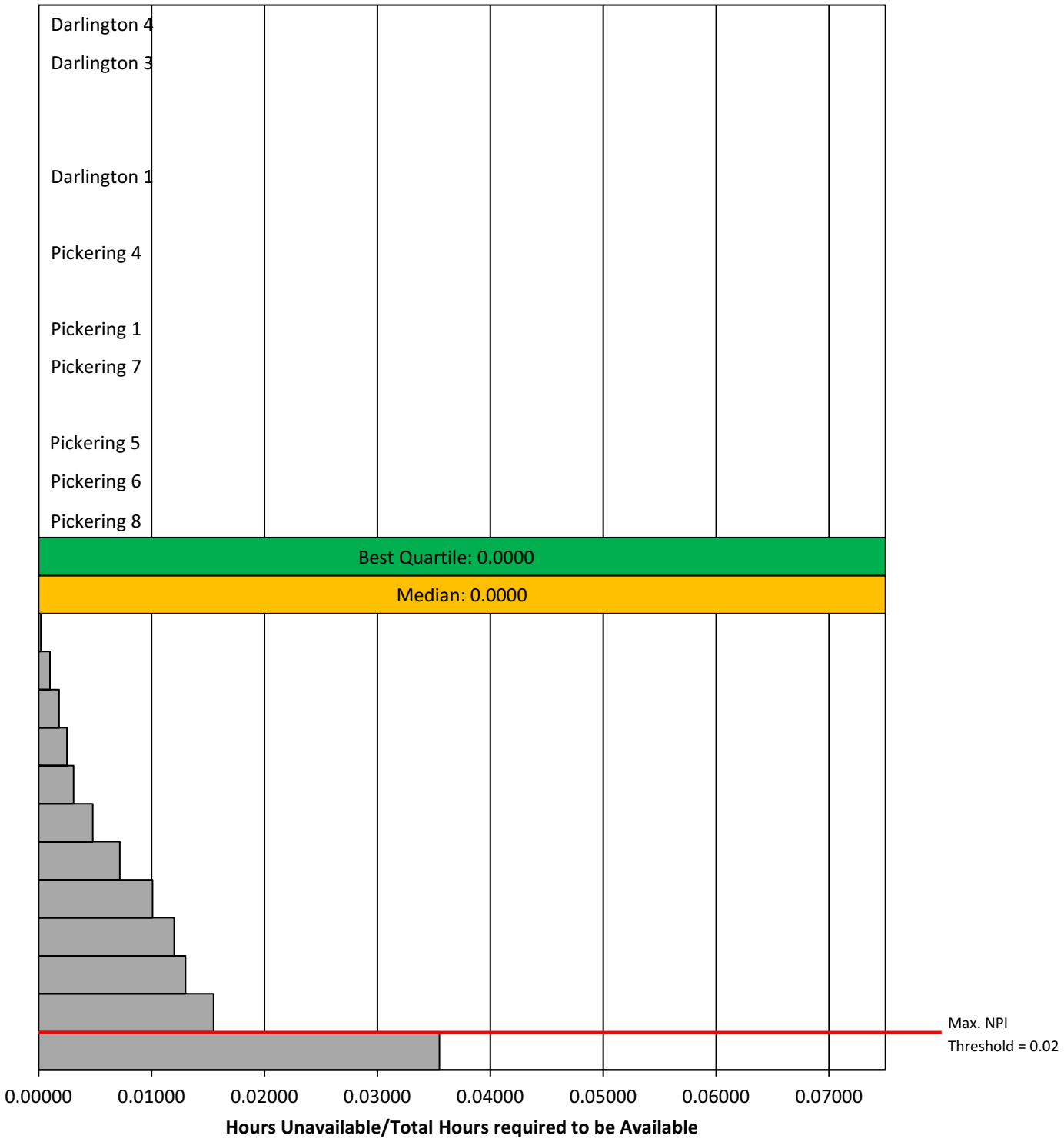
2017 3-Year Auxiliary Feedwater Safety System Performance (Unavailability) CANDU Unit Level Benchmarking



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Observations – 3-Year Auxiliary Feedwater System (CANDU)

2017 (3-Year Rolling Average)

- Auxiliary feedwater (AFW) safety system performance at best quartile for CANDU plants was zero with a median value of 0.0001. For individual CANDU units, the best quartile and median values were zero.
- Pickering station achieved best quartile performance of zero unavailability at both the station and unit levels in 2017.
- Darlington station achieved best quartile performance of zero unavailability at both the station and unit levels in 2017. Performance of Unit 2 at Darlington is excluded due to refurbishment.

Trend

- The 3-Year Auxiliary Feedwater unavailability best quartile performance of CANDU plants maintained zero unavailability from 2012 to 2017. The plant level industry median value has fluctuated slightly over the review period but has remained below the NPI maximum threshold. At the unit level, the industry best quartile has remained at zero over the review period and the median value at or close to zero over the review period.
- At the plant level, Pickering station performance has improved since 2014 and achieved zero unavailability in 2017.
- Darlington station and unit performance has been at zero unavailability since 2012.

Factors Contributing to Performance

- Key performance drivers for this metric include: general equipment reliability, material condition, and human performance.

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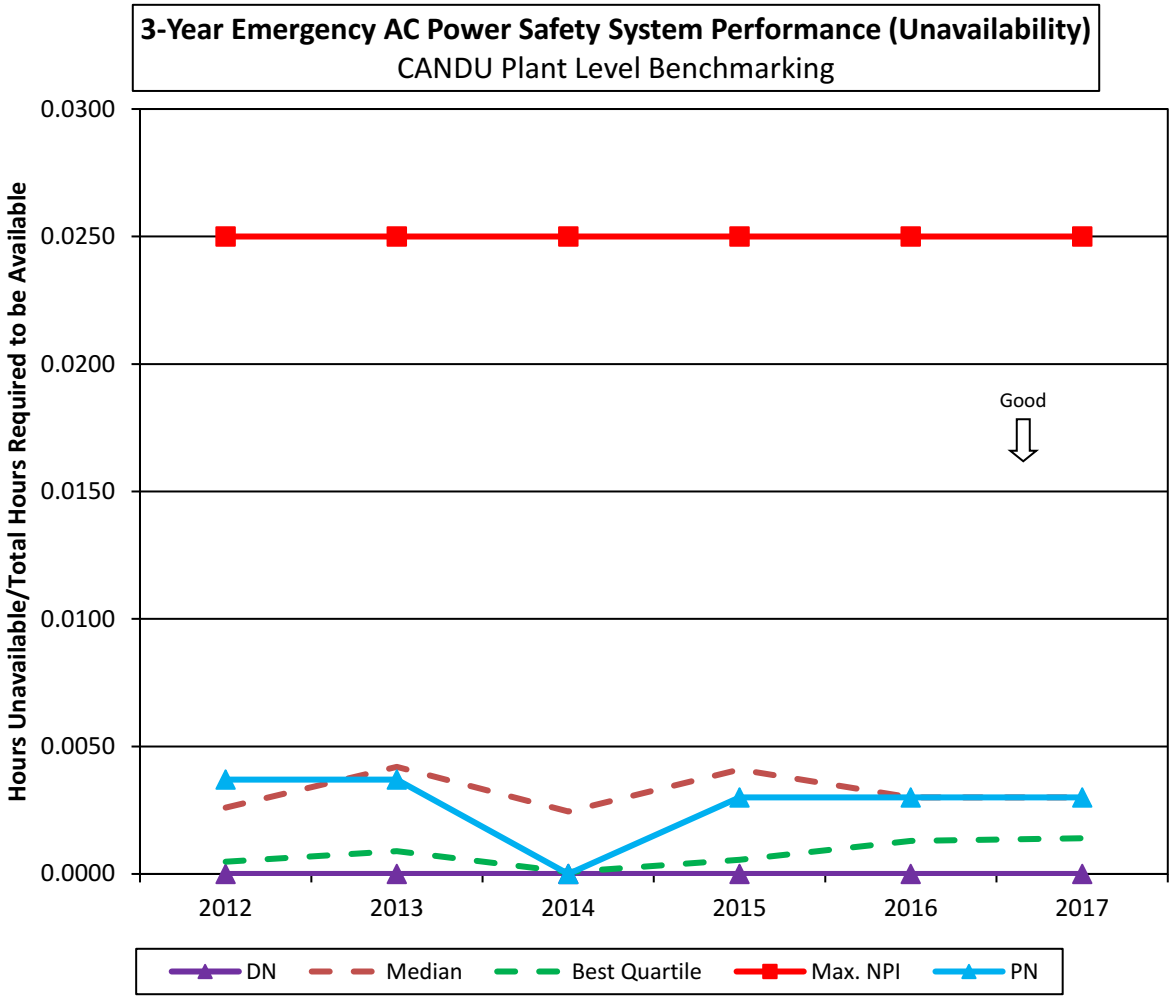
3-Year Emergency AC Power Safety Unavailability



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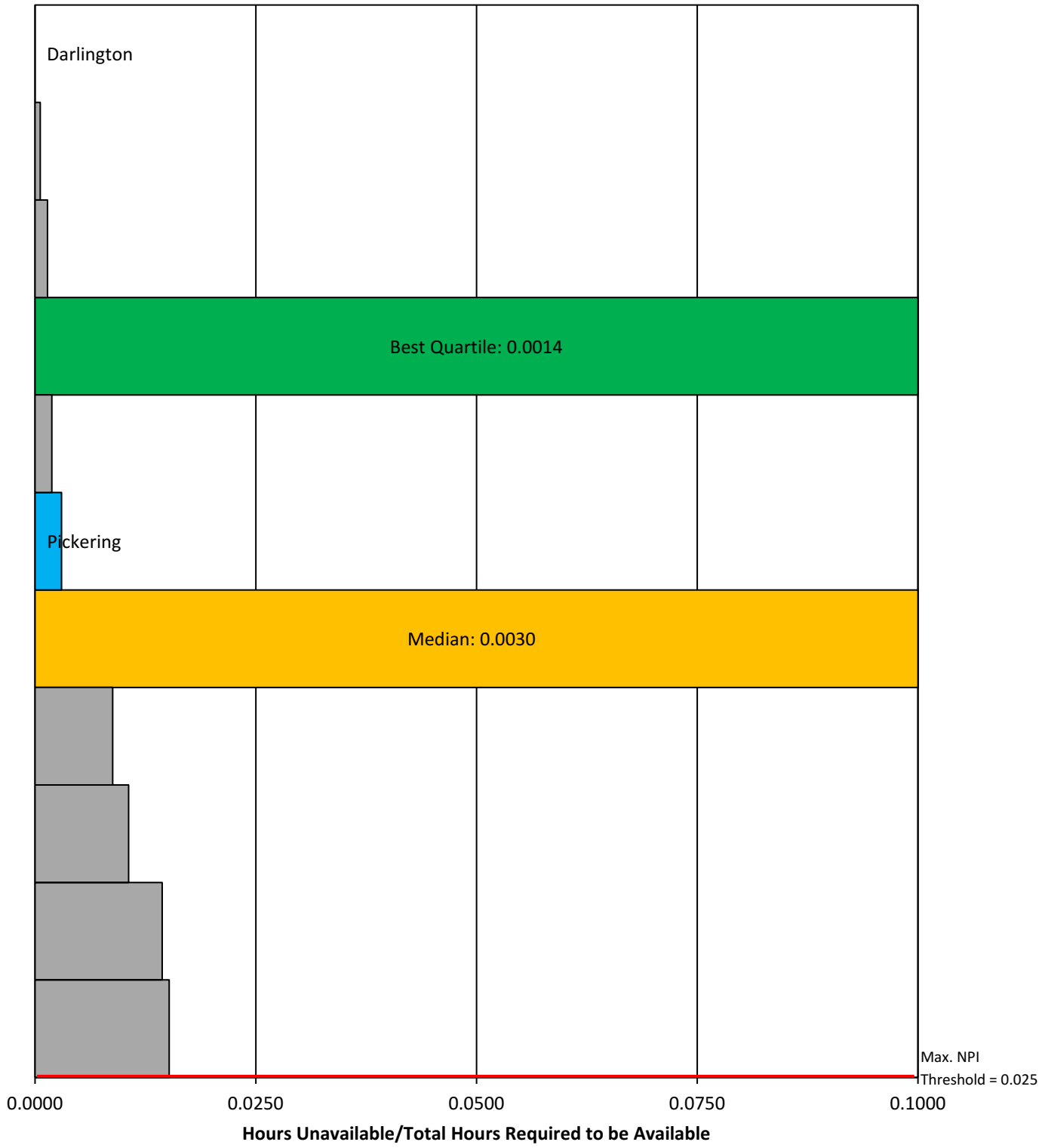
2017 3-Year Emergency AC Power Safety System Performance (Unavailability)
CANDU Plant Level Benchmarking



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

2017 (3-Year Rolling Average)

- 3-Year Emergency AC Power Safety System performance at best quartile for CANDU plants was 0.0014. The industry median value was 0.0030.
- At the plant level, Pickering station, with an unavailability of 0.003, is below the maximum NPI threshold of 0.025.
- Darlington was one of the best performing stations in the CANDU peer group, achieving zero unavailability, best quartile performance, and maximum NPI results.

Trend

- The 3-year Emergency AC Power Safety System unavailability industry best quartile for CANDU plants declined from 2012 to 2013 and reached the lowest level of the review period in 2014. Then it declined each year from 2015 to 2017. The industry median value declined from 2012 to 2013 and improved in 2014, followed by a decline in 2015. Performance improved in 2016 and remained unchanged in 2017.
- Pickering station performance has improved compared to 2012 and has remained consistent since 2015.
- Darlington station performance achieved zero unavailability over the review period of 2012 to 2017.

Factors Contributing to Performance

- Key performance drivers for this metric include: general equipment reliability, material condition, and human performance.

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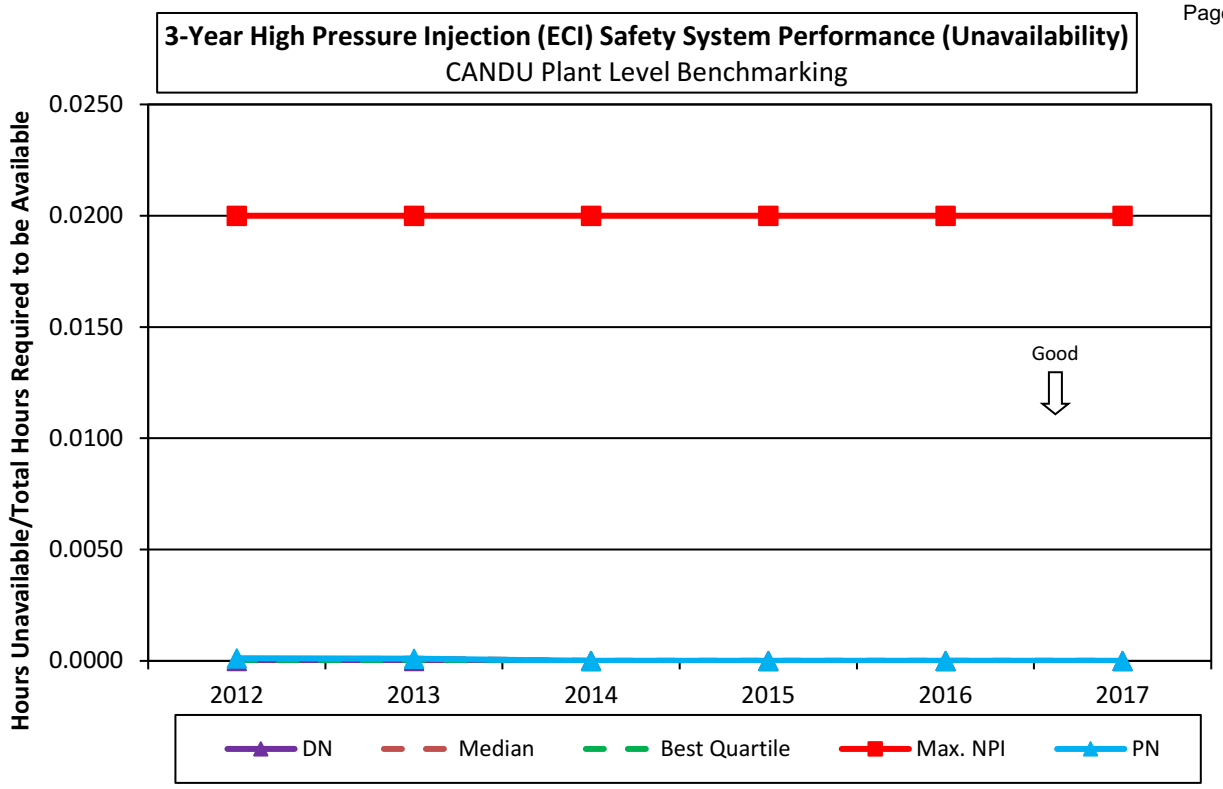
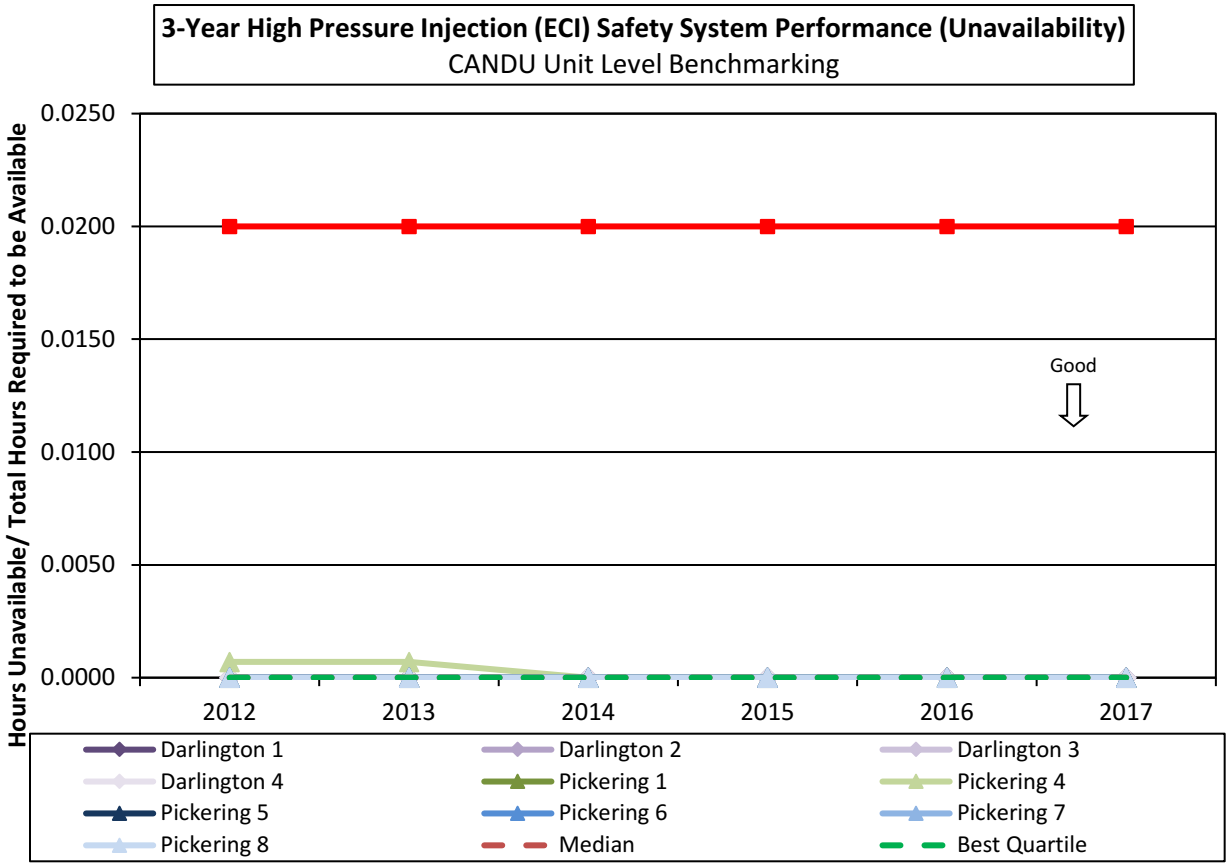
3-Year High Pressure Safety Injection





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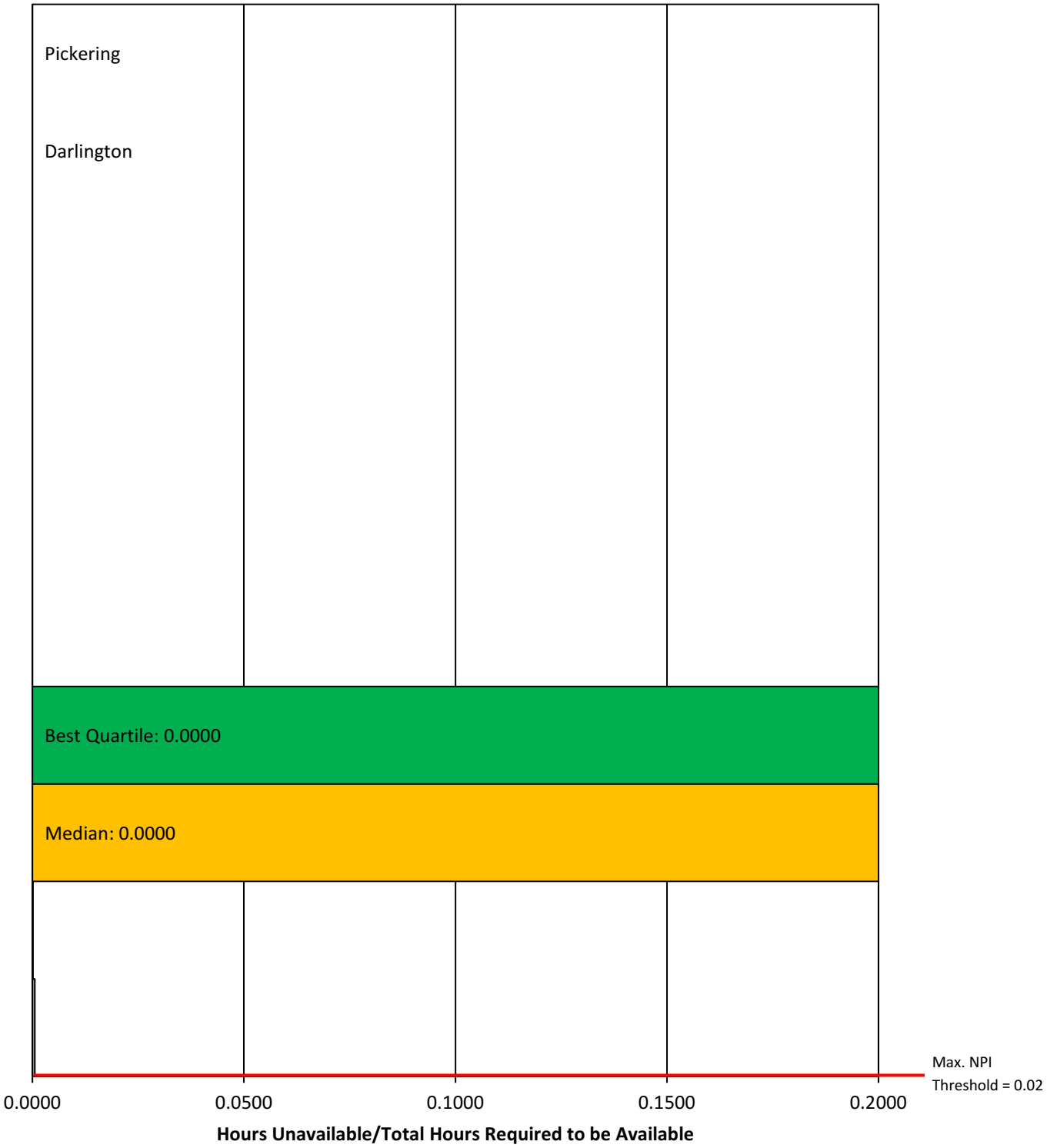
2017 3-Year High Pressure Injection (ECI) Safety System Performance (Unavailability)
CANDU Plant Level Benchmarking



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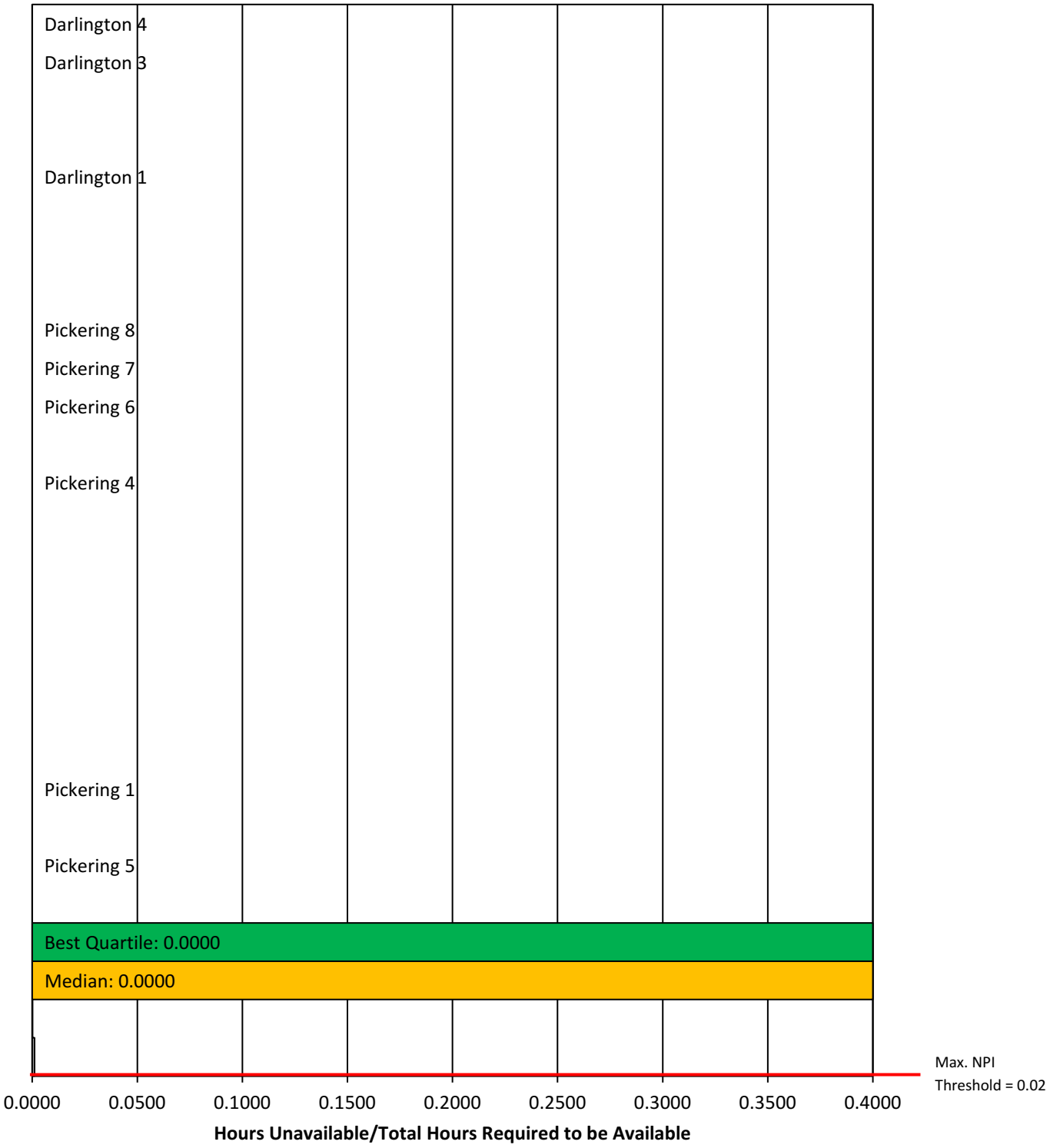
2017 3-Year High Pressure Injection (ECI) Safety System Performance (Unavailability)
CANDU Unit Level Benchmarking



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

2017 (3-Year Rolling Average)

- The best quartile and median values for the 3-Year High Pressure Safety Injection Unavailability performance for CANDU plants were zero. For individual CANDU units, both the best quartile and median value were zero.
- Pickering achieved best quartile performance of zero unavailability at both the station and unit levels in 2017.
- Darlington achieved best quartile performance of zero unavailability at both the station and unit levels in 2017. Performance of Unit 2 is excluded due to refurbishment.

Trend

- The 3-Year High Pressure Safety Injection unavailability best quartile performance of CANDU plants has been zero since 2012. The plant level industry median performance was the same in 2012 and 2013 and achieved zero unavailability from 2014 to 2017. At the unit level, the industry best quartile and median value have remained at zero over the review period.
- At the plant level, Pickering station performance has consistently improved over the review period, achieving zero unavailability from 2014 to 2017. On an individual unit basis, Units 1, 5, 6, 7, and 8 have been at the best quartile value of zero since 2012. Unit 4 performance improved over the review period, achieving zero unavailability from 2014 to 2017.
- At the plant level, Darlington station performance has maintained a best quartile value of zero from 2012 to 2017. On an individual unit basis, Units 1, 2, 3, and 4 have been at the best quartile value of zero since 2012.

Factors Contributing to Performance

- Key performance drivers for this metric include: general equipment reliability, material condition, and human performance.

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

Two 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. The On-line Deficient and Corrective maintenance backlog industry data was collected from INPO for 2017. 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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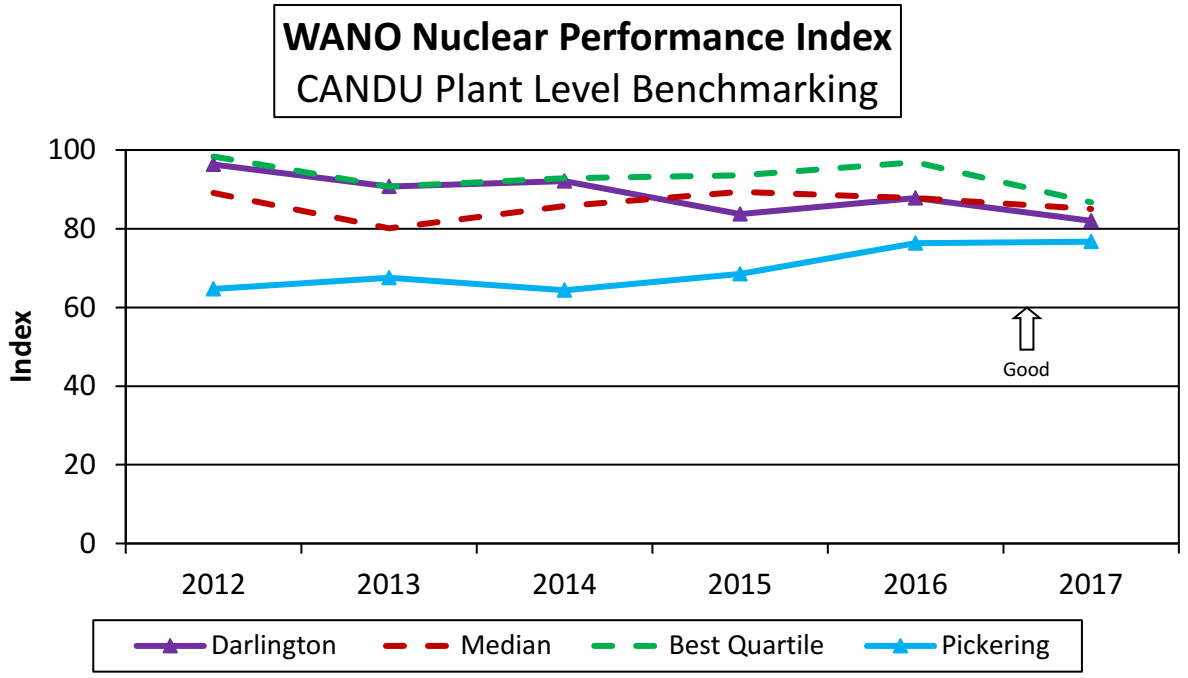
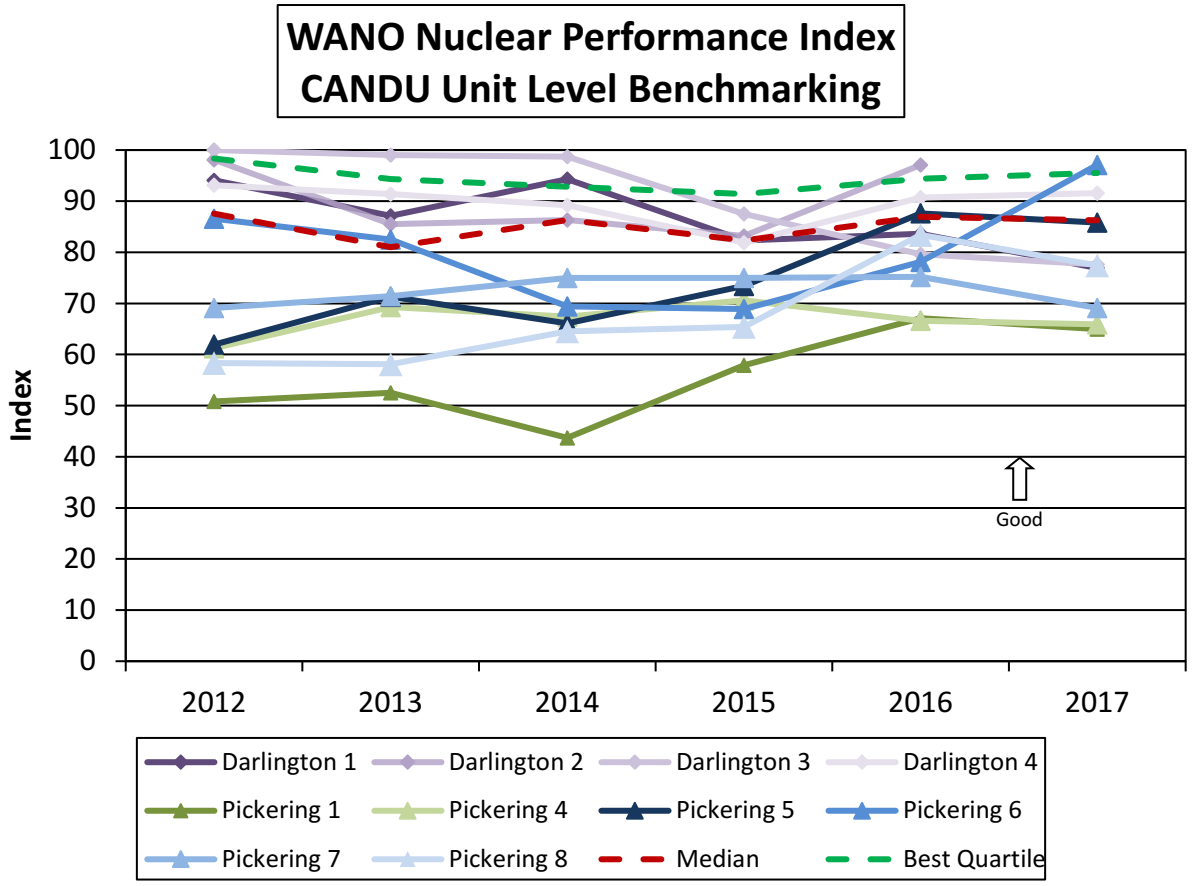
WANO Nuclear Performance Index





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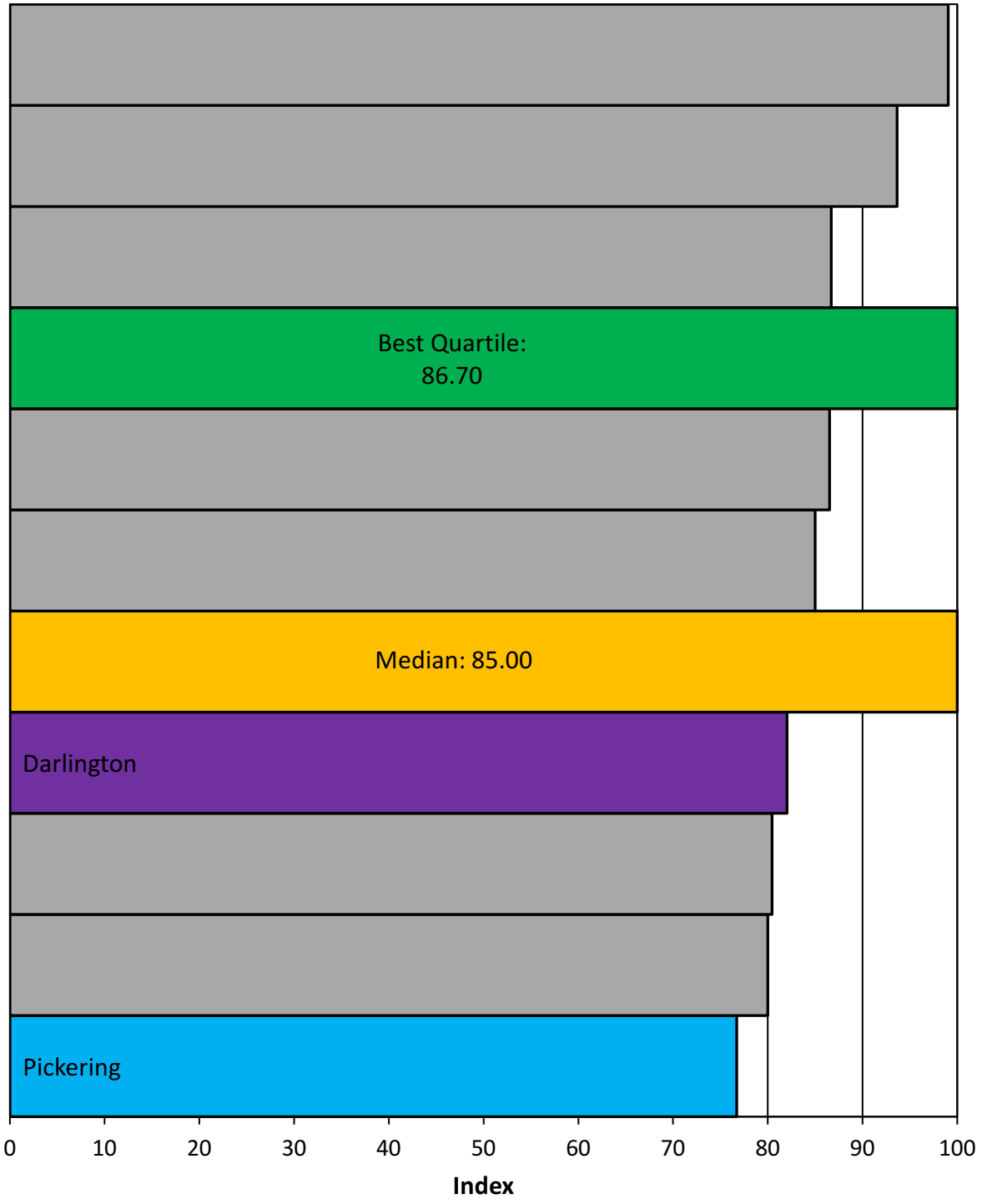
2017 WANO Nuclear Performance Index
CANDU Plant Level Benchmarking



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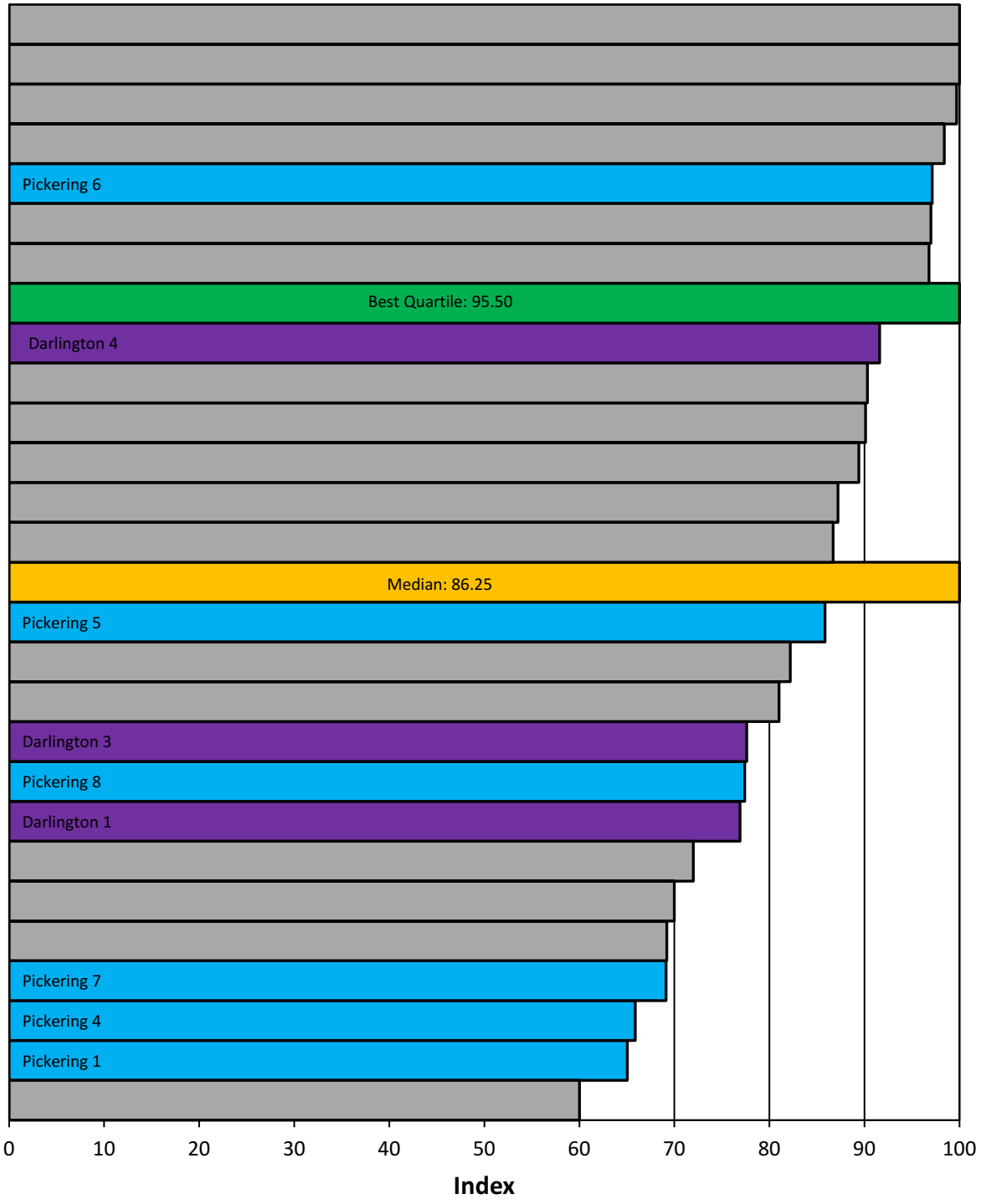
2017 WANO Nuclear Performance Index
CANDU Unit Level Benchmarking



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

2017

- The 2017 best quartile of the CANDU plant comparison panel for WANO NPI is 86.70. This represents a 10.2 points decrease when compared with the 2016 best quartile.
- The median of the CANDU plant comparison panel decreased 2.8 points, compared to last year, to 85.00 in 2017.
- At the plant level, both Darlington and Pickering scored below median NPI performance in 2017.
- Please refer to Table 14 of the Appendix for an NPI plant level performance summary of OPG nuclear stations against the North American panel.

Trend

- The best quartile of the CANDU plant comparison panel decreased from 2012 to 2013. In the subsequent three years, the best quartile improved. In 2017 the best quartile performance trended downward.
- The median value of the CANDU plant comparison panel decreased from 2012 to 2013. This performance recovered in 2014 and 2015 and declined again in 2016. The decline continued in 2017.
- Pickering has had a positive trend from 2014 onward, mainly due to improvements in the Forced Loss Rate (FLR) results.
- Darlington achieved best quartile performance over half of the review period, ranking at or just below top quartile until 2014. Performance declined beginning in 2015 driven by life extension requirements as described below.

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Factors Contributing to Performance

Pickering

- For 2017, Pickering achieved maximum scores or majority points for 4 out of 10 NPI sub-indicators.
- For the key safety system related metrics of high pressure injection, auxiliary feedwater and emergency alternating current (AC) power, the station received 10 out of 10 points. For reactor trip rate Pickering has received 9.9 points.
- Pickering has also achieved a perfect score for industrial safety accident rate (5 out of 5).
- Pickering earned 8.8 points for fuel reliability.
- Pickering achieved 4.6 points out of 5 for chemistry performance and 7.5 out of 10 for collective radiation exposure.
- Pickering's NPI performance is impacted by life extension requirements, including the need for long outages to accommodate fuel channel inspection programs, planned outages extension and forced outages that are affecting the unit capability factor, forced loss rate and collective radiation exposure metrics
- Pickering received 2.9 out of 15 points for unit capability factor and 8.0 out of 15 for forced loss rate.

Darlington

- Performance declined in 2015 due to the station vacuum building containment outage for planned regulatory maintenance and higher FLR. The declining trend continued in 2016 due to Primary Heat Transport pump motor replacements affecting UCF and higher radiation dose from life extension nuclear safety improvements projects (i.e. Shield Tank Over-Pressure Protection). In October 2016 Darlington unit 2 entered refurbishment. The trend continued in 2017 due primarily to a planned unit 2 bulkhead install no fuel window, which resulted in a unit 1 de-rate (33-days) affecting unit capability factor.
- Darlington's 2017 NPI performance has also been impacted by higher forced loss rate and by a lower unit capability factor due to forced outages, planned outages and unbudgeted planned outages.
- For 2017, Darlington has achieved maximum points for 6 out of 10 NPI sub-indicators.
- For the key safety system related metrics of reactor trip rate, high pressure injection, auxiliary feedwater and emergency alternating current (AC) power, the station received 10 out of 10 points.
- Darlington has also achieved a perfect score for industrial safety accident rate (5 out of 5) and fuel reliability (10 out of 10).
- Darlington earned 4.8 out of 5 points for chemistry performance and 8 out of 10 points for collective radiation exposure.
- Darlington achieved 3.9 out of 15 points for unit capability factor and 10.3 out of 15 points for forced loss rate.

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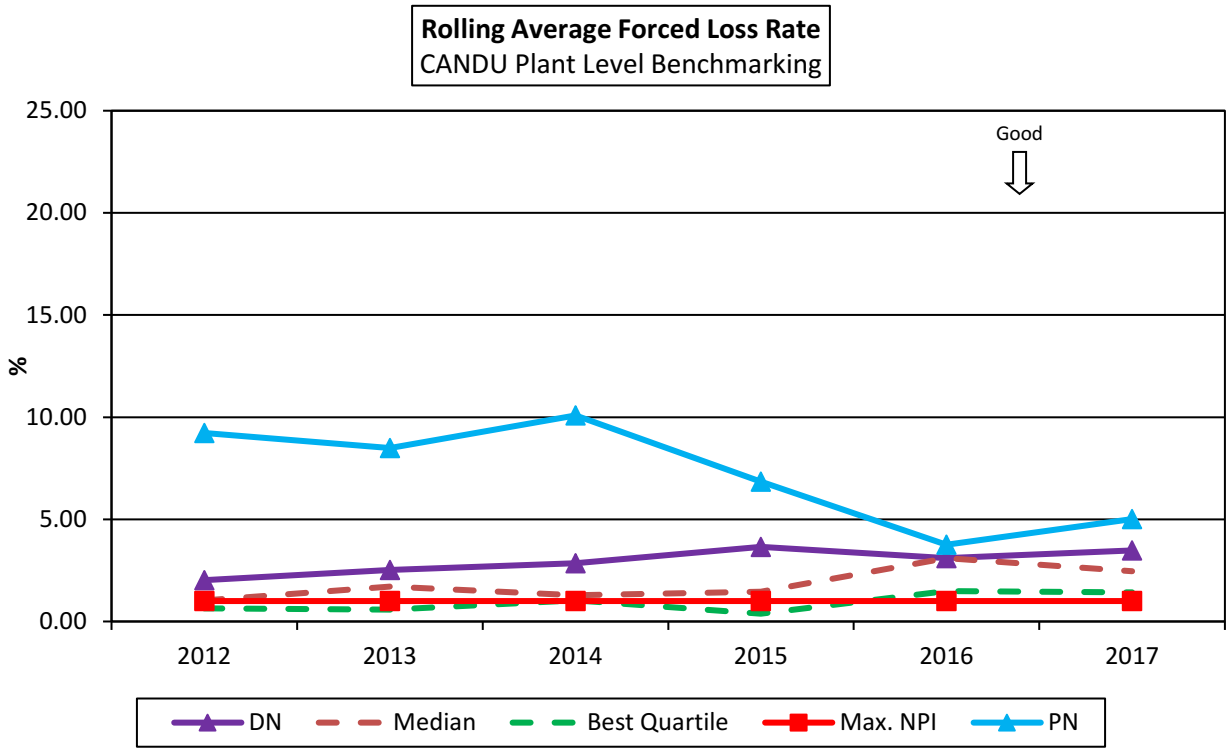
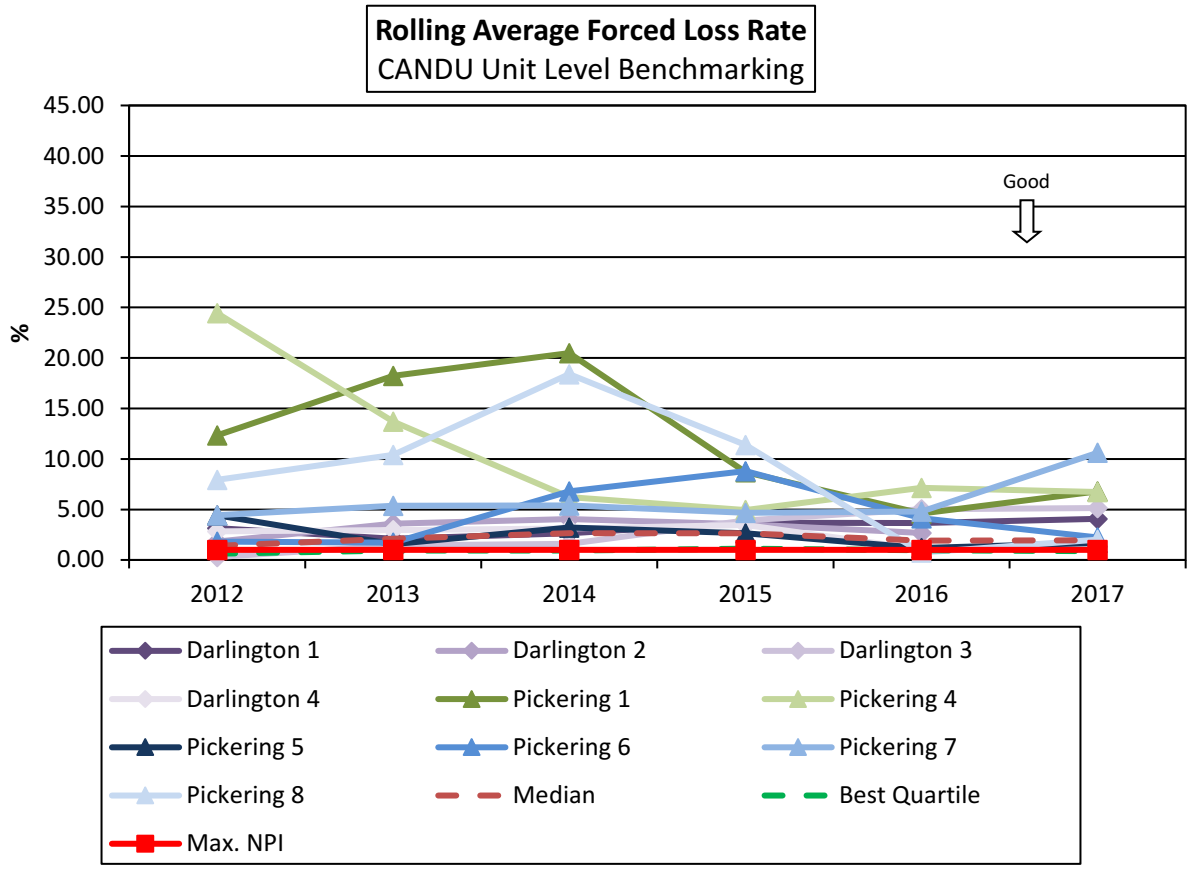
Rolling Average Forced Loss Rate





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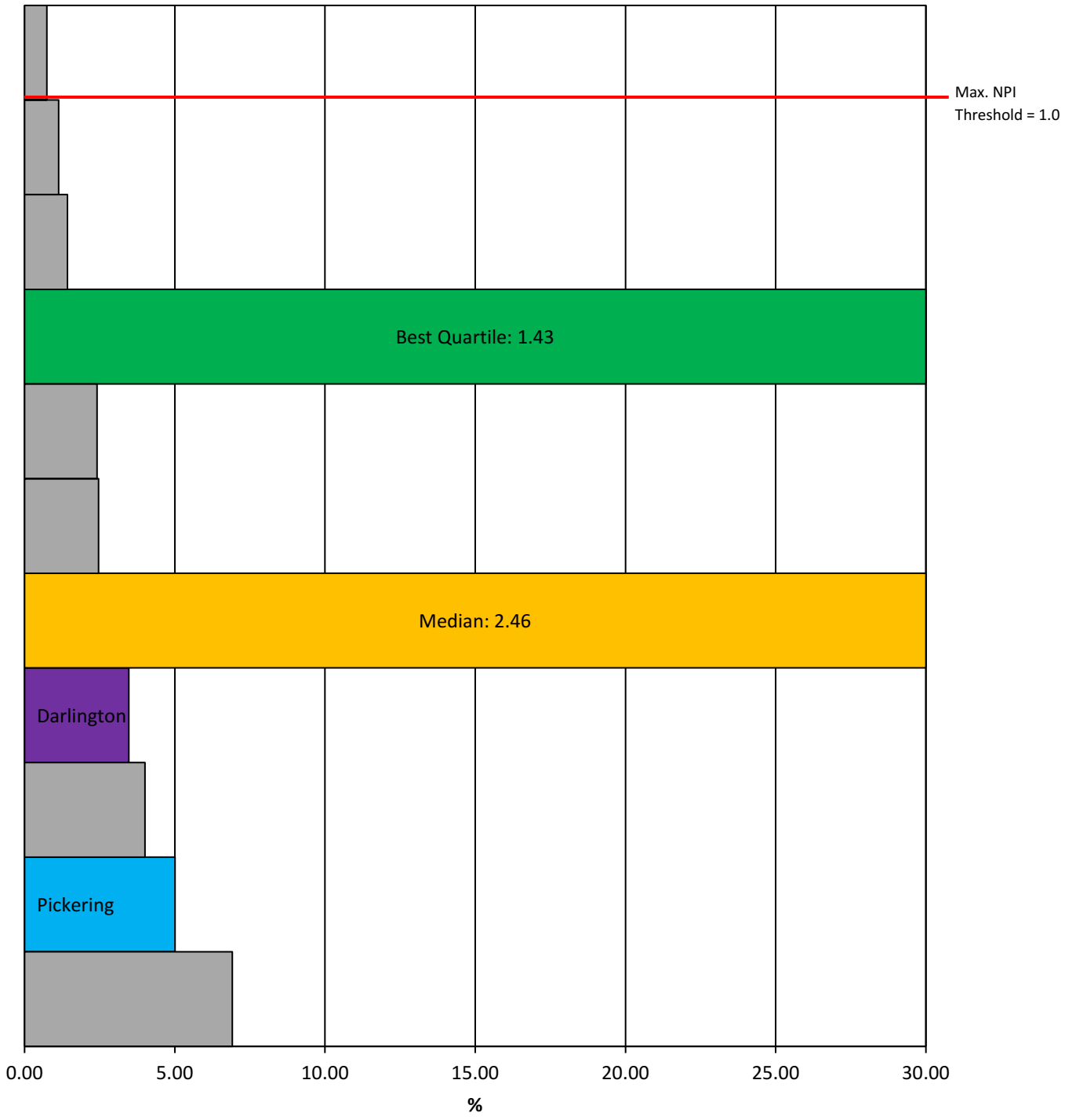
2017 Rolling Average Forced Loss Rate
CANDU Plant Level Benchmarking



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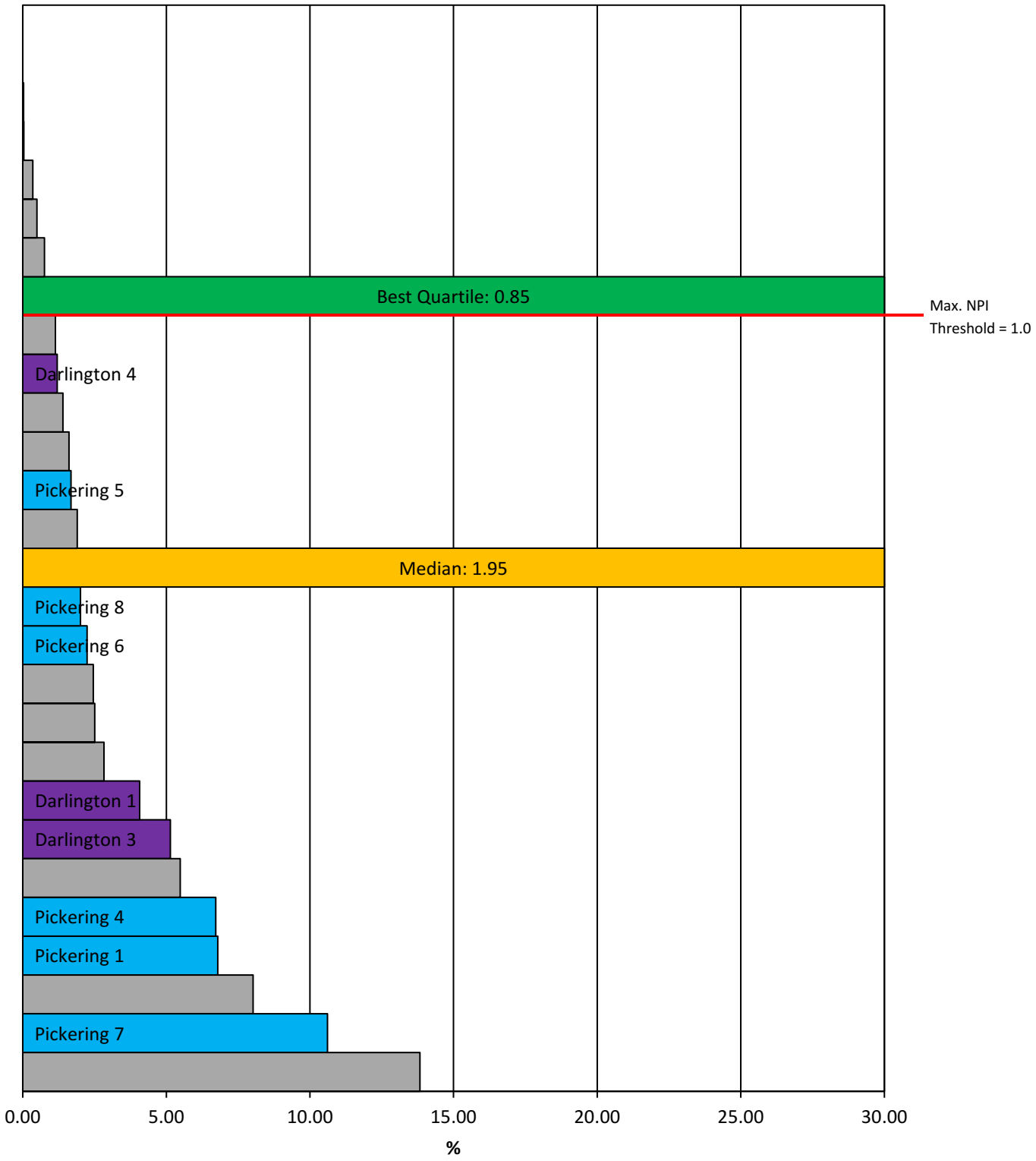
2017 Rolling Average Forced Loss Rate
CANDU Plant Level Benchmarking



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Observations – Rolling Average Forced Loss Rate (CANDU)

2017 (Rolling 2 Year Average, Pickering %; Rolling 3 Year Average, Darlington %)

- The industry first quartile was 1.43 and the industry median was 2.46.
- Pickering Forced Loss Rate (FLR) performance had a slight decline from 3.76 in 2016 to 5.01 in 2017.
- At the plant level, Darlington FLR performance declined slightly to 3.47. Unit 2 was excluded in 2017 due to refurbishment.

Trend

- Industry plant median FLR trend improved slightly from 3.10 to 2.46.
- Pickering's overall trend over the review period, has shown considerable improvement, having been as high as 10.08 in 2014. The equipment reliability improvements at Pickering have been the main drivers for the favourable improvement in FLR performance.
- Over the review period, there has been a minor decline in FLR performance at Darlington coinciding with life extension requirements. The average FLR over the trending period was 2.94.

Factors Contributing to Performance

- At Pickering, causes for 2017 forced losses were varied, including:
  - Issues with the Electro-Hydraulic Governor (EHG) system on Unit 7 (3 forced outages in 2017)
  - Unit 7 bridge tilt issue due to challenges with coupling hub installation
  - Unit 1 sudden outage due to Calandria Inlet Valves closing on both lines

  At Darlington, the causes for 2017 forced losses were also varied, including:
  - Unit shutdowns following spurious shutoff rods falling into core (Unit 3 – due to failed clutch card, Unit 4 – due to faulty logic module)
  - Turbine trip during SRST 10.05 Loss of Lube Oil Pressure test
  - Manual turbine trip due to sustained high flux tilt

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Observations – Rolling Average Forced Loss Rate (CANDU) (CONT'D)

Factors Contributing to Performance

- Pickering continues to execute a list of high priority work orders to improve equipment reliability and reduce operator burden.
- Pickering continues reducing corrective and deficient work order backlogs through a reduction of incoming emergent work orders by proactive equipment replacements and minor modifications to improve/correct system and equipment performance.
- Darlington continues to drive plant reliability improvements via the system health improvement process and recovery actions. The Plant Reliability List of important work orders are implemented to improve system health.
- Both Pickering and Darlington have seen significant improvement in the PM program due to improved oversight and advocacy
- Nuclear Equipment Reliability initiative is on-going with a focus on reduction of critical components, streamlining of system health reporting, and value based maintenance
- The definition of critical components was aligned with industry standards which has allowed the organization to better focus the station equipment reliability processes and resources on the most critical components to improve overall equipment reliability and safety

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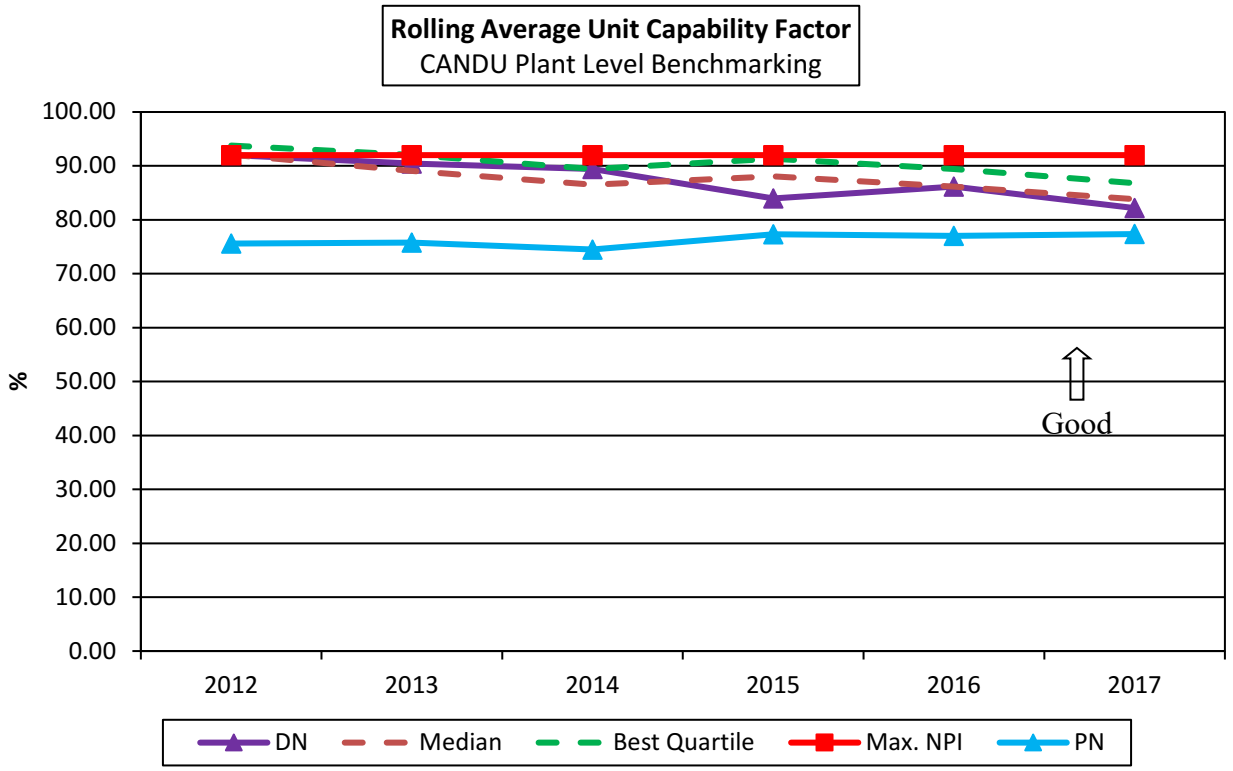
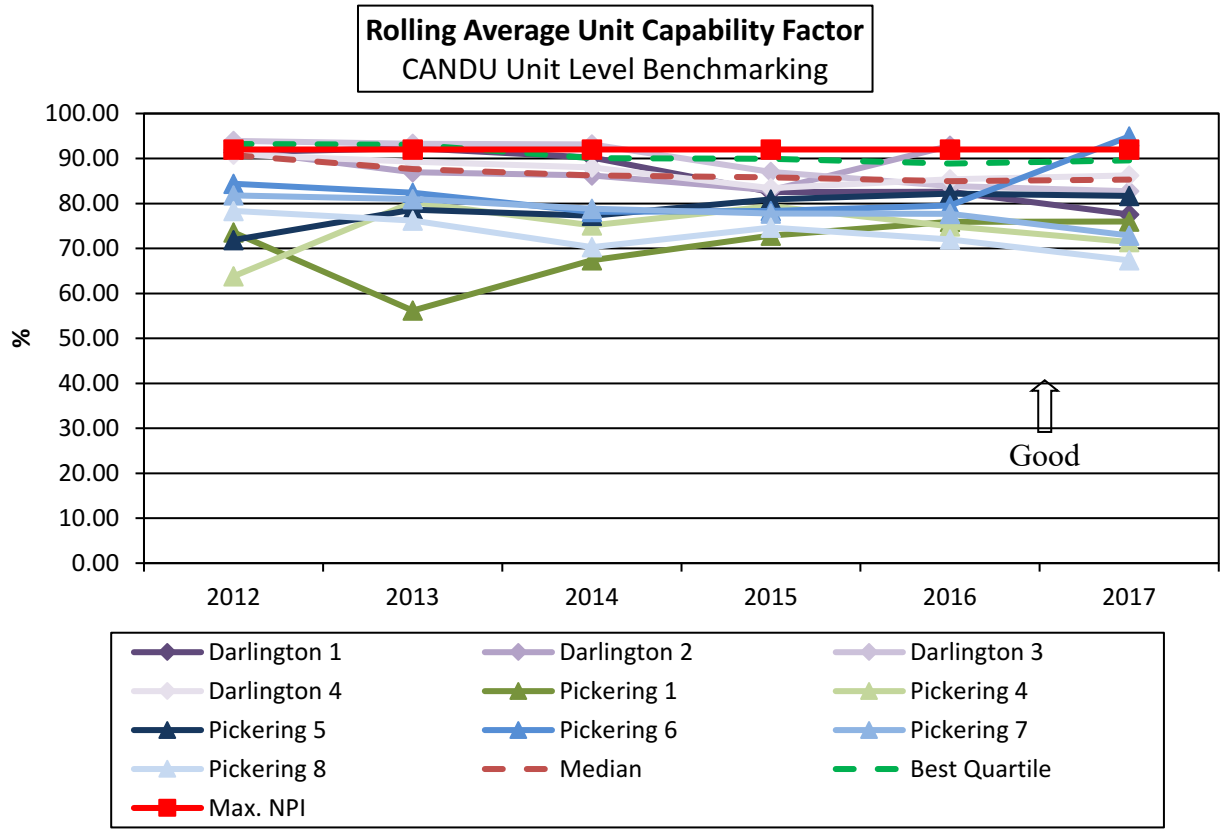
Rolling Average Unit Capability Factor





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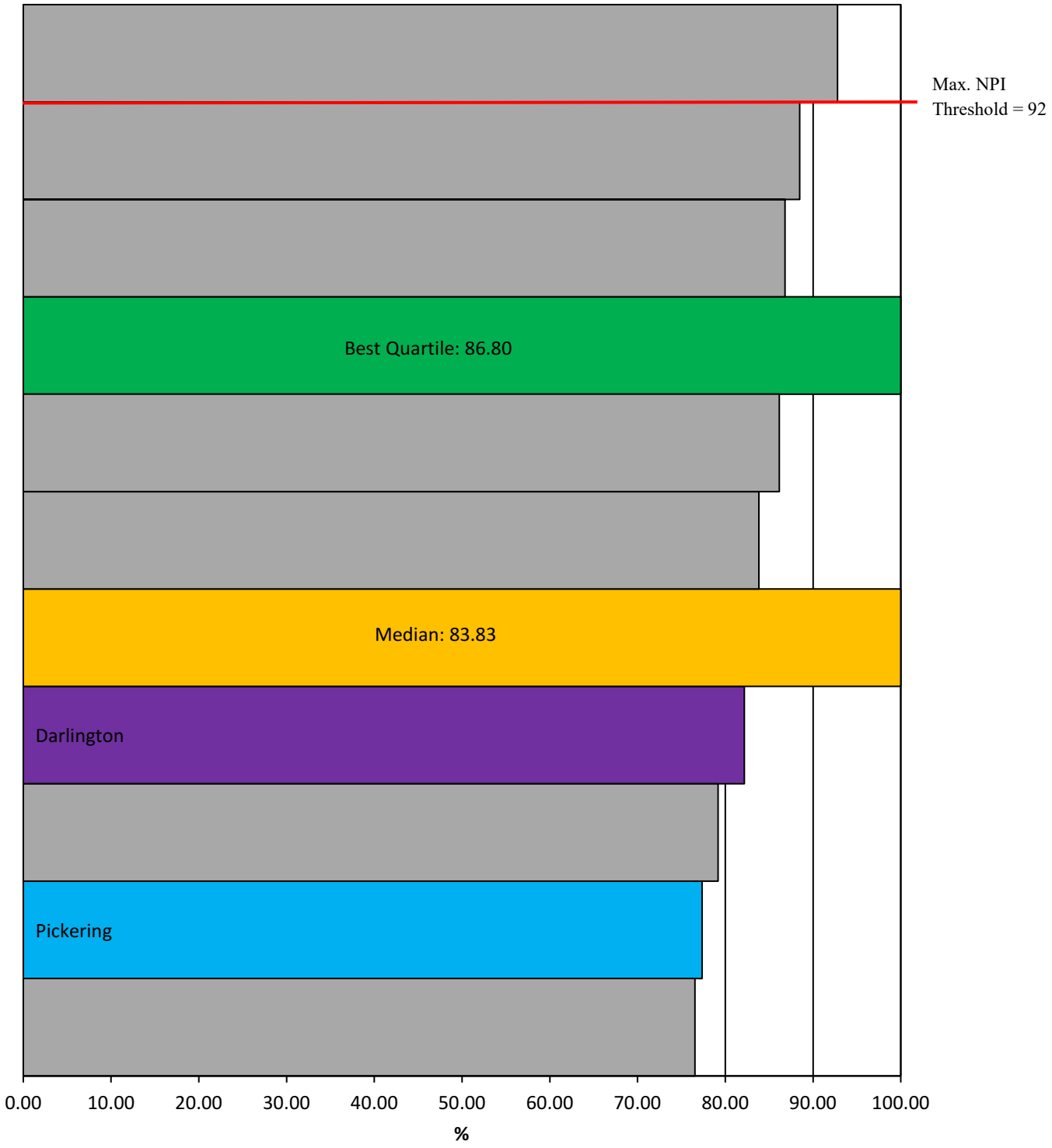
2017 Rolling Average Unit Capability Factor
CANDU Plant Level Benchmarking



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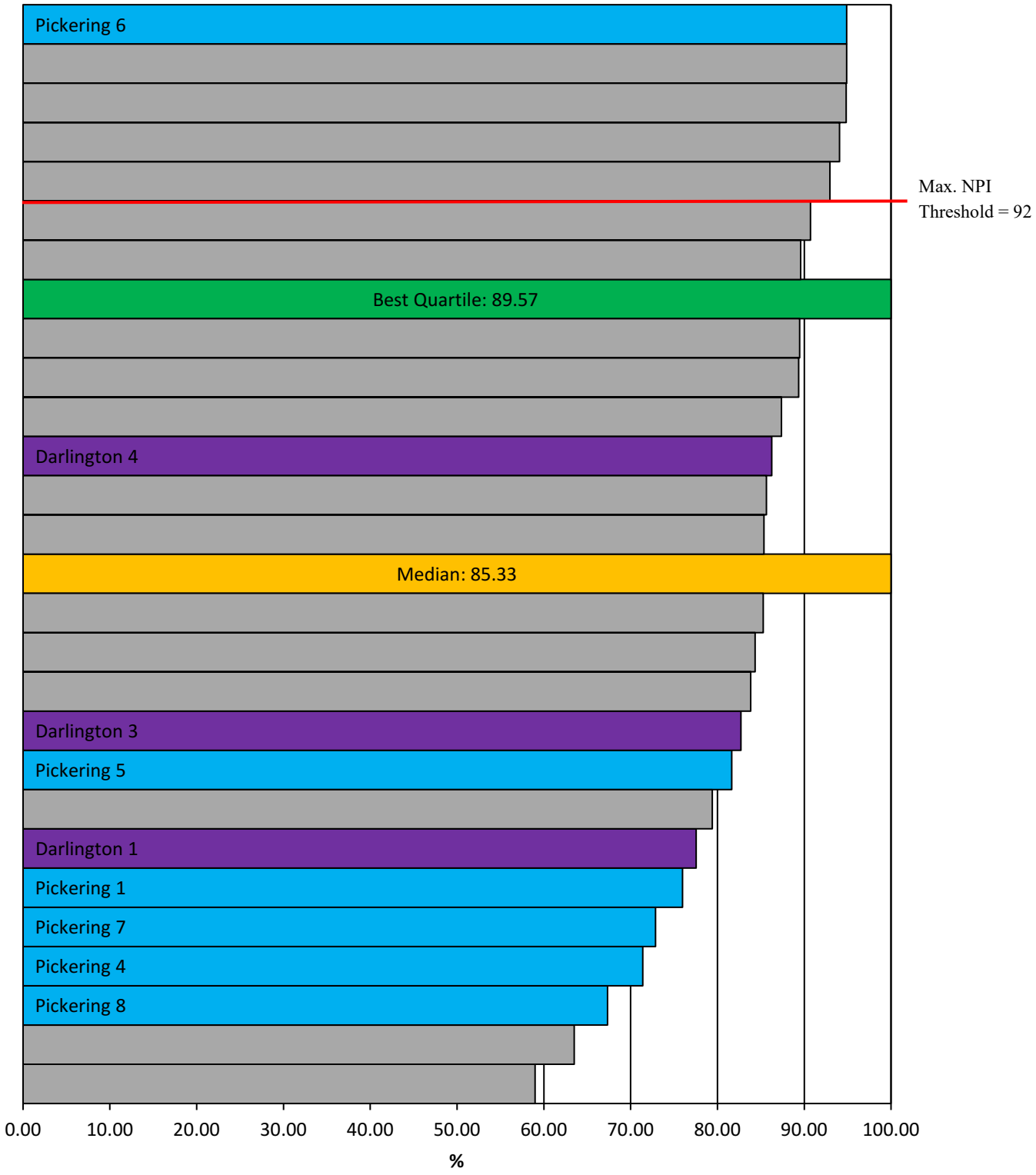
2017 Rolling Average Unit Capability Factor
CANDU Unit Level Benchmarking



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

2017 (Rolling 2 Year Average, Pickering %; Rolling 3 Year Average, Darlington %)

- The industry first quartile was 86.80 and the industry median was 83.83.
- Pickering improved slightly to 77.36.
- Darlington UCF performance declined in 2017 to 82.17. Darlington Unit 2 began a long-term refurbishment outage on October 15, 2016. Data points associated with Refurbishment have been excluded with respect to UCF.

Trend

- Pickering's UCF performance has improved since 2012, with the last 3 years remaining relatively stable. The equipment reliability improvements at Pickering has contributed to this improvement in recent UCF performance.
- Darlington's plant UCF has declined, coinciding with life extension requirements.
- Industry plant median and best quartile UCF benchmarks both declined in 2017.

Factors Contributing to Performance

- The primary factors impacting UCF are longer outages to accommodate reactor component inspections necessary for extended life at Pickering. Reduced FLR at Pickering contributed favourably to Pickering's UCF performance trend.
- Higher numbers of planned outage days and forced extensions to planned outages contribute to lower UCF compared to CANDU peers.
- FLR performance challenges also negatively impact UCF. Significant improvements in equipment reliability are expected to correlate with improved FLR and UCF performance.

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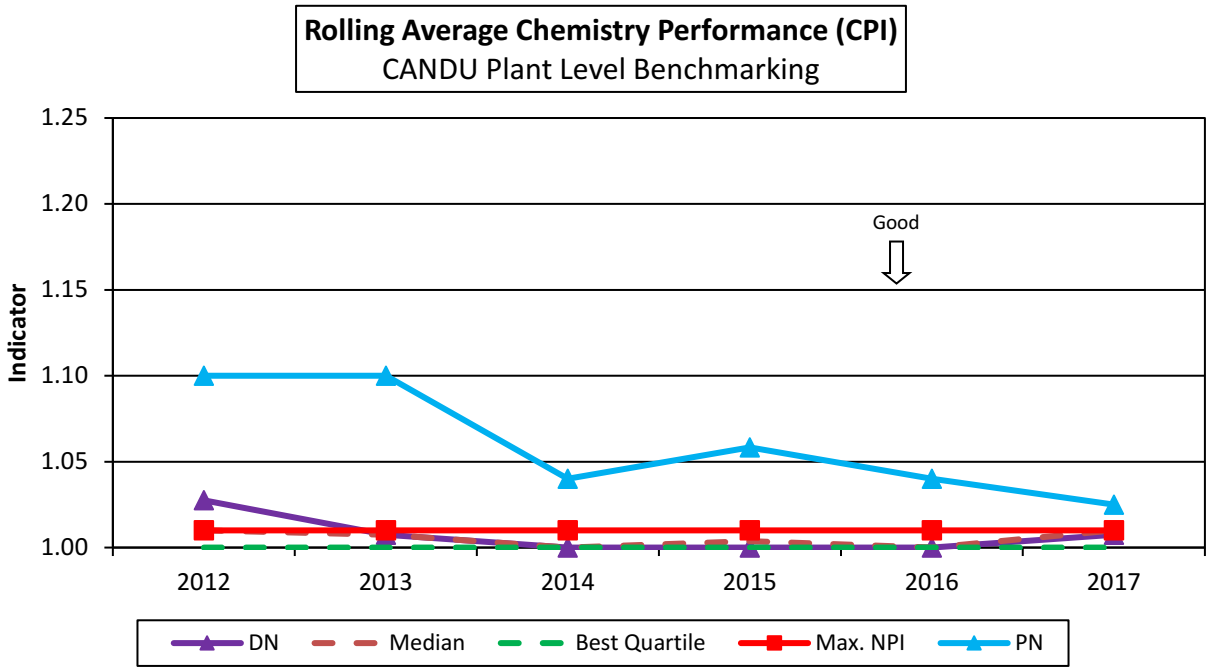
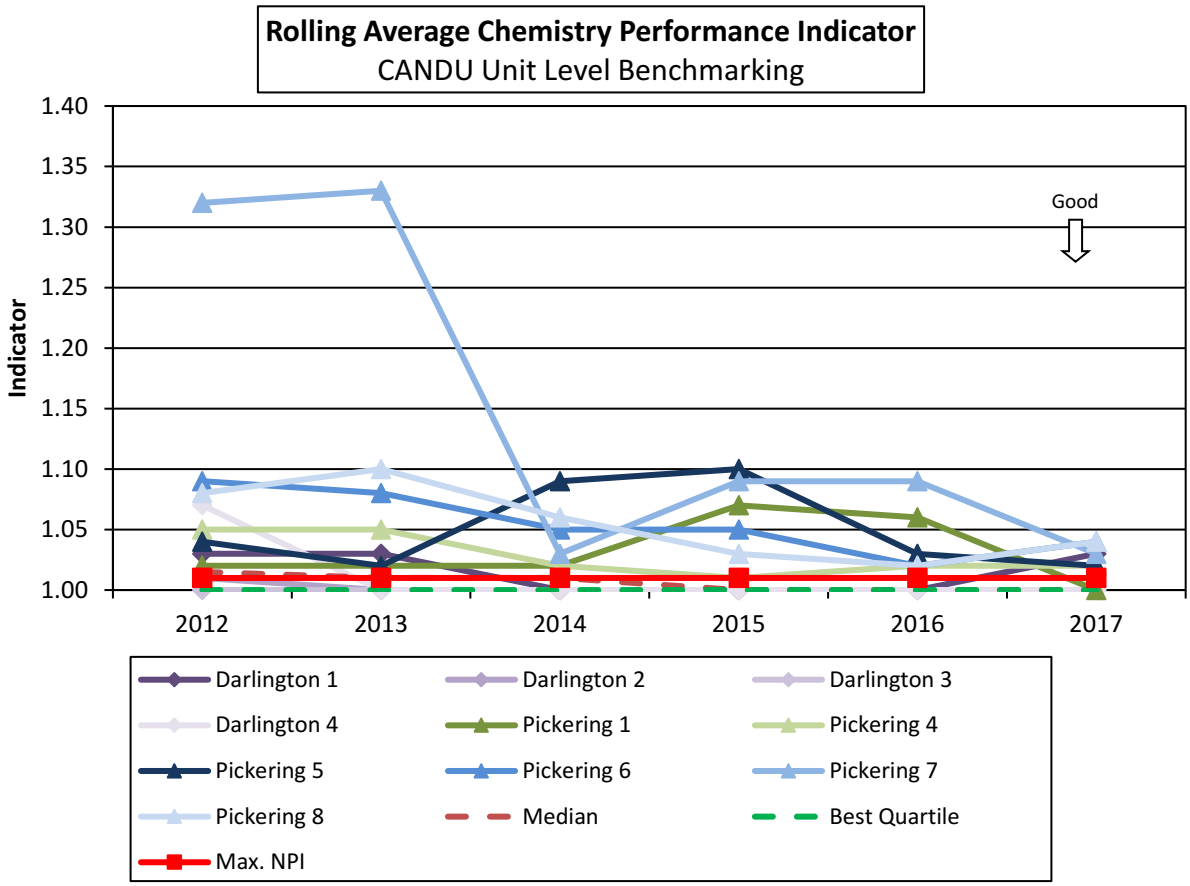
Rolling Average Chemistry Performance Indicator





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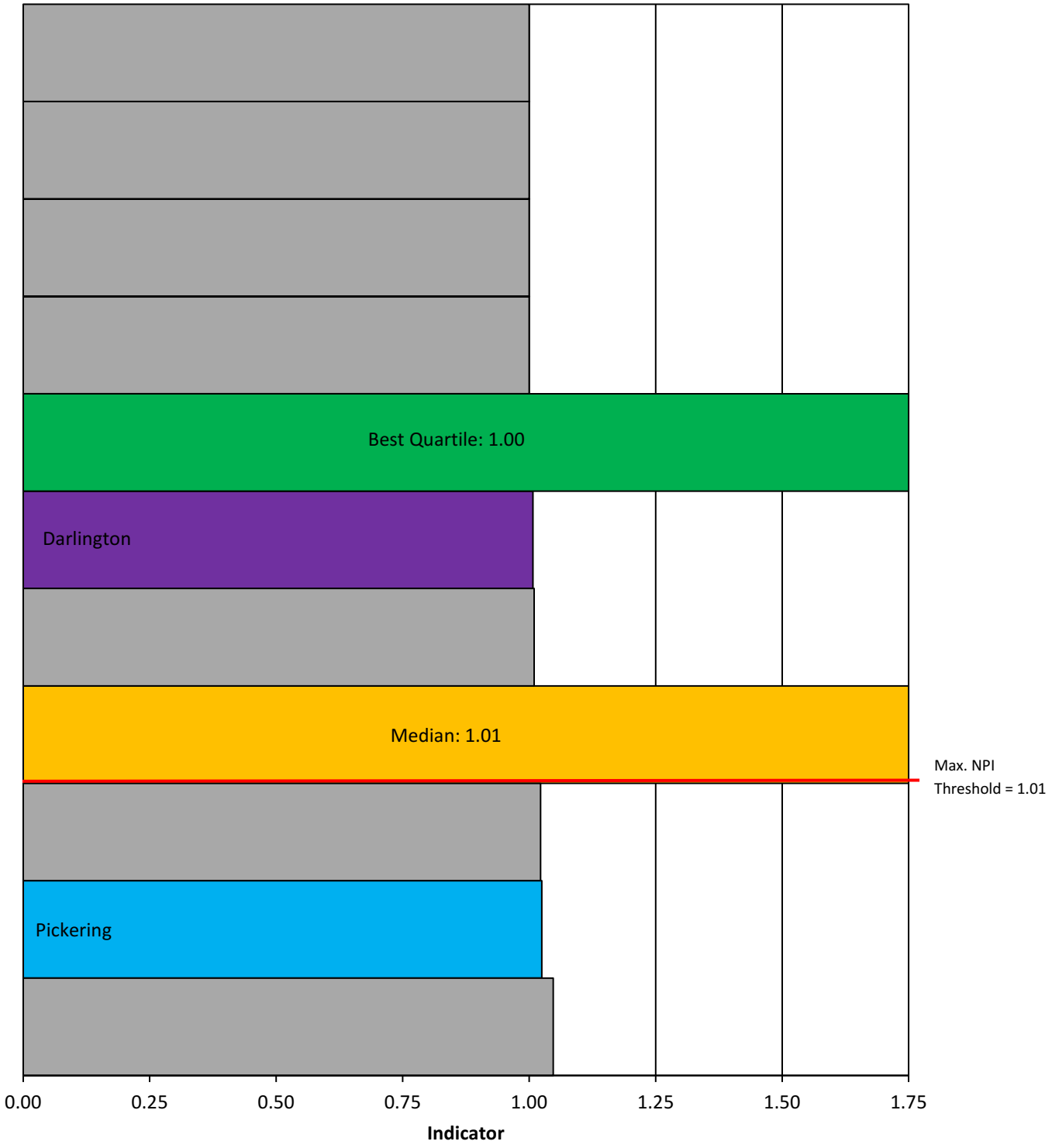
2017 Rolling Average Chemistry Performance Indicator
CANDU Plant Level Benchmarking



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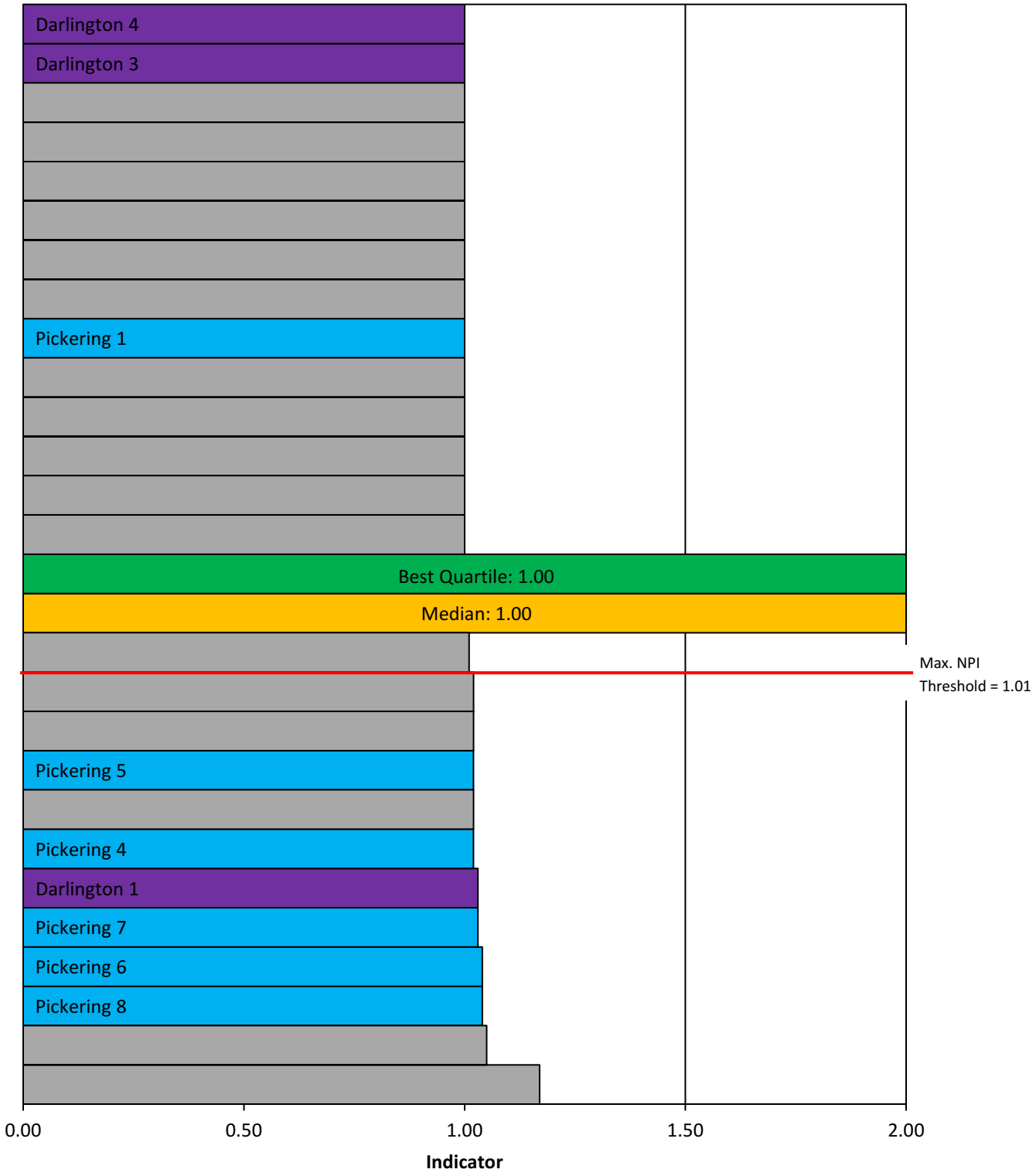
2017 Rolling Average Chemistry Performance Indicator
CANDU Unit Level Benchmarking



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Observations – Rolling Average Chemistry Performance Indicator (CANDU)

2017 (Rolling 2 Year Average Pickering, Rolling 3 Year Average Darlington)

- The CANDU plant median and best quartile values are 1.01 and 1.00, respectively.
- The CANDU unit median and best quartile values are both 1.00.
- WANO CPI is calculated using secondary side chemistry data during normal operation (> 30% Full Power).
- The Pickering station level of performance has improved from 1.04 in 2016 to 1.02 in 2017.
- Darlington station performance declined to the median 1.01 in 2017 from the best quartile 1.00 in 2016.

Trend

- Pickering station CPI performance has improved significantly over the review period. Contribution to Nuclear Performance Index (NPI) has gone up from 4.2 in 2016 to 4.6 in 2017, out of total 5 points.
- Darlington station CPI overall performance has declined to median 1.01 in 2017 from best quartile 1.00 in 2016. NPI contribution has dropped from 5 points in 2016 to 4.8 points in 2017, out of total 5 points.

Factors Contributing to Performance

- Contributing factors for chemistry performance improvement at Pickering were the better outage Foreign Materials Exclusion practices, improved Water Treatment Plant (WTP) output quality controls, blowdown frequency adherence, timely support from the organization and an improved advocacy at all levels to bring back secondary side chemistry parameters within their respective limits as soon as possible.
- Darlington performance has been impacted by elevated Feed Water iron levels following unit outages and delayed power ascension after the most recent planned maintenance outage. Corrosion product transport (CPT) reduction plans are in place such as condenser cleaning following maintenance; condenser hot well flushing prior to restart and startup condensate filtration. Another contributor has been the chronic condenser tube leak in Unit 3. The leaking tubes were identified shortly before the outage and tube plugging was completed during the outage.

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Observations – Rolling Average Chemistry Performance Indicator (CANDU)

Chemistry initiatives in place to further improve CPI to best quartile:

- Boiler blowdown piping (buried section) improvement project at Pickering to support system reliability and availability to the Station end-of-life.
- Condenser hot well cleaning during planned outages
- Ongoing use of local portable feedwater dissolved oxygen analyzer carts at Pickering to ensure representative feed water dissolved oxygen monitoring
- Leveraging emergent work processes, utilizing cross-functional resolution teams, and advocacy forums to ensure a coordinated effort is timely to mitigate condenser tube leak
- Ongoing oversight of water treatment plant (WTP) product water quality to meet boiler make-up water specifications.
- Condensate Filtration Project for the control of corrosion product transport at Darlington during startup after the planned outage
- Online analyzers replacement project both at Pickering and Darlington to support analyzer reliability/availability.
- Continue corrective actions taken post Unit 4 outage in 2017 at Pickering, including reinstatement of low power boiler blowdown, minimization of boiler drained period, ensuring boiler wet lay-up specs, reducing Morpholine concentration for pH/organic anions control.

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Observations – Rolling Average Chemistry Performance Indicator (CANDU)

Factors Contributing to Performance (continued)

- Improved CPT monitoring using X-ray fluorescent (XRF) technology for faster CPT results to take corrective actions if necessary
- Procurement of a new WTP at Darlington
- Boiler secondary side deposit minimization initiatives such as:
    - Darlington's tubesheet waterlancing in planned outages
    - Pickering's tubesheet waterlancing campaign strategy
    - Pickering's preliminary plan for first-of-a-kind support plate water lancing and potential soft chemical clean application on Unit 4 in 2019.

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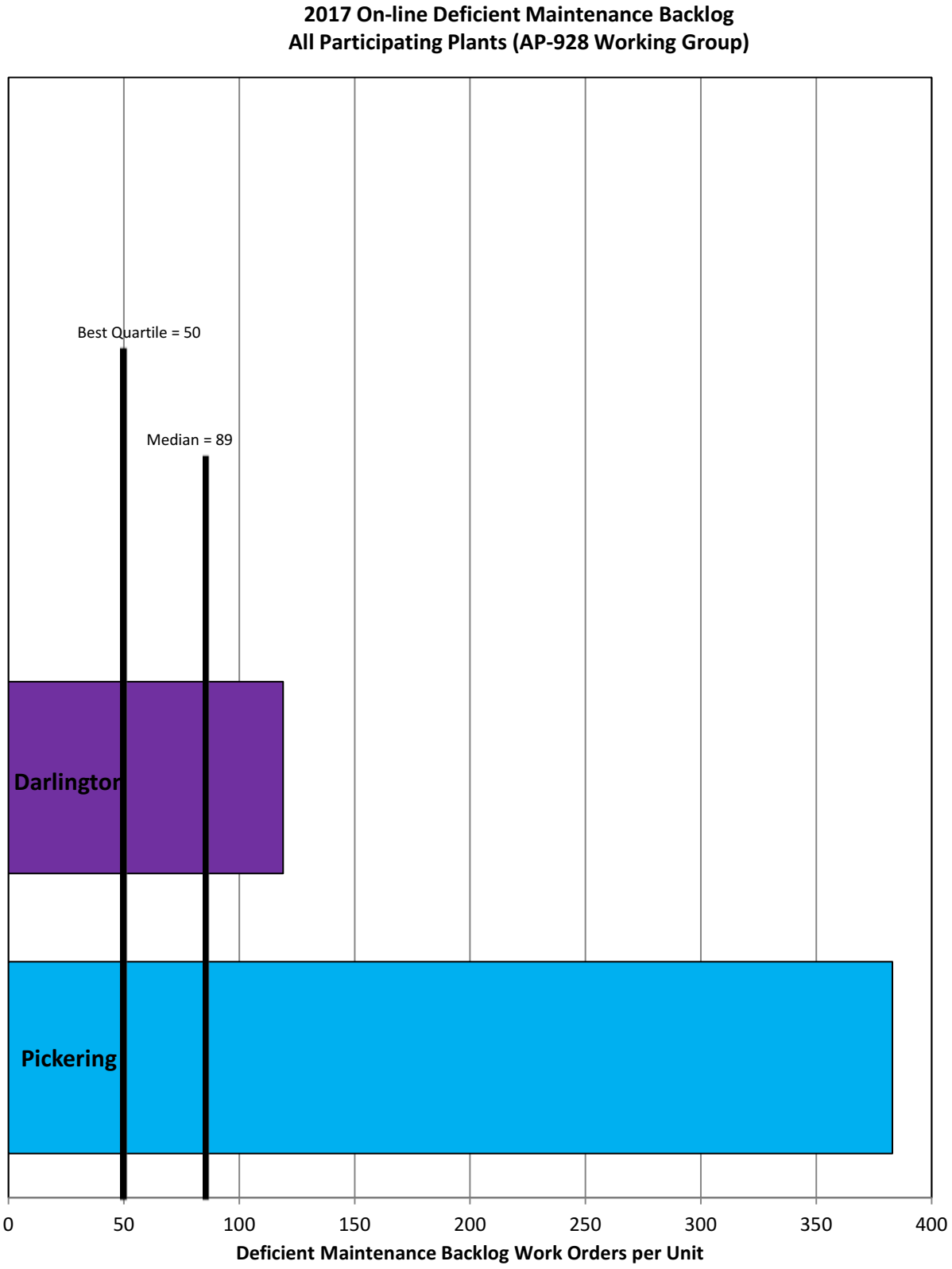
1-Year On-line Deficient Maintenance Backlog



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

2017 (Annual Value)

- The industry Best Quartile and Median Thresholds were 50 and 89 work orders per unit respectively for On-Line Deficient Maintenance (DM) backlog.
- Darlington DM backlogs were at 119 Work Orders per unit and deficient critical backlogs were at 15 work orders per unit
- Pickering DM backlogs were at 383 Work Orders per unit and deficient critical backlogs were at 41 work orders per unit

Trend

- In comparison to the 2016 data:
  - Darlington performance in 2017 has improved from 170 to 119 work orders per unit
  - Pickering performance in 2017 declined from 350 to 383 work orders per unit
  - Median backlog has improved from 134 to 89 work orders per unit.
- Darlington has shown steady backlog improvement from 2013 through 2017
- Pickering has had backlog increases in each of the last two years

Factors Contributing to Performance

- At Pickering the increase in deficient maintenance backlog is due, in part, to a deliberate focus on planning and scheduling corrective maintenance. Reducing the corrective backlog has a greater effect on the safe and reliable operation of the plant than the deficient items.
- At both stations, the focus has been to reduce on-line deficient critical and corrective critical backlogs, which has resulted in the corrective critical backlogs being at zero for Pickering and one for Darlington.
- To improve performance there are two fleet wide plans:
  - 1. Maintenance Initiative:
    - Working Efficiently – to do more work without increasing resources
    - Assessing Optimization – to reduce resources required to plan work
    - Enhancing Fix It Now Teams – to complete more work without detailed planning
    - Resourcing Strategy – to optimize the focus of specialty crews; use of purchased services agreement to get non-core work done through contracting
    - Management & Leadership – to develop business acumen; foster an innovation culture; improve performance oversight and reporting

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

Factors Contributing to Performance (continued)

- 2. Value Based Maintenance Initiative:
  - Preventative Maintenance Program Reduction – to match the program to available resources and support condition based maintenance
  - Work Management & Resource Strategy – to align with supporting processes and maintenance strategy
  - Monitoring & Diagnostic Centre – to leverage technology to support value based and condition based maintenance strategies
  - Data Analytics and Reporting – to identify opportunities for improvement
  - Culture Shift – to adopt value based and condition based maintenance

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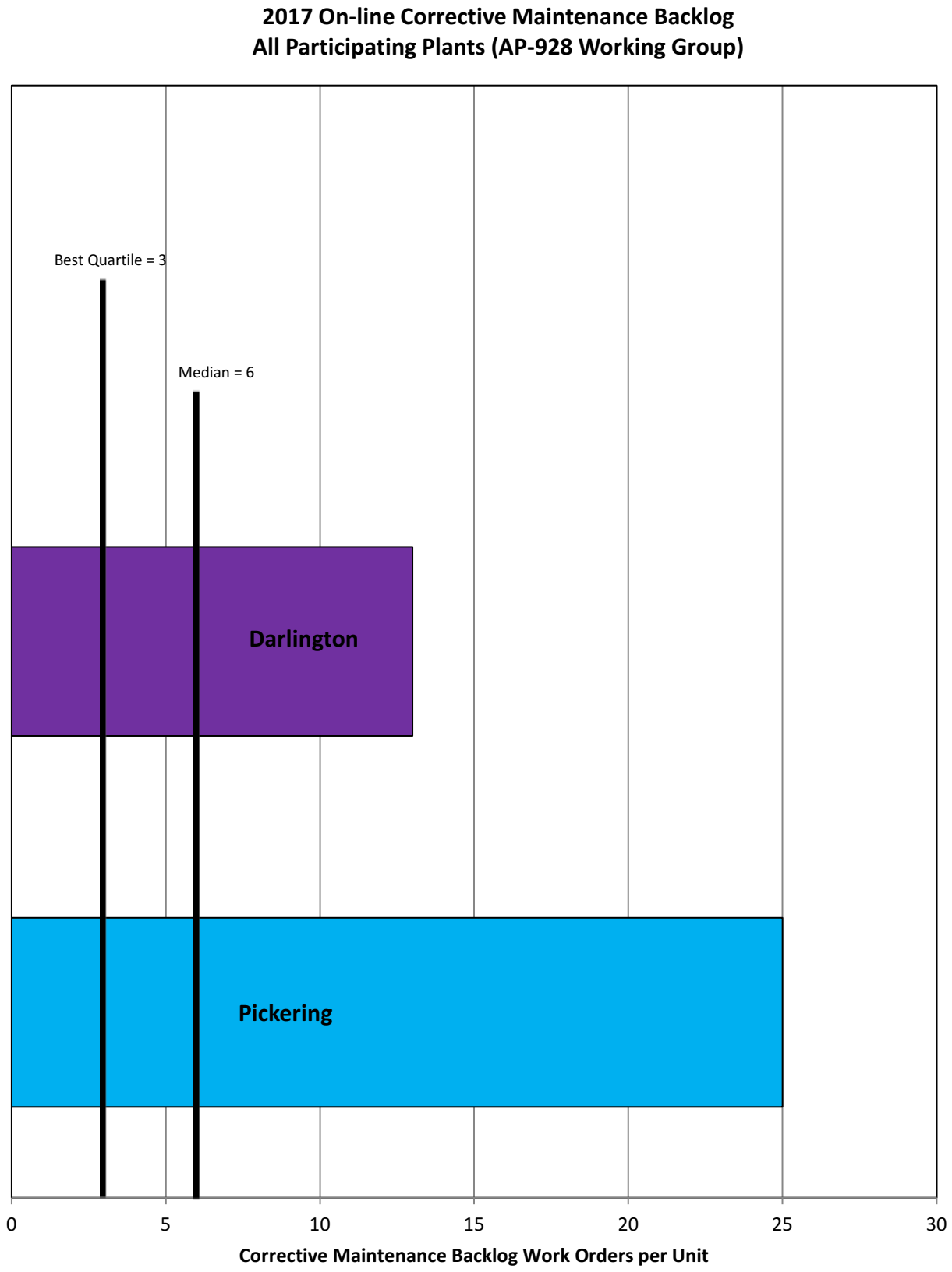
1-Year On-line Corrective Maintenance Backlog



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

2017 (Annual Value)

- The industry Best Quartile and Median Thresholds were 3 and 6 work orders per unit respectively for On-Line Corrective Maintenance (CM) backlog.
    - Darlington CM backlogs were at 13 Work Orders per unit and corrective critical backlogs were at 1 work order per unit
    - Pickering CM backlogs were at 25 Work Orders per unit and corrective critical backlogs were at 0 work orders per unit

Trend

- In comparison to the 2016 data:
    - Darlington performance in 2017 has improved from 14 to 13 work orders per unit
    - Pickering performance in 2017 improved significantly from 116 to 25 work orders per unit
    - Median backlog has improved from 10 to 6 work orders per unit.
- Darlington has shown backlog improvement from 2013 through 2017.
- Pickering has shown significant backlog improvement in each of the last three years.

Factors Contributing to Performance

- Refer to the Factors Contributing to Performance discussed above in the 1 Year On-Line Deficient Maintenance Backlog, as the same factors affect both backlog measures.

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4.0 VALUE FOR MONEY

Methodology and Sources of Data

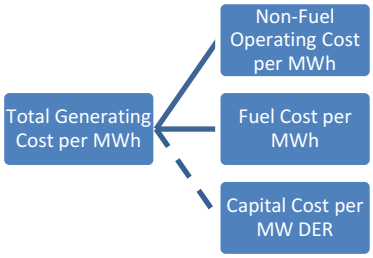
The Electric Utility Cost Group (EUCG) database is the source for cost benchmarking data. Data was collected for three-year rolling averages for all financial metrics covering the period from 2012-2017. All data submitted to and subsequently extracted from EUCG by OPG is presented in Canadian dollars.

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.

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

Diagram of Summary Relationship of Value for Money Metrics



Beginning in 2017, Darlington's TGC per MWh and NFOC per MWh performance has been normalized for refurbishment. OPG is performing a major mid-life refurbishment at Darlington, which involves 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 methodology to normalize TGC per MWh and NFOC per MWh for refurbishment. The new normalization methodology allows OPG to adjust the distribution of actual costs to reflect performance of the

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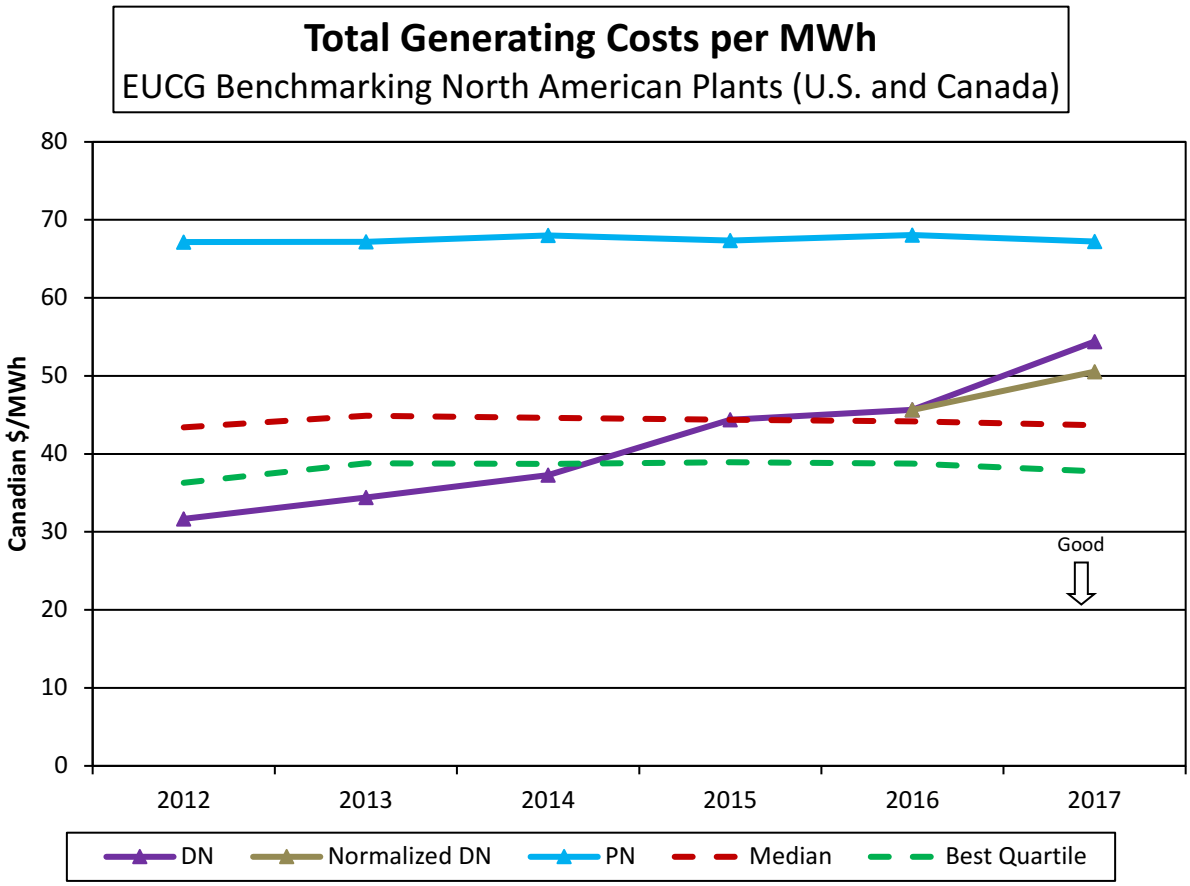
operating nuclear units while using actual generation in the denominator. The normalization methodology, as well as ScottMadden's review and validation of OPG's application of that methodology, is attached in Appendix 1.

3-Year Total Generating Cost per MWh



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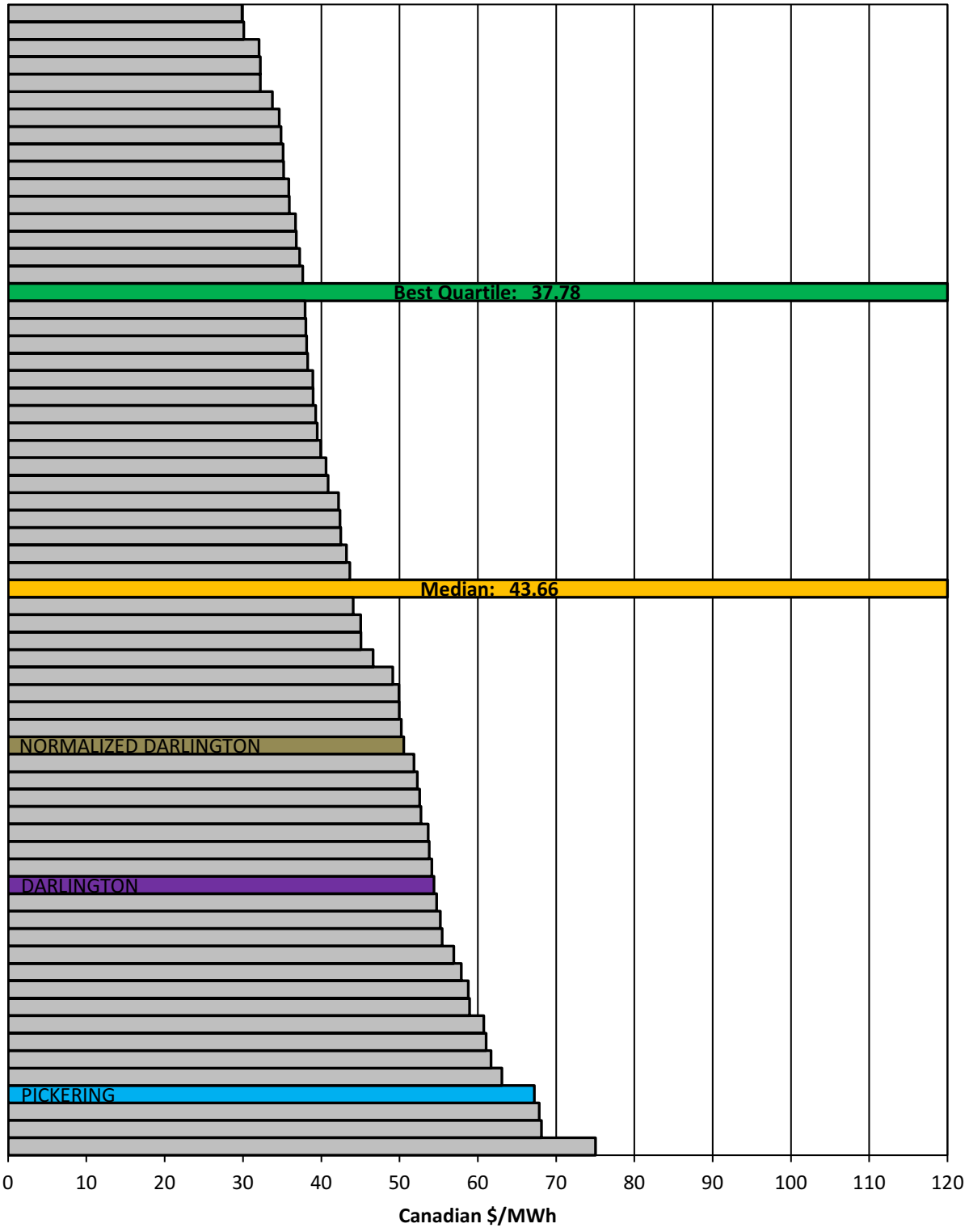
2017 3-Year Total Generating Costs per MWh
EUCG Benchmarking North American Plants (U.S. and Canada)



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

2017 (3-Year Rolling Average)

- The best quartile level for Total Generating Cost per MWh (TGC/MWh) among North American EUCG participants was $37.78/MWh while the median level was $43.66/MWh.
- Darlington normalized TGC/MWh was $50.54 and non-normalized was $54.40/MWh.
- Pickering TGC/MWh was $67.22/MWh.

Trend

- Over the 2012 to the 2017 period the best quartile cost rose by $1.49/MWh while the median cost rose by $0.26/MWh. Darlington non-normalized rose by $22.73/MWh and Pickering rose by $0.06/MWh.
- Pickering largely managed cost increases and remained flat over the review period with a compound annual growth rate (CAGR) of 0.0% whereas the best and median quartile levels increased by a CAGR of 0.8% and 0.1% respectively.
- Darlington's costs increased over the review period with a CAGR of 11.4%.

Darlington

- A major driver of Darlington's TGC/MWh is the Vacuum Building Outage (VBO).
- The 3-Year Rolling Average for Darlington (non-normalized) from 2016 to 2017 rose $8.77/MWh. The primary drivers at Darlington are lower generation (8,663 GWh) and costs associated with life extension.
- Planned Outage days at Darlington increased by 34 days for the 2015-2017 period versus the 2014-2016 period mainly due to the Darlington Unit 1 Planned Outage in 2014 being shorter than typical duration.
- Capital costs increased by 52% at Darlington from 2014 – 2017 (increase of $91M), primarily due to life extension.
- Darlington performed within the best quartile for Fuel Cost per MWh and better than median for Capital Cost per MW DER while performing worse than the median for the Non-Fuel Operating Cost per MWh.
- For Non-Fuel Operating Cost, the larger equipment inventory in a CANDU unit compared to the pressurized water reactors and boiling water reactors units represents a net increase in maintenance and operations workload, which requires additional staff.

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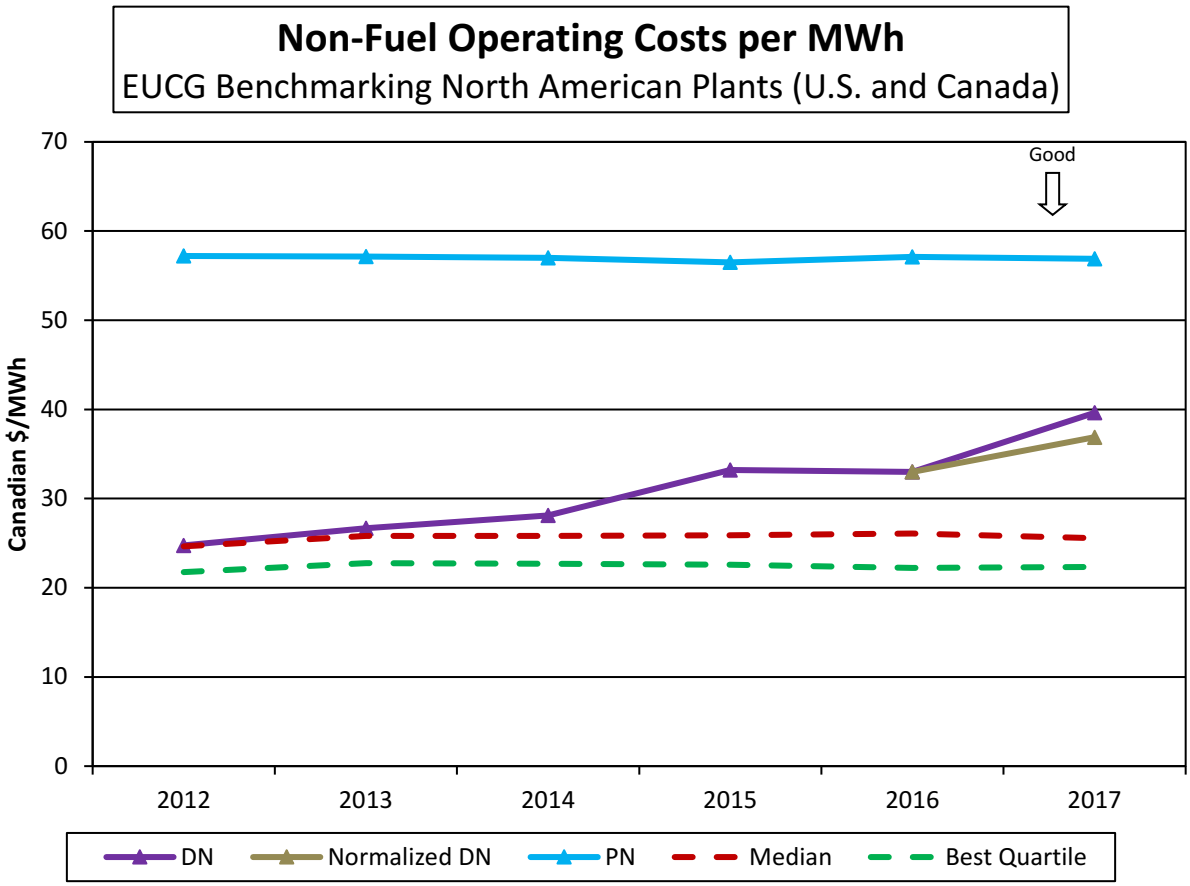
Observations – 3-Year Total Generating Cost per MWh (All North American Plants) (CON'T)

Pickering

- A major driver of Pickering's TGC/MWh is the size of the units, which at 540 MW are the smallest size amongst the peers and compare negatively to the average size of 1,024 MW.
- The 3-Year Rolling Average for Pickering from 2016 to 2017 decreased by $0.84/MWh. The primary driver at Pickering was higher generation (1,331 GWh).
- Planned Outage days for Pickering increased by 40 days for the 2015-2017 period versus the 2014-2016 period leading to increased outage costs in 2017 versus 2014.
- Pickering performed within the best quartile for Fuel Cost per MWh and Capital Cost per MW DER while performing worse than the median for Non-Fuel Operating Cost per MWh.
- For Non-Fuel Operating Cost, performance gap drivers for Pickering include CANDU technology, capability factor, smaller unit sizes, age of the plant, and the fact that Pickering was built based on first generation CANDU technology. While OPG's ten nuclear units are all CANDU reactors, they reflect three generations of design philosophy and technology which impacts the extent and nature of operations and maintenance activity.

3-Year Non-Fuel Operating Cost per MWh



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2017 3-Year Non-Fuel Operating Costs per MWh
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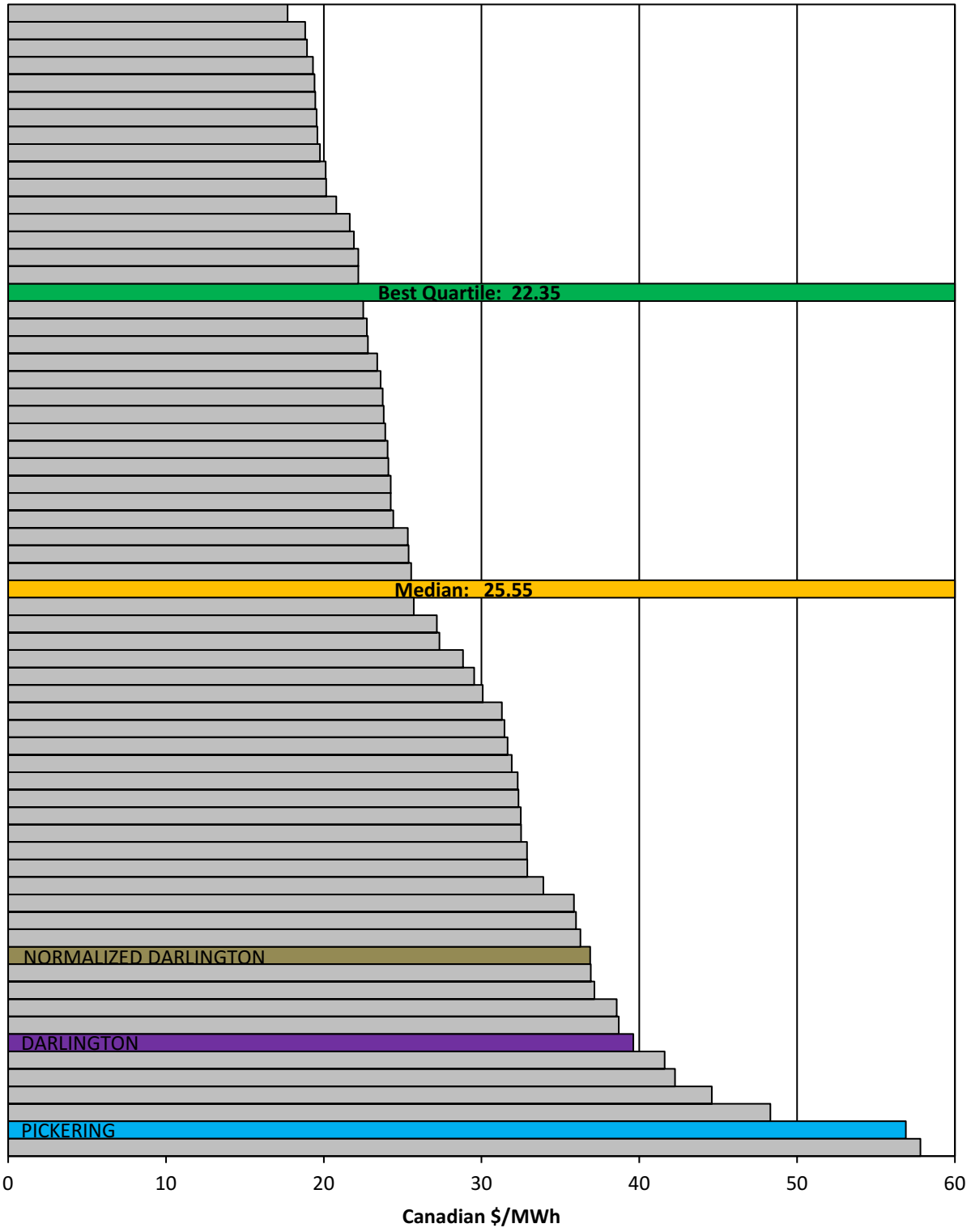

Observations – 3-Year Non-Fuel Operating Cost per MWh (All North American Plants)

2017 (3-Year Rolling Average)

- Best quartile plants had Non-Fuel Operating Costs per MWh (NFOC/MWh) at or below $22.35 while the median plant level threshold was $25.55/MWh.
- Darlington's non-normalized NFOC per MWh, at $39.62/MWh, was $17.27/MWh higher than best quartile and $14.07/MWh higher than the median. Darlington's normalized NFOC per MWh was $36.89MWh
- Pickering's NFOC per MWh, at $56.89/MWh, was $34.54/MWh higher than best quartile and $31.34/MWh higher than median.

Trend

- Pickering largely managed cost increases and remained relatively flat over the review period with a compound annual growth rate (CAGR) of -0.1% whereas both the best and median quartile levels increased by a CAGR 0.5% and 0.7% respectively.
- Pickering NFOC/MWh decreased slightly from 2012 ($57.21/MWh) to 2017 ($56.89/MWh).
- Pickering's annual Non-Fuel Operating Cost over 2012-2017 has been managed through the continuous pursuit of efficiency improvements enabled by initiatives such as the amalgamation of the Pickering A and Pickering B stations into one Pickering site. The company-wide business transformation project launched in 2011 also helped streamline, eliminate and reduce work to leverage attrition profiles while sustaining safety and reliability performance excellence.
- Over the 2012-2017 review period, Darlington's Non-Fuel Operating Cost increased from 2012 ($24.76/MWh) to 2017 ($39.62/MWh).
- Darlington's NFOC/MWh had an annual compound growth rate of 9.9% from 2012 to 2017 as compared to 0.5% for the best quartile and 0.7% for median levels. The 2017 increase in Darlington's NFOC/MWh from 2016 is primarily due to lower generation associated with refurbishment.

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Observations – 3-Year Non-Fuel Operating Cost per MWh (CONT'D)

Factors Contributing to Performance

- Performance in Non-Fuel Operating Cost per MWh drives the majority of OPG's financial performance. Overall, the biggest drivers include: capability factor, station unit size and CANDU technology. The biggest drivers are further expanded below:
  - The 'capability factor' driver is related specifically to generation performance of the station in relation to the overall potential for the station (results are discussed under the Reliability section within the Rolling Average Unit Capability Factor metric).
  - The 'station size' driver is the combined effect of number of units and size of units which can have a significant impact on plant cost performance (refer to the Executive Summary section).
  - The 'CANDU technology' driver reflects specific cost disadvantages related to the overall engineering, maintenance, and inspection costs. OPG undertook a staffing study through a third-party consultant which concluded that technology, design and regulatory differences exist between CANDU and PWR reactor units and that such factors drive staffing differences. The study established that CANDU technology was a contributor to explaining higher staffing levels for CANDU versus PWR plants, which also contributed to OPG's performance in Non-Fuel Operating Cost. The study also found that labour for CANDU stations is approximately 20% higher than in benchmarked PWR stations.

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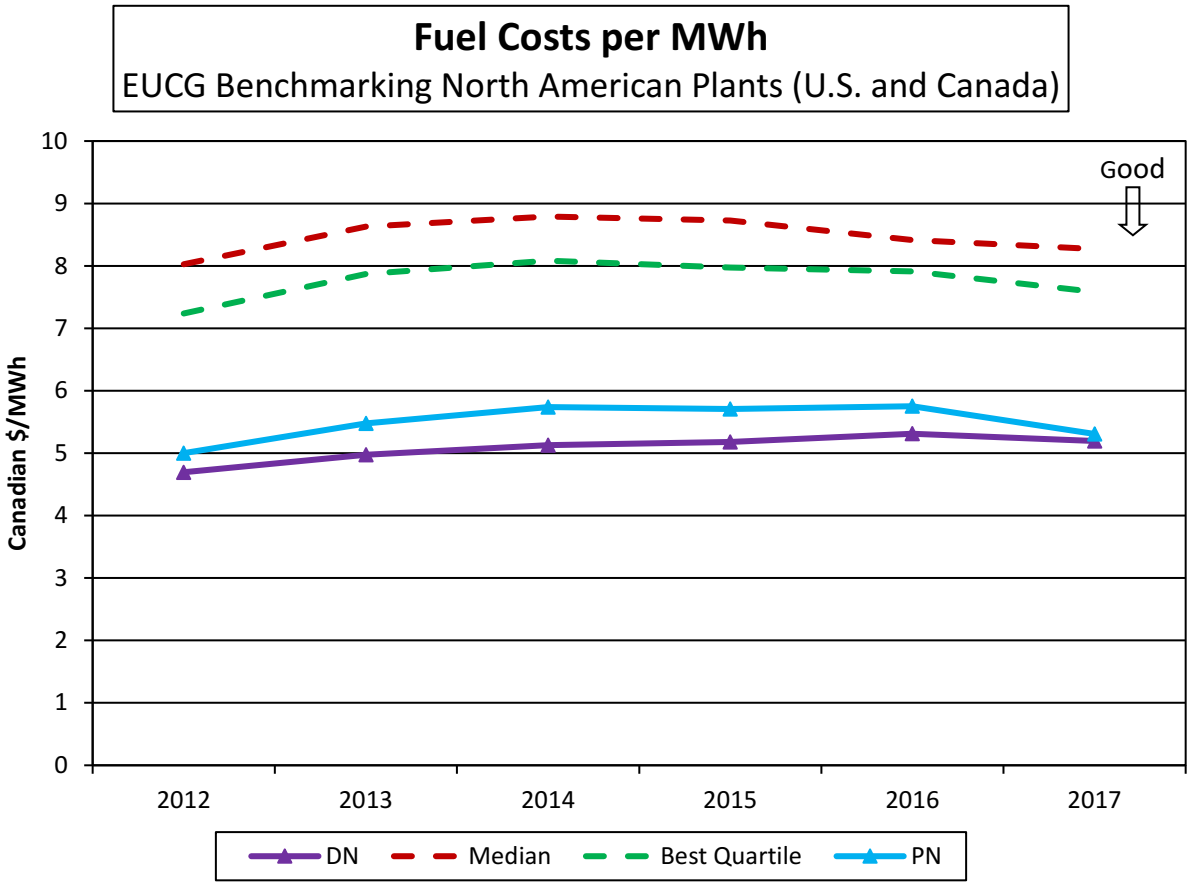
3-Year Fuel Cost per MWh



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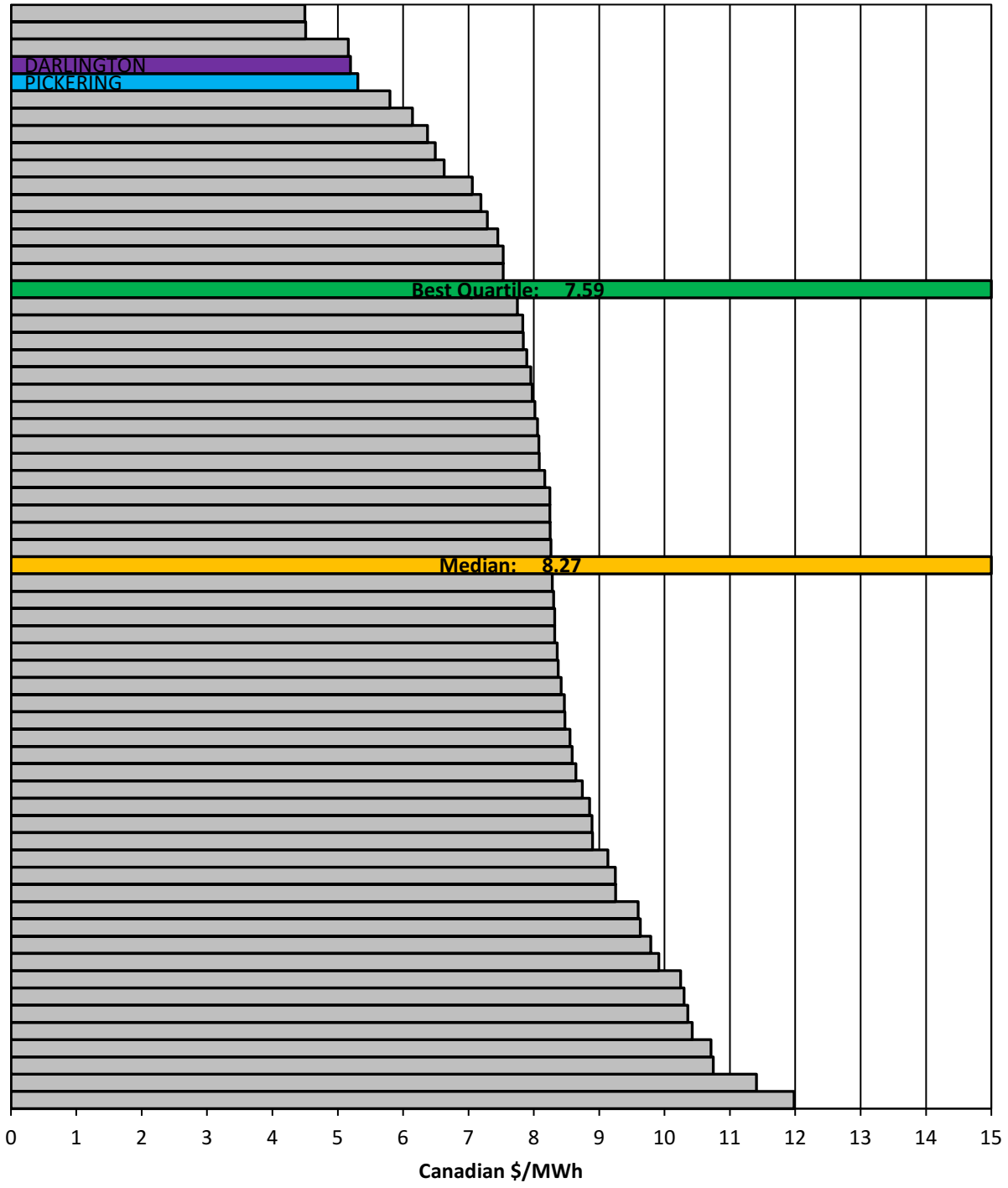
2017 3-Year Fuel Costs per MWh
EUCG Benchmarking North American Plants (U.S. and Canada)



* One plant is excluded due to the plant shutdown in 2019 and significant impairment write-downs on fuel inventory

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

2017 (3-Year Rolling Average)

- Fuel Cost per MWh for all Canadian CANDU plants are better than the best quartile threshold ($7.59/MWh) for the panel of North American EUCG plants.
- The three CANDU plants in the peer panel ranked in the top five lowest fuel cost plants in the North American panel.

Trend

- The best quartile Fuel Cost per MWh has trended lower over 2016 and 2017.
- Fuel Cost per MWh for all OPG plants decreased in 2017. The decrease in the Fuel Cost per MWh is due to a combination of lower input uranium costs offset by general escalation in the fuel conversion and fuel fabrication costs. For 2017, provisions for used fuel storage and disposal costs were excluded from total fuel costs resulting in the decrease. The exclusion of used fuel storage and disposal costs by OPG is consistent with the reporting by other members of the panel of North American EUCG plants.

Factors Contributing to Performance

- Fuel costs, primarily driven by the technological differences in CANDU technology, are lower for OPG than most North American Pressurized Water Reactors or Boiling Water Reactors (PWR/BWR) reactors as CANDUs do not require enriched uranium like BWRs and PWRs. This provides a significant advantage for OPG and other CANDUs in this cost category.

Best quartile fuel cost performance noted above is due to the following factors:

- Uranium fuel costs: Raw uranium is processed directly into uranium dioxide to make fuel pellets, without the cost and process complexity of enriching the fuel as required in light water reactors. The advantage due to fuel costs also includes transportation, handling and shipping costs.
- Reactor core efficiency: 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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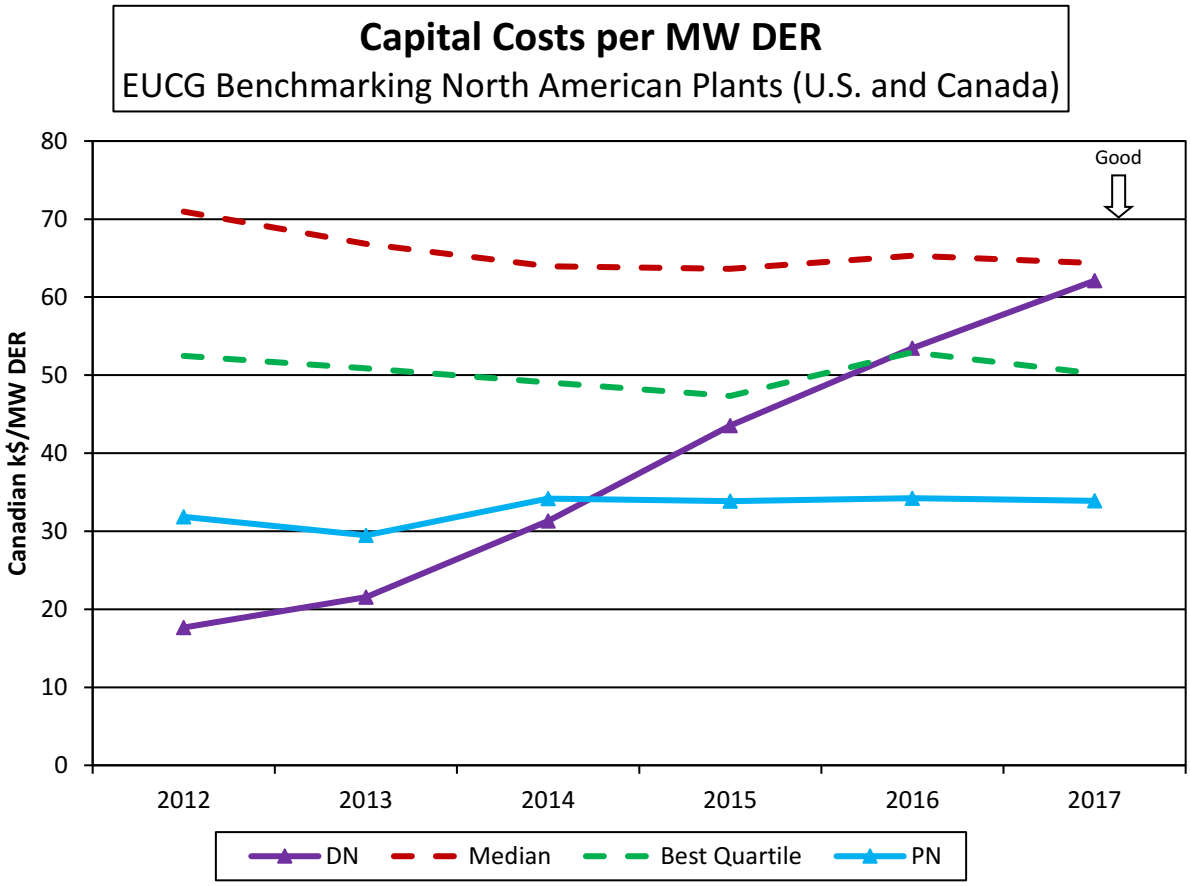
3-Year Capital Cost per MW DER (Design Electrical Rating)



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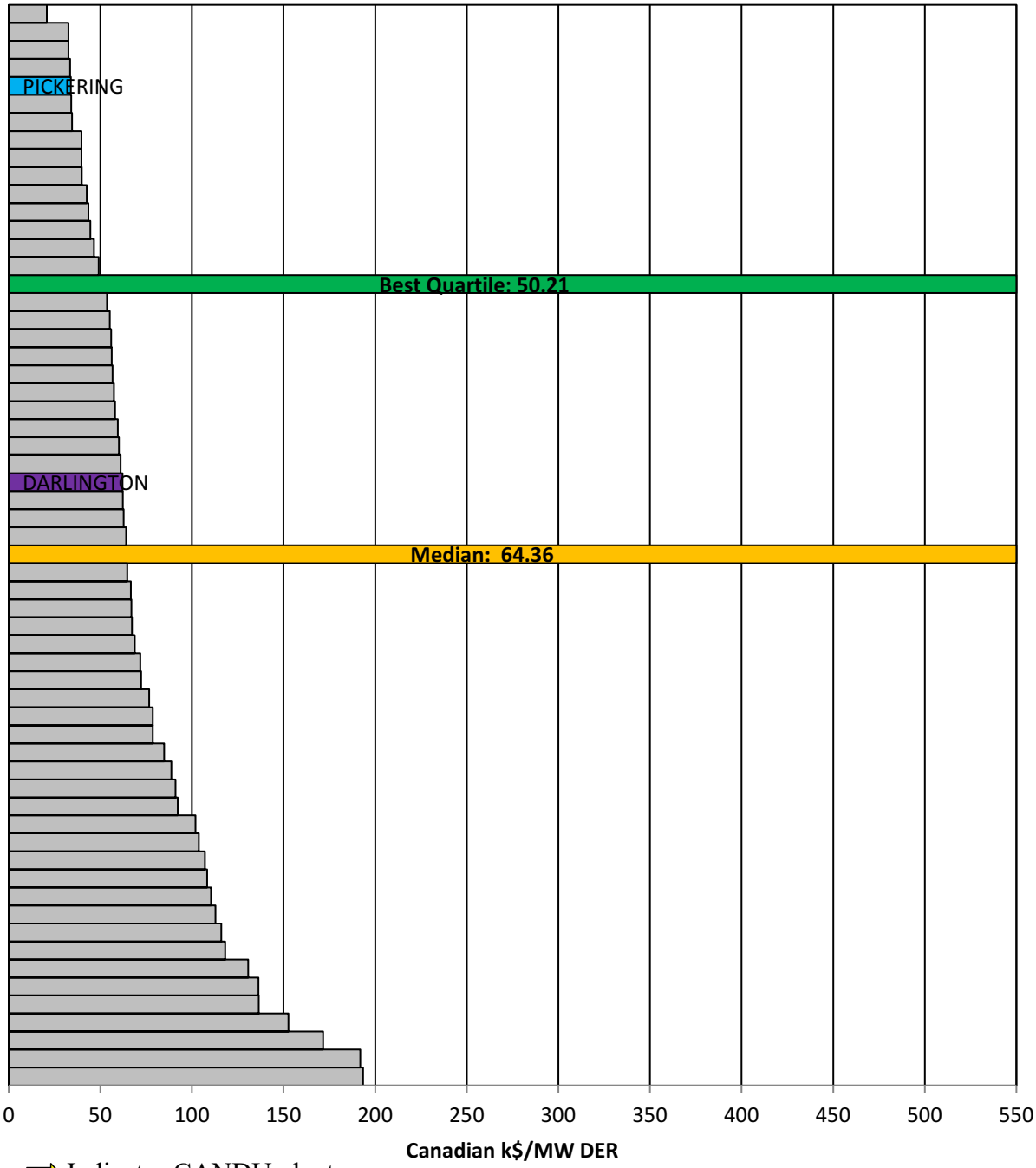
2017 3-Year Capital Costs per MW DER
EUCG Benchmarking North American Plants (U.S. and Canada)



Indicates CANDU plant

* Five plants are excluded as plants are shutting down within 2021 and would be scaling back capital investments

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

2017 (3-Year Rolling Average)

- The first quartile threshold for Capital Cost per MW DER across the North American EUCG peer panel plants was $50.21k/MW DER.
- Median cost for the panel was $64.36k/MW DER.
- Pickering had lower capital cost/MW DER than the first quartile threshold, whereas Darlington had a capital cost/MW DER just below the median cost.

Trend

- The first quartile threshold decreased in 2017 due to reduced spending on Fukushima response and sustaining investments offset by increased spending on reliability improvements.
- Darlington's Capital Cost per MW DER increased in 2017 due to increased spending on life extension, performance improvements, sustaining investments, and Fukushima response.
- Pickering's Capital Cost per MW DER was steady in 2017.

Factors Contributing to Performance

- Pickering is performing in the first quartile overall for the period. This performance reflects spending on enhancements, information technology, infrastructure, regulatory and sustaining investments
- Darlington is performing in the second quartile for the period. This performance reflects spending on information technology, regulatory investments, enhancements, infrastructure, and sustaining investments.
- Darlington's ranking reflects investments to support post-refurbishment operations. Non-power block infrastructure spending at Darlington to support post-refurbishment operations continues to be higher than the majority of its peers.
- Investment in capital spares at both Darlington and Pickering has increased to support overhauls of aging equipment and support safe and reliable operations

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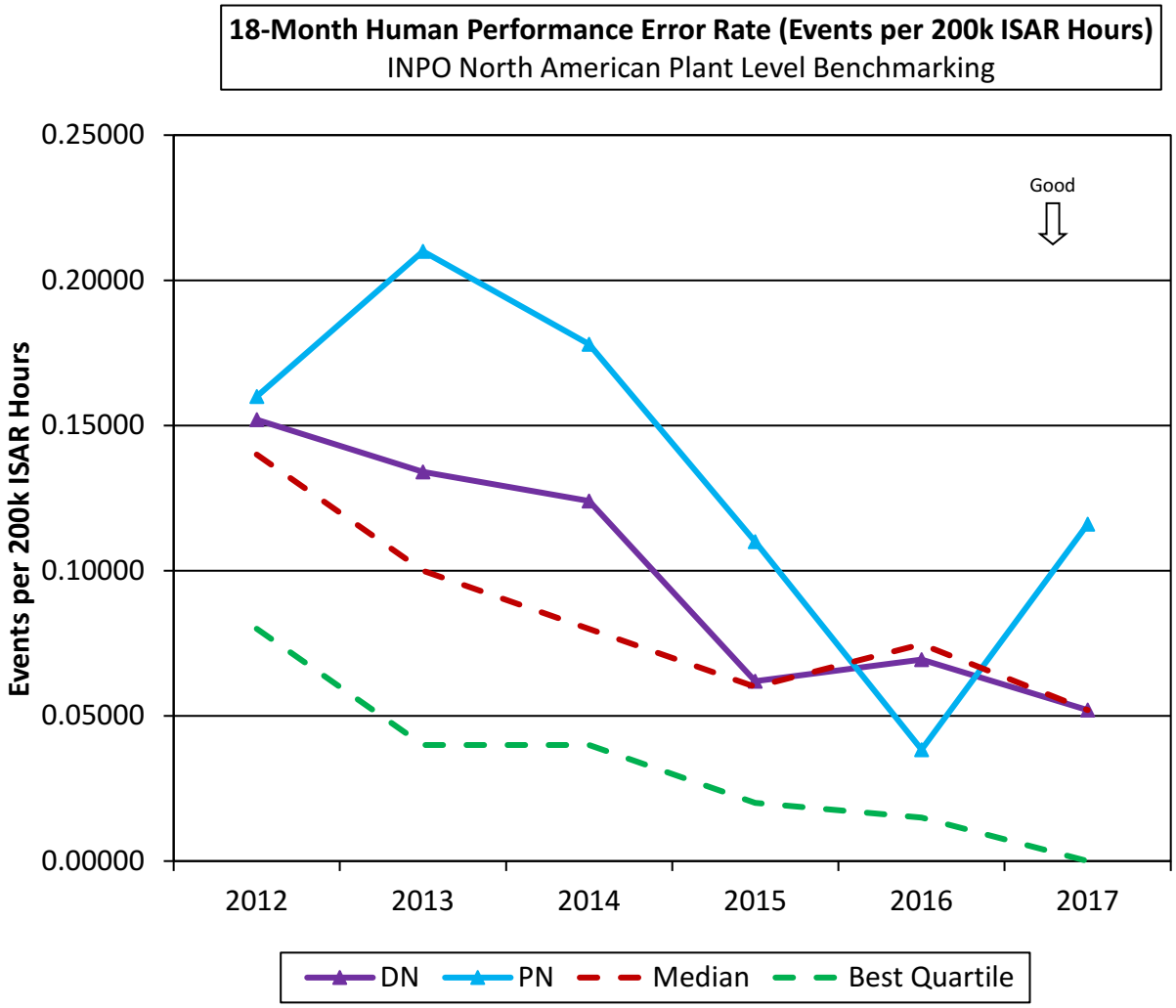
5.0 HUMAN PERFORMANCE

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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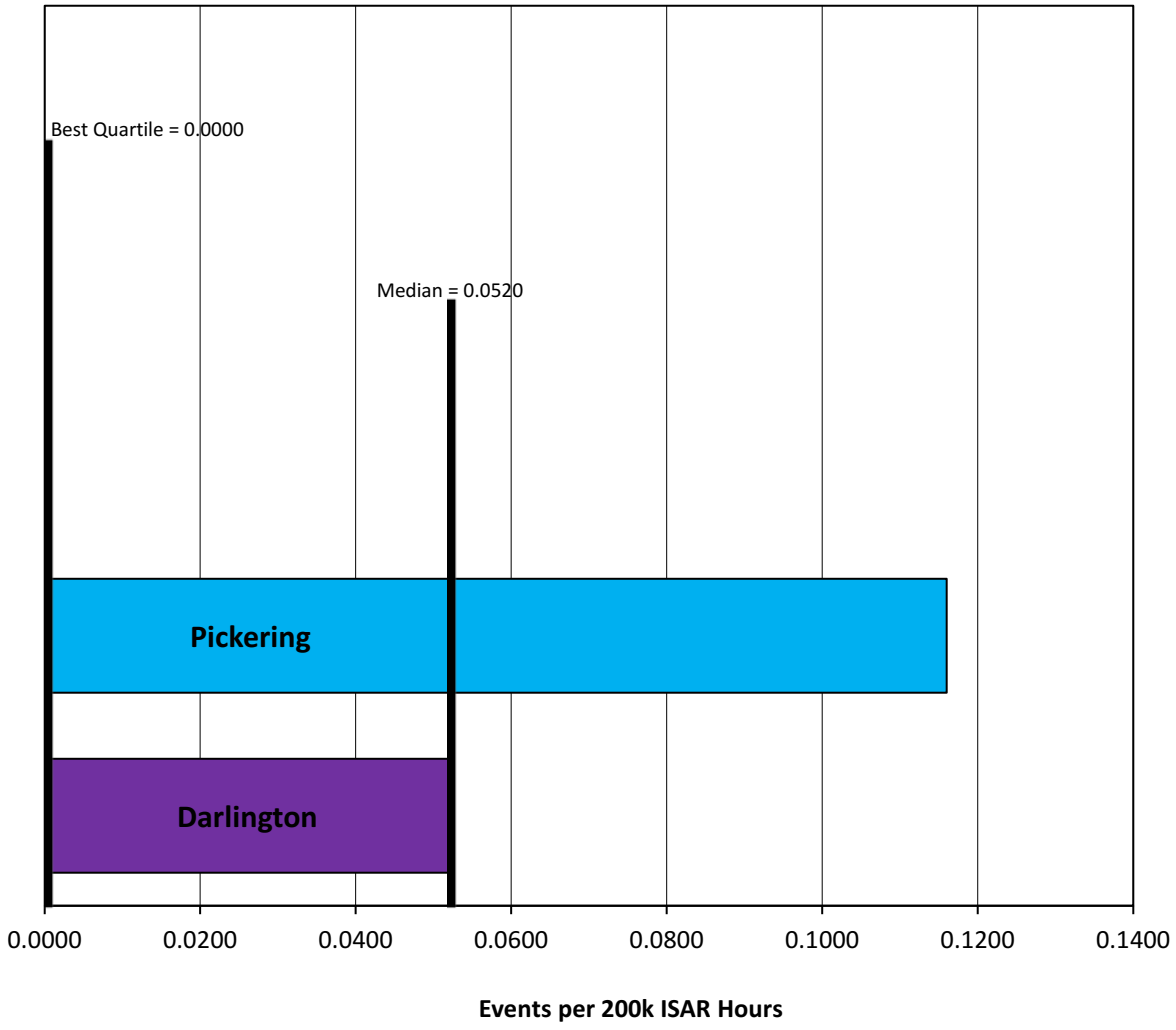
2017 18-Month Human Performance Error Rate

INPO North American Plant Level Benchmarking



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

2017 (18 Month Rolling Average)

- The industry 18-month Human Performance Error Rate (HPER) 2017 INPO best quartile was 0.0000. The median quartile was 0.0520 in 2017.
- Pickering and Darlington 2017 performance was as follows:
  - Pickering station performance was 0.116.
  - Darlington station performance was 0.052.

Trend

- The industry HPER has shown improved performance year over year in the INPO top quartile performance. The 2017 INPO best quartile achieved 0.0000 representing continued improvement in performance since 2012. The median quartile has decreased since 2016 when it was 0.0747, and was 0.0520 in 2017. The overall trend since 2012 showed improvement in the median.
- In 2016, Pickering station's HPER was at its lowest point but has shown a decline in 2017 to below the industry median, resulting from five station event free day resets. Pickering's performance showed a significant improvement since 2013 with the lowest error rate ever in 2016.
- Darlington's performance was trending around the industry median ranking in 2016 and continues with the same performance at the end of 2017.

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Observations – 18 Month Human Performance Error Rate (CONT'D)

Factors Contributing to Performance

- While OPG showed improved HPER performance since 2012, 2017 shows an overall decline in performance for OPG Nuclear. Challenges include integrating a large number of newly hired workers performing work on units being refurbished, which will continue for a number of years. There has been an increased activity at the sites resulting from the refurbishment project at Darlington. Implementation of key strategic initiatives to address behavioural performance is being executed in 2018. The Human Performance Fleet Excellence plan addresses the key opportunities in Human Performance and reinforces the need for OPG leadership to remain focused on setting, communicating and reinforcing standards and expectations through effective coaching in the field. Measures are being taken to ensure vendor partners as well as OPG staff demonstrate Nuclear Professional behaviours around safety and Human Performance to reduce consequential errors.
- The Human Performance Fleet Excellence plan is intended to:
    - Strengthen the use of proactive, risk-based approaches to improve Human Performance through Pre-job Briefings, proficiency, and performance analysis methods.
    - Strengthen performance of Human Performance Managers, Practitioners, Advocates, and Human Performance Peer Team.
    - Improve training and proficiency in Human Performance that focuses on Nuclear Professional standards, innovation, and industry Human Performance best practices.
    - Enhance Facilitative Leadership, Observation & Coaching alignment, and communications to promote Human Performance excellence, and event prevention.
    - Implement actions to address shortfalls in work practices amongst Vendor partners and bring them to the level of OPG staff expectations and standards for performing work.

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Observations – 18 Month Human Performance Error Rate (CONT'D)

Factors Contributing to Performance

- A Qualification has been developed and registered in the Training Information Management System for all Human Performance practitioners who are responsible for the development and implementation of Human Performance initiatives. Implementation of the Human Performance job familiarization guide scheduled for 2018 will serve as a tool to develop the proficiency of Human Performance Managers, Practitioners, cross-functional Practitioners, Human Performance Advocates, and Human Performance Peer Team.
- Improved Human Performance governance and training includes: iCare peer to peer coaching initiative; alignment and simplification of Site and Department Event Free Day Reset criteria and adoption of a standard personnel error rate measure; Observation & Coaching instruction and gap training for middle managers in paired observation and coaching, and Observation & Coaching for First Line Managers and First Line Manager Assistants. 700 leaders have completed the training in 2017. Observation & Coaching remains a focus area in 2018 including completion of the remaining Observation & Coaching checkouts with middle managers, improvements to the Observation & Coaching database to enable better methods to capture, assess, trend and communicate Observation & Coaching results and low-level Human Performance issues.
- Pre-job Briefing procedure was improved to streamline the requirements for delivery of Level 4 Pre-job Briefings. The new streamlined requirement for the delivery of Level 4 high hazard radiation work allows for the health physicist or Radiation Protection department to deliver the Pre-job Briefing given their expertise and involvement in developing the high hazard work plan.

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Observations – 18 Month Human Performance Error Rate (CONT'D)

Factors Contributing to Performance (continued)

- Event analysis and communication process has been revised to introduce an improved Accountability Analysis Process and the Human Performance learning brief. The benefit is to facilitate and promote a healthy reporting culture where all individuals at every level of the organization feel safe reporting errors and mistakes enabling learning and improving performance. A fleet Self Assessment will provide insights into the success of the implementation of the process and further actions will be taken to address gaps.
- In 2018, progress is being made on developing, and piloting methods and tools to identify early stages of Human Performance decline so that they can be arrested before triggering Human Performance events.
- Human Performance and high Maximum Reasonable Potential for Harm events are challenged for the Darlington Refurbishment project and a significant effort is being expended in 2018 to help bring vendor partner Human Performance practices up to OPG standards, and to provide sufficient coaching and oversight to reduce the risk of significant events impacting the project. OPG is collaborating with Vendor Partners and Bruce Power to improve Human Performance training and evaluation opportunities for supplemental workers and supervisors. Actions are captured in the Human Fleet Excellence Plan, 2018-19.

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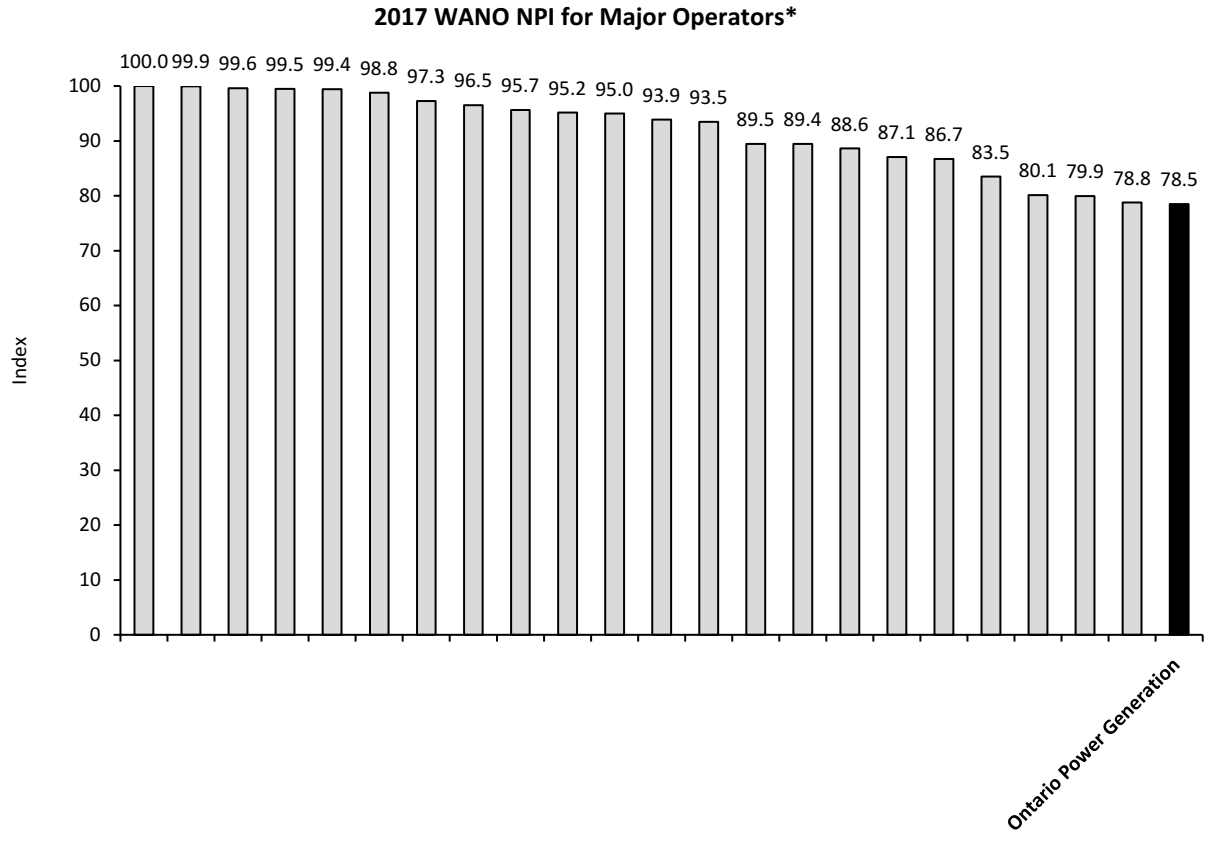
6.0 MAJOR OPERATOR SUMMARY

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. Although the benchmarking study has been primarily focused on operational performance comparison to COG CANDUs, this section of the report compares OPG Nuclear's performance against North American PWR and PHWR operators in addition to the international CANDU panel. 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. 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 because costs are not allocated to specific units within the EUCG industry panel.

WANO Nuclear Performance Index Analysis

The WANO Nuclear Performance Index (NPI) results for the operators in 2017 are illustrated in the graph below. OPG Nuclear performance ranking declined from 2017 shown in Table 3.



*See Table 8 in the Appendix for listing of operators and plants.
**OPG Nuclear unit values averaging to a WANO NPI of 78.5 in 2017 are shown below:

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Unit	2017 WANO NPI
Pickering 1	65.0
Pickering 4	65.9
Pickering 5	85.8
Pickering 6	97.1
Pickering 7	69.1
Pickering 8	77.4
Darlington 1	76.9
Darlington 2	N/A
Darlington 3	77.6
Darlington 4	91.6

OPG ranked 23rd, with an NPI of 78.5. OPG's NPI performance decreased by 2.4 compared to the 2016 ranking. As discussed in Section 3.0 above, NPI has been impacted by plant life extension activities (i.e., Pickering Extended Operations and Darlington Refurbishment).

The NPI rankings of the major operators from 2012 to 2017 are listed in Table 3. The list and ranking of operators has been updated to reflect any industry developments if applicable.

Table 3: Average WANO NPI Rankings

Operator	2012	2013	2014	2015	2016	2017
	22	10	5	5	3	1
	10	13	2	4	13	2
	12	9	12	16	14	3
	18	8	9	2	2	4
	7	4	7	10	7	5
	11	15	18	21	15	6
	6	5	4	6	6	7
	5	6	10	8	10	8
	3	1	13	9	9	9
	1	18	20	20	12	10
	8	7	6	17	17	11
	23	24	3	15	16	12
	2	12	16	1	8	13
	24	23	19	7	11	14
	13	17	15	12	4	15
	17	16	8	3	1	16
	15	19	11	11	20	17
	27	25	24	24	23	18
	20	21	21	22	19	19
	4	2	14	13	5	20
	19	14	1	14	18	21
	21	3	17	19	22	22
Ontario Power Generation	25	22	22	23	21	23
	9	20	23	18	NA	NA
	16	11	NA	NA	NA	NA
	14	NA	NA	NA	NA	NA
	26	NA	NA	NA	NA	NA
	26	NA	NA	NA	NA	NA

Note: Five operators are no longer ranked in 2017 (reason for 28 ranked operators in 2012 vs. 23 in 2017). These operators were removed as a result of plant acquisitions or closures. All 2012-2016 rankings and numbers are carried over from previous Benchmarking reports.

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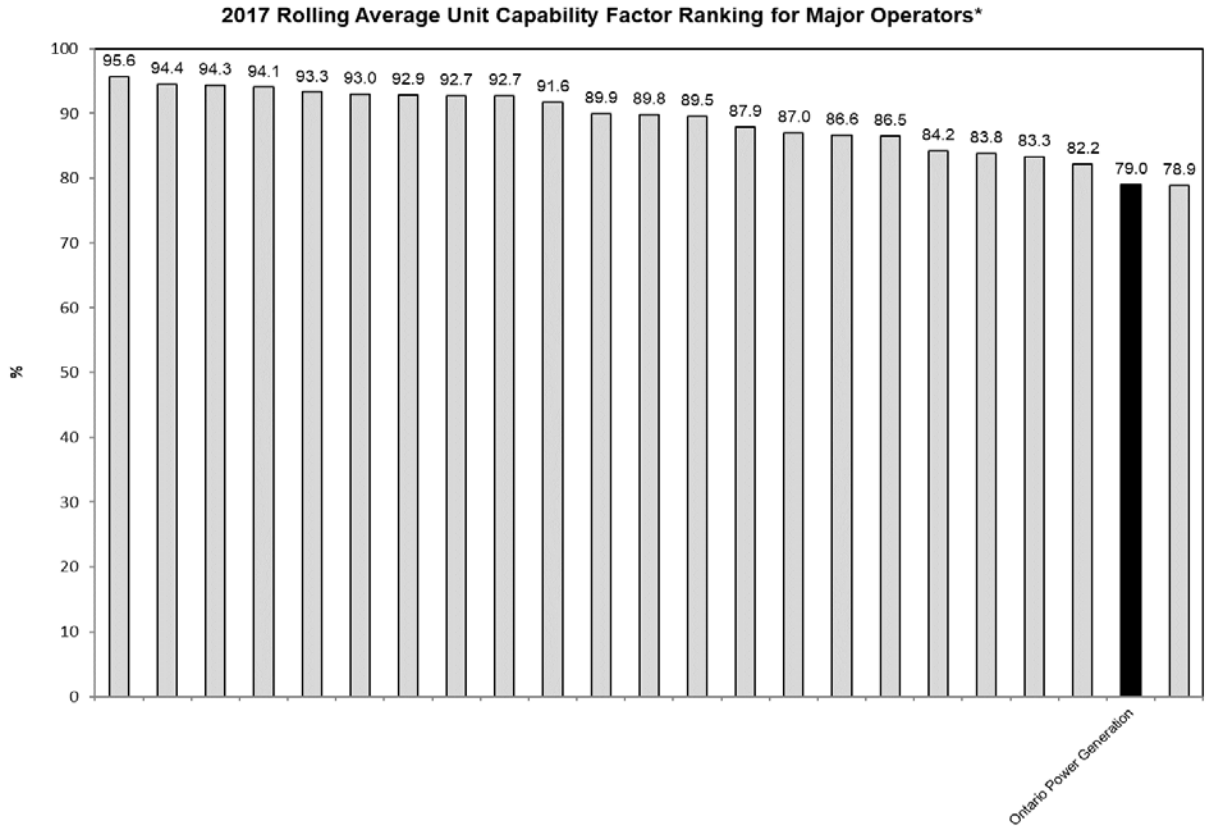
Unit Capability Factor Analysis

Unit Capability Factor (UCF) is the ratio of available energy generation over a given time period to the reference energy generation of the same time period, expressed as a percentage. Reference energy generation is the energy that could be produced if the unit were operating continuously at full power under normal conditions. Since nuclear generation plants are large fixed assets, the extent to which these assets generate reliable power is key to operating and financial performance.

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 industry developments if applicable. 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 outage cycle. OPG Nuclear achieved a rolling average UCF of 79.0% and ranked 22 out of 23 operators in the WANO data set. As discussed in Section 3.0 above, NPI has been impacted by plant life extension activities (i.e., Pickering Extended Operations and Darlington Refurbishment).



* See Table 8 in the Appendix for listing of operators and plants.

**OPG unit values averaging to a rolling average UCF of 79.0% in 2017 are shown below:

Unit	2017 Rolling Average UCF
Pickering 1	76.0
Pickering 4	71.4
Pickering 5	81.7
Pickering 6	94.9
Pickering 7	72.9
Pickering 8	67.3

Unit	2017 Rolling Average UCF
Darlington 1	77.6
Darlington 2	N/A
Darlington 3	82.7
Darlington 4	86.3

Rankings for the major operators for UCF over the past six years are provided in Table 4 below.

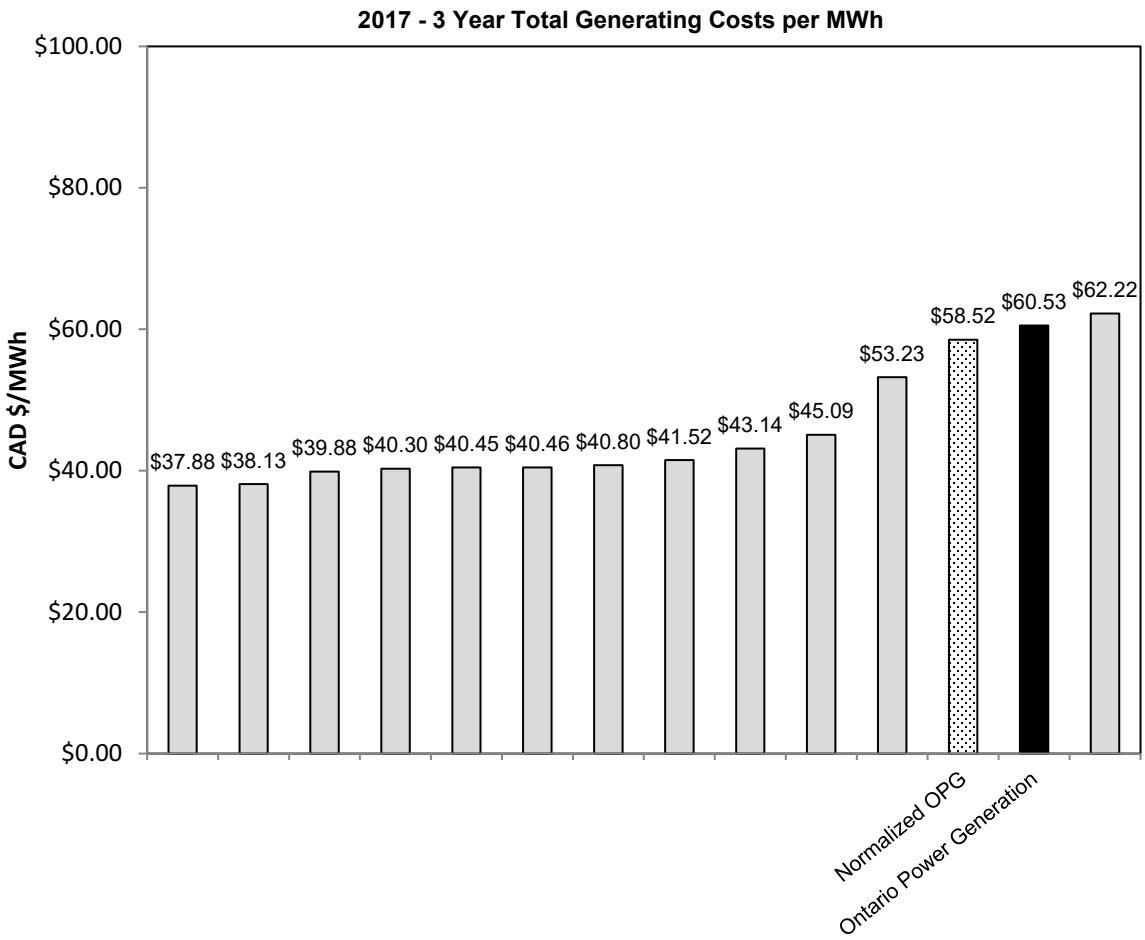
Table 4: Rolling Average Unit Capability Factor Rankings

Operator	2012	2013	2014	2015	2016	2017
	4	4	1	1	1	1
	15	8	8	6	5	2
	22	6	2	7	2	3
	20	21	20	17	14	4
	1	2	6	5	8	5
	10	7	4	9	11	6
	13	9	10	14	10	7
	6	12	13	12	4	8
	12	10	7	2	7	9
	24	23	16	15	13	10
	18	11	12	21	9	11
	23	22	23	22	21	12
	19	20	18	20	20	13
	5	1	5	10	3	14
	3	3	9	8	18	15
	14	16	11	11	15	16
	17	17	15	18	17	17
	9	14	17	3	12	18
	27	24	22	24	23	19
	2	13	19	4	6	20
	8	5	14	19	19	21
Ontario Power Generation	21	19	21	23	22	22
	16	15	3	13	16	23
	26	25	24	16	NA	NA
	7	18	NA	NA	NA	NA
	11	NA	NA	NA	NA	NA
	25	NA	NA	NA	NA	NA

Note: Four operators are no longer ranked in 2017 (reason for 27 ranked operators in 2012 vs. 23 in 2017). These operators were removed as a result of plant acquisitions or closures. All 2012-2016 rankings and numbers are carried over from previous Benchmarking reports.

Total Generating Cost/MWh Analysis

The 3-year Total Generating Cost/MWh results for the major operators in 2017 are displayed in the graph below. Total Generating Costs are defined as total operating costs plus capital costs and fuel costs of all plants that the operator operated in 2015-2017. This value is divided by the total net generation of all plants that the operator operated for the same period and is provided as a three-year average. OPG Nuclear ranked 12th, with a 3-year Total Generation Cost of $60.53 per MWh (non-normalized). After normalizing performance for refurbishment, OPG's TGC per MWh is $58.52 per MWh.



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

Unit	2017 3-Year TGC
Darlington (non-normalized)	$54.40/MWh
Darlington (normalized)	$50.54/MWh
Pickering	$67.22/MWh

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Table 5: Three-Year Total Generating Cost per MWh Rankings

	2012	2013	2014	2015	2016	2017
	4	1	1	1	2	1
	5	4	4	2	1	2
	9	10	11	11	9	3
	1	2	2	4	5	4
	2	6	5	3	3	5
	NA	11	7	7	6	6
	3	3	3	5	4	7
	14	14	12	8	7	8
	6	5	8	9	10	9
	7	7	6	6	8	10
	11	9	9	10	11	11
Ontario Power Generation	10	8	10	12	12	12
	13	13	13	13	13	13
	12	12	NA	NA	NA	NA
	8	NA	NA	NA	NA	NA

Note: Two operators have been removed due to acquisitions by the other operators in the panel (reason for 14 ranked operators in 2012 vs. 13 in 2017).

Table 6 shows the relative contribution of Non-Fuel Operating Costs, Fuel Costs and Capital Costs to Total Generating Cost and compares OPG's non-normalized costs to those of all EUCG operators.

Table 6: EUCG Indicator Results Summary (Operator Level)

EUCG Indicator Results Summary	OPG Average	EUCG Major Operators*		Units
		Median	Best Quartile	
Value for Money Performance				
3-Yr. Non-Fuel Operating Costs per MWh	$ 47.88	$ 24.37	$ 23.50	CAD $/MWh
3-Yr. Fuel Costs per MWh	$ 5.25	$ 8.30	$ 7.68	CAD $/MWh
3-Yr. Capital Costs per MWh	$ 7.41	$ 8.01	$ 7.41	CAD $/MWh
3-Yr. Total Generating Costs per MWh	$ 60.53	$ 40.80	$ 40.30	CAD $/MWh

*See Table 9 in the appendix for list of operators included.

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
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.

All Injury Rate is the average number of fatalities, total temporary disabilities, permanent total disabilities, permanent partial disabilities and medical attention 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.

Airborne Tritium Emissions per Unit: Tritium emissions to air.

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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

- PHWRs on molar ratio control
  - Steam generator blowdown chloride
  - Steam generator blowdown sulfate
  - Final feedwater iron
  - Final feedwater copper
  - Feedwater dissolved oxygen
  - Steam generator molar ratio target range (by reporting the upper and lower range limits (as "from" and "to" values)
  - Steam generator actual molar ratio

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 2018 EUCG Nuclear Committee Nuclear Database Instructions*.

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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.

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 total operating costs and capital costs.

Total Operating Costs ($)
The sum of operating costs and fuel costs.

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

Human Performance Definitions

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)

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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 7: Industry Peer Groups

	WANO / COG CANDUs	All North American PWR and PHWRs (WANO)	INPO AP-928 Workgroup	INPO	CEA	EUCG North American Plants (U.S. and Canada)
Safety						
All Injury Rate					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 Cost / MWh						X
3-Year Non-Fuel Operating Cost (OM&A) / MWh						X
3-Year Fuel Cost / MWh						X
3-Year Capital Cost / 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 All Injury Rate 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.

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.

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Panels

Table 8: 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
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
South Carolina Electric & Gas Co.	V.C. Summer
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 9: EUCG Panel

Major Operator	Plant
Bruce Power	Bruce A Bruce B
Dominion Generation	Millstone North Anna Surry
Duke Energy	Brunswick Catawba Harris Mcguire Oconee Robinson
Entergy Nuclear	Arkansas Nuclear One Fitzpatrick Grand Gulf Indian Point Palisades Pilgrim River Bend Waterford
Exelon Generation Co.	Braidwood Byron Calvert Cliffs Clinton Dresden 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	South Carolina Electric & Gas Company (SCE&G)	V.C. Summer
Energy Northwest	Columbia	STP Nuclear Operating Co.	South Texas
Luminant Generation	Comanche Peak	Wolf Creek Nuclear Operations Corp.	Wolf Creek

Table 10: 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 11: CEA Members

Companies
AltaLink
ATCO Electric
ATCO Power
BC Hydro and Power Authority
Brookfield Renewable Energy Group
Capital Power Corporation
City of Medicine Hat, Electric Utility
Columbia Power Corporation
Emera Inc.
ENMAX
EnWin
EPCOR
FortisAlberta Inc.
FortisBC Inc.
Horizon Utilities Corp
Hydro One
Hydro Ottawa

Companies
Hydro Quebec
Manitoba Hydro
Maritime Electric Company
Nalcor Energy
New Brunswick Power
Newfoundland Power
Northwest Territories Power Corp.
Nova Scotia Power
Oakville Hydro Corp.
Ontario Power Generation
PowerStream
Saint John Energy
Saskatoon Light & Power
SaskPower
Toronto Hydro Corp.
TransCanada
Yukon Energy Corp.

Table 12: 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	

Table 13: INPO Members for On-Line Maintenance Backlogs

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	

Table 14: NPI Plant Level Performance Summary (North American Panel)

	2017 Actuals				
Indicator	NPI Max	Best Quartile	Median	Pickering	Darlington
Rolling Average Industrial Safety Accident Rate (#/200k hours worked)	0.20	0.00	0.00	0.05	0.04
Rolling Average Collective Radiation Exposure (person-rem per unit)	80.00	24.74	36.40	83.96	91.80
Fuel Reliability Index (microcuries per gram)	0.000500	0.000001	0.000005	0.000584	0.000179
2-Year Reactor Trip Rate (# per 7,000 hours)	0.50	0.00	0.21	0.26	0.29
3-Year Auxiliary Feedwater System Unavailability (#)	0.0200	0.0027	0.0042	0.0000	0.0000
3-Year Emergency AC Power Unavailability (#)	0.0250	0.0084	0.0141	0.0030	0.0000
3-Year High Pressure Safety Injection Unavailability (#)	0.0200	0.0015	0.0027	0.0000	0.0000
Rolling Average Forced Loss Rate (%)	1.00	0.62	1.28	5.01	3.47
Rolling Average Unit Capability Factor (%)	92.00	94.29	91.89	77.36	82.17
Rolling Average Chemistry Performance Indicator (Index)	1.01	1.00	1.00	1.02	1.01
WANO NPI (Index)	Not Applicable	100.0	97.0	76.7	82.0