Compilation and Assessment of Lab Samples from EGCS Washwater Discharge on Carnival ships

February 2019

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EXECUTIVE SUMMARY

Background to the work

- In 2016 Carnival Corporation collected an initial set of 79 Exhaust Gas Cleaning System (EGCS) washwater samples from 23 ships.
- Samples were collected by shipboard staff using a standard US EPA-referenced sampling protocol and training, and analysed for 54 test parameters at independent SGS environmental specialist ISO certified laboratories, all using EPA standard methods.
- DNV GL's Maritime Advisory Services were engaged by Carnival to compile and review the laboratory test data and to compare the washwater lab results to various national and international point source discharge limits and water quality standards.
- Since the completion of the 2016 study, Carnival has continued to take additional samples - a total number of 281 by early 2018, taken from 53 ships.
- In 2018, the assessment was updated and re-evaluated to incorporate these additional standards.
- The objective of this work is to better to understand the quality of EGCS washwater and the parameters which are present.
- As no water quality standards contain criteria for all the EGCS test parameters, in both assessments the results were compared to both "point source" and "water quality" standards in order to gain the fullest understanding of the potential EGCS impact on water quality.

Sampling and analysis methods

Sampling

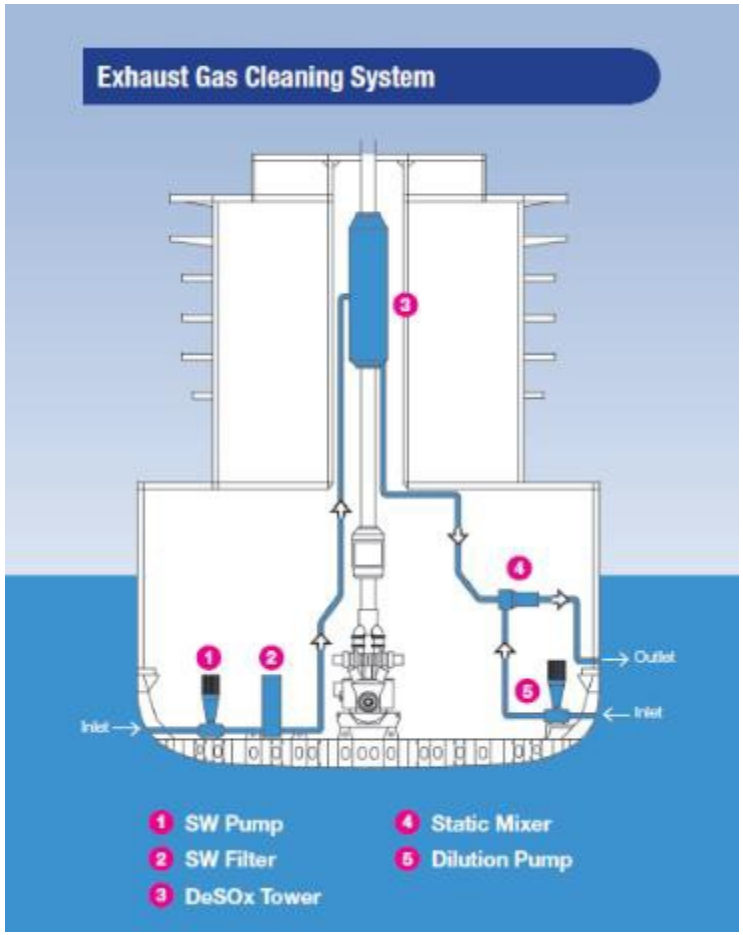
- Samples are collected and analysed in accordance with a standard US EPA-referenced Protocol developed in cooperation with SGS. Samples are taken by ship's Environmental Officers and Engineers following an onboard training program.
- The sample data base includes samples taken at the inlet, EGCS tower, and outlet.
- The expanded sample data base also includes samples from 11 ships with wash-water filtration installed, providing a fourth sample from a point before this filter.

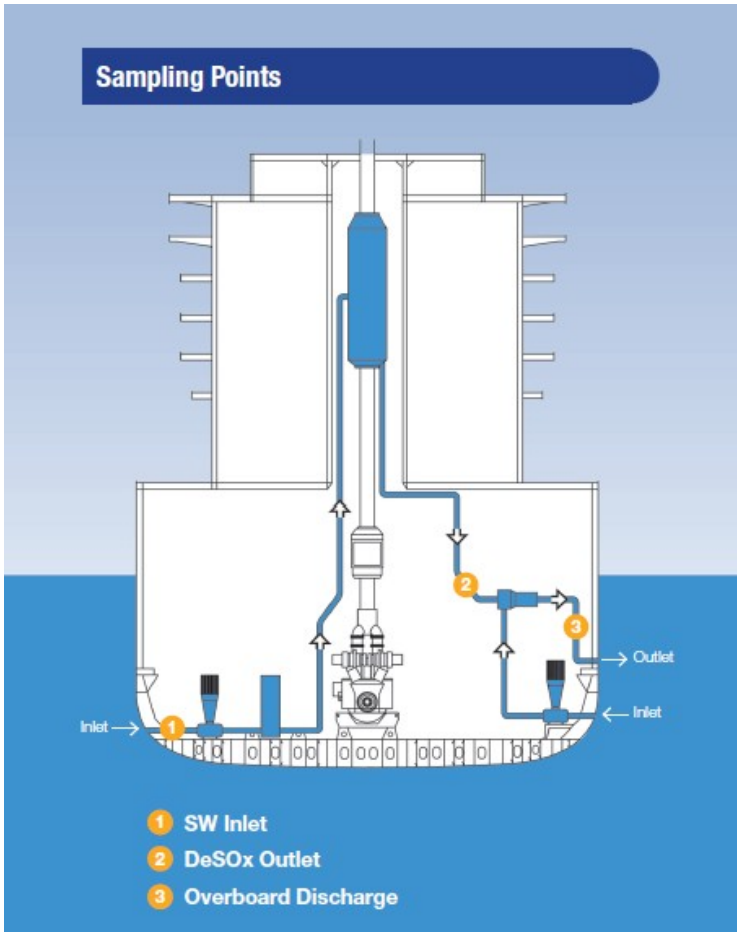
Analysis

- Sample analysis is conducted by ISO 17025 certified SGS laboratories using US EPA approved methods (or equivalent) to test for 54 parameters, including PAHs and metals.
- A "net post-EGCS" methodology is used to compare to various water quality standards, with the additional analytic step of using a trimmed mean excluding statistical outliers more than three standard deviations from the mean.*
- The laboratory results have been compiled and reviewed by DNV GL. DNV GL were not involved in the sampling process or the laboratory analysis of samples.

*This is consistent with the United States Geological Survey's Statistical Methods in Water Resources.

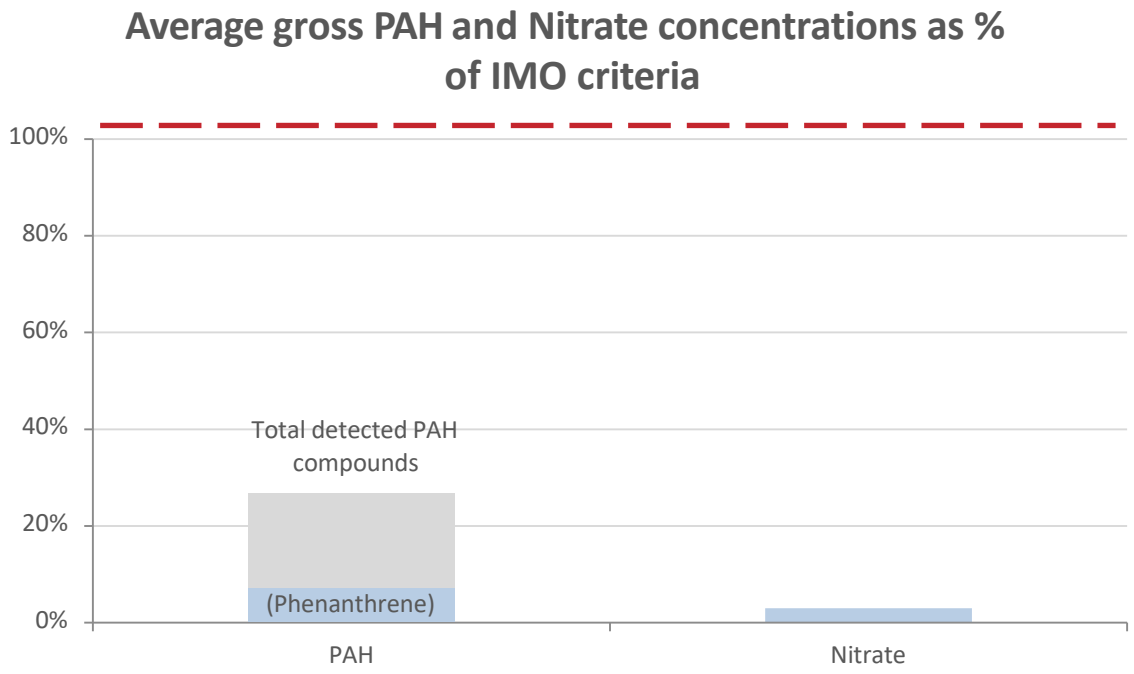
Carnival Open Loop EGCS





NOTE: Sampling points are installed at the seawater inlet (1), the EGCS tower (DeSOx) outlet (2) and before the overboard Net post-EGCS values were calculated by comparing the post-EGCS tower outlet values (2) with SW inlet values (1).

Sample analysis shows average PAH and Nitrate levels below IMO washwater criteria



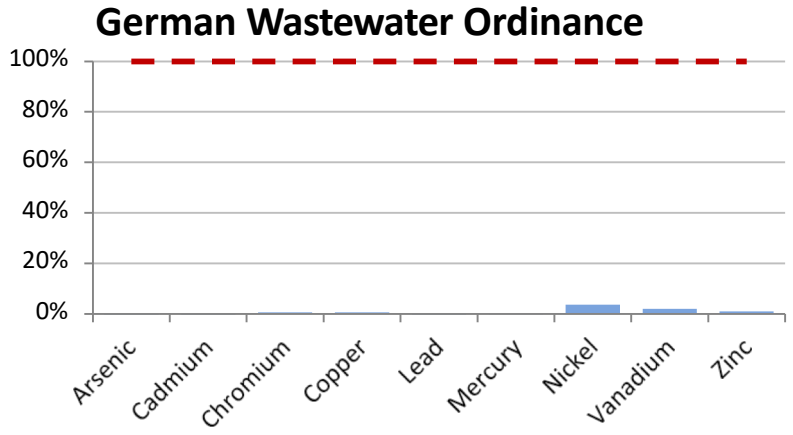
Compound	Lowest IMO criteria (based on 90 t/MWh flow rate)		Average gross post EGCS concentration	
PAH	25	µg/L	1.77	µg/L *
Nitrate	30	mg/L	0.8	mg/L

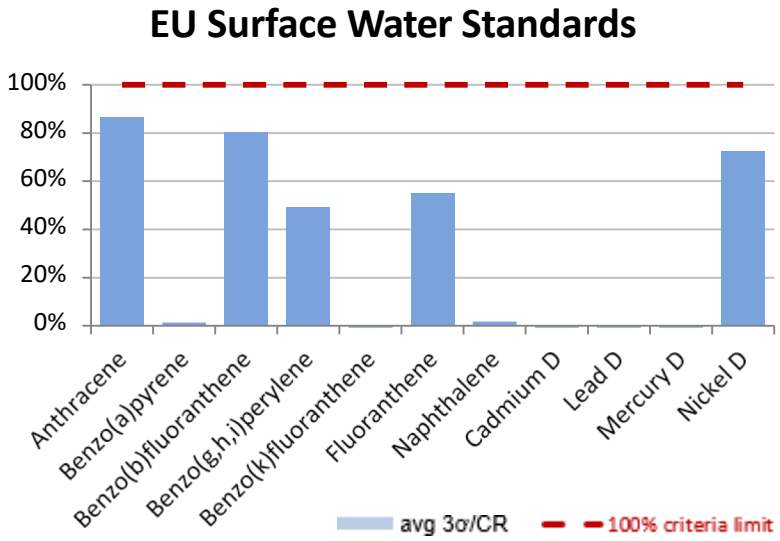
* IMO requirements for PAH are based on phenanthrene equivalence, so the post-EGCS value given is for phenanthrene. Total detected PAH compounds are shown on the graph for information.

- The wash-water discharge limitations vary according to the EGCS wash-water output, i.e. the higher the wash-water flow the lower the allowed concentration.
- Here, the weighted average **gross** post-EGCS concentrations are compared with the lowest theoretical requirements.
- Both the post-EGCS PAH values for phenanthrene and the average sum of all detected PAH values are below the strictest IMO requirements.
- This comparison is for illustrative purposes, and does not constitute approval of any vessel with IMO requirements.

Comparison to water quality standards gives a deeper understanding of washwater composition

- Comparing the wash-water to various water standards does not intend to indicate compliance with those - only to illustrate the quality in a way that is easy to understand.
- Comparison is made to various standards including:
  - **The German Wastewater Ordinance:** Point source wastewater limitations from biological waste treatment.
  - **The EU Surface Water Standards** (part of EU Water Framework Directive): A water quality standard showing the maximum allowed concentration in inland surface waters.
- This method uses the difference between the average of inlet values and the average of post-EGCS values (sampling point 2 – point 1).
- All non-detected sample parameters are given a value equal to 50% of the laboratory equipment detection limit.
- Results shown exclude statistical outliers more than three standard deviations (3σ) from the mean sample parameter value.





Summary

- The study presents a snapshot of average washwater concentrations across a significant fleet of operating EGCS equipped ships.
- The study provides an objective evaluation of washwater quality as the basis for more informed debate. It does not:
  - Attempt to assess the cumulative effect of washwater parameters entering seawater or the potential environmental impact.
  - Make any conclusions regarding washwater parameter concentrations and fuel types, engine and flow conditions.
- All laboratory analysed samples remain comfortably within the minimum IMO criteria for PAH and nitrate concentrations.
- As with the earlier 2016 study, the concentrations of all tested parameters for the 2018 samples are below the criteria for relevant land-based point source waste water standards.
- In addition to point source standards, the samples are compared to standards with stricter criteria. These standards are not directly applicable to point source discharges but provide a broader context for understanding washwater quality. When statistical outliers with a three-sigma deviation are excluded through a trimmed mean statistical method, the washwater parameters are below these criteria.*

*Only a low proportion of samples are excluded by this method and many of these statistical outliers are present in the inlet as well as post-EGCS samples.

- Executive Summary
- **Background**
- Sampling and Analysis Methodology
- Observations from Lab Results
- Comparison to Water Quality Standards
- Conclusions

- Evaluating washwater beyond compliance
- Assessment approach
- Limitations of the Assessment
- The 2016 and 2018 Assessments

Evaluating washwater beyond compliance

- Carnival Corporation employs **continuous** monitoring of required Exhaust Gas Cleaning System (EGCS) washwater parameters according to:
  - IMO requirements (MEPC.259(68) 2015 Guidelines for Exhaust Gas Cleaning Systems)
  - EU Sulphur Directive (EU/2012/33)
  - US EPA Vessel General Permit
- All Carnival vessels are equipped with continuous monitoring equipment to log required parameters automatically.
- The IMO encourages **periodic** monitoring to test for additional parameters with spot samples, using measurement techniques which are more advanced than those possible to achieve during continuous monitoring.
  - In 2016 a total of 79 samples were collected and analysed from the first 23 Carnival EGCS vessels.
  - Sampling continued and in 2018 a re-analysis was undertaken on a total of 281 samples taken from 53 ships.

Vessels are encouraged to perform periodic monitoring for:*

- pH
- PAH and oil
- Nitrate
- Nitrite
- Cadmium
- Copper
- Nickel
- Lead
- Zinc
- Arsenic
- Chromium
- Vanadium

Periodic monitoring is separate from the required continuous monitoring.

* The US VGP also requires periodic monitoring for selenium and thallium.

Assessment approach

- Samples were collected by shipboard staff using a standard US EPA-referenced sampling protocol and training, and analysed for 54 test parameters at independent SGS environmental specialist accredited laboratories, all using EPA standard methods.
- DNV GL's Maritime Advisory Services were not involved in the sampling process or the laboratory analysis, but were engaged by Carnival to:
  - Compile and review the lab test data; and
  - Compare wash-water test parameters to various water quality standards.

- Since no water quality standards exist which contain criteria for all parameters tested in the sampling campaign, two land-based point source discharge standards were chosen in addition to the IMO's EGCS washwater requirements to provide a benchmark for total metal concentrations.
- A comparison was also made to water quality standards as a means of evaluating PAH levels in context. While the water quality standards refer to bodies of water rather than a discharge, they illustrate the general quality of the washwater discharge and provide a broader perspective than comparison to IMO requirements, or simply a compilation of the average concentration alone can provide.
- Non-weighted averages of the net post-EGCS concentration for each parameter have been calculated and compared to the relevant criteria limits for these water quality standards.

Limitations of the assessment

- Comparing the washwater to various water standards does not intend to indicate compliance with those - only to illustrate the quality in a way that is easy to understand.
- The study and comparison with water quality standards does not constitute an environmental impact assessment.*
- The objective of this study was to present a snapshot of average washwater concentrations. It was not within the scope of this assessment to identify relationships or correlations between parameter concentration in the washwater and the following factors:
  - Fuel type and quality
  - Fuel consumption
  - Dilution rates
  - Flow rates of sea water inlet, post EGCS tower and overboard discharge
  - Engine loads at sampling
- The test results from the SGS laboratory were taken at face value, assumed to be in accordance with relevant laboratory standards.

*Areas for further study planned by Carnival include: quantification of the accumulation of washwater parameters entering seawater; determine the potential environment impact on marine life.

The 2016 and 2018 Assessments

- The same EPA-referenced standard sampling protocol and training were used in gathering the samples used for the 2016 and the 2018 Assessments.
- The same "net post-EGCS" methodology was used as in the 2016 DNVGL Assessment, with the additional analytic step of using a trimmed mean* excluding statistical outliers more than three standard deviations from the mean.
- In addition to samples at the inlet, post-EGCS tower, and outlet; the expanded sample data base also includes samples from some ships with washwater filtration installed, providing a fourth sample from after this filter.
- DNV GL was again engaged by Carnival to review the laboratory analysis results and make the comparison to water quality standards for the 2018 expanded sample base.
- During the 2016 assessments, comparison was made to water quality standard criteria for:
  - German Wastewater Ordinance (Article 2 of 6th Ordinance for Amendment of Waste Water Ordinance, Federal Water Act)
  - EU Surface Water Standards (Directive 2013/39/EU, amending Water Framework Directive 2000/60/EU)
  - EU Drinking Water Standards (Council Directive 98/83/EC)
  - US EPA Drinking Water Standards (Clean Water Act, nickel criteria only)

- In the 2018 assessment, EU Industrial Emissions Directive standards for incineration plant waste gas cleaning waste water were included in the comparison. The EU drinking water standards are in the process of being revised and updated with reference to the World Health Organization (WHO) *Guidelines for Drinking-Water Quality (Fourth Edition)* and therefore the 2018 Assessment instead makes a comparison to WHO criteria.

*This is consistent with the United States Geological Survey's Statistical Methods in Water Resources.

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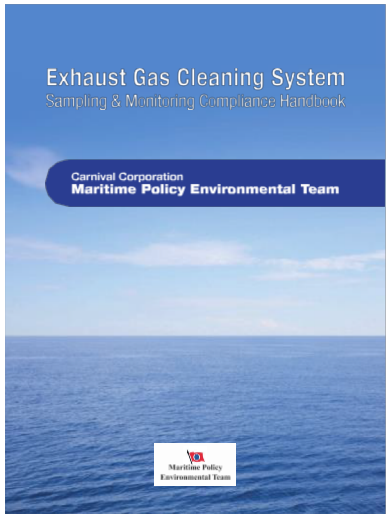
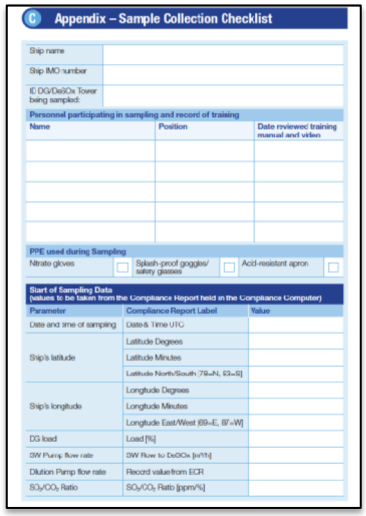
- Sampling campaign protocol
- Sample custody and lab analysis
- Process of sampling and analysis results
- Parameters tested for by SGS
- Handling of “Non-Detects”
- Calculation of “net Post-EGCS” concentrations

Sampling Campaign protocol overview

Samples are collected and analysed in accordance with US EPA guidelines

- Protocol was developed in cooperation with SGS, which has a worldwide network of fully accredited laboratories, and is based upon protocols used in published washwater sample studies and is consistent with the guidelines set forth in US 40 CFR Part 136 and the US EPA Handbook for Sampling and Sample Preservation of Water and Wastewater Under the US Clean Water Act
- Carnival provides an onboard sampling training program for ship's Environmental Officers and Engineers that includes a Sampling Manual with Sampling Protocol and tailored training video series, to ensure that samples are consistently collected per the approved standard procedures.
- Sample kits are prepared and supplied by SGS, each kit contains pre-labeled sample bottles, a Sample Collection Checklist, Sample Receipt and Offloading Checklist, and Chain of Custody documentation.
- Sample integrity is maintained from collection to analysis following required temperature, handling, and hold times, detailed in the sampling protocol.





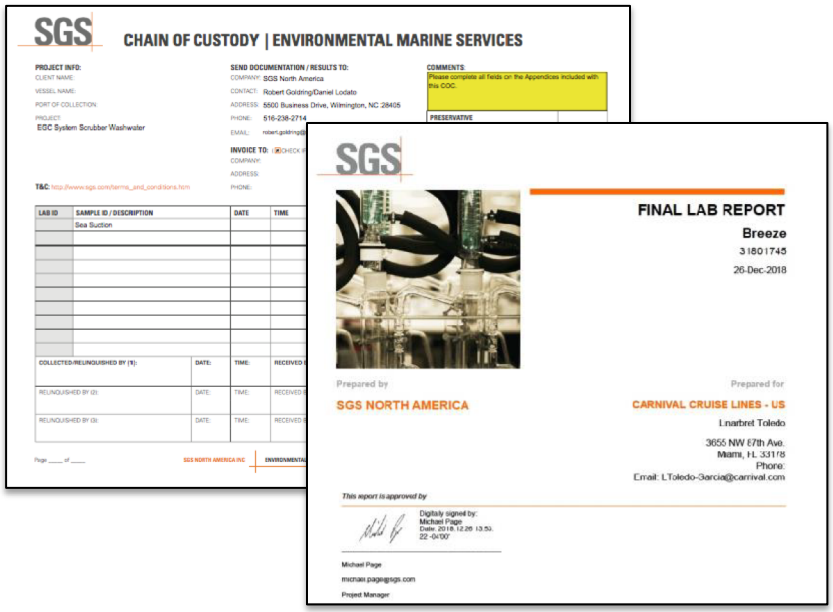
Sample custody and lab analysis

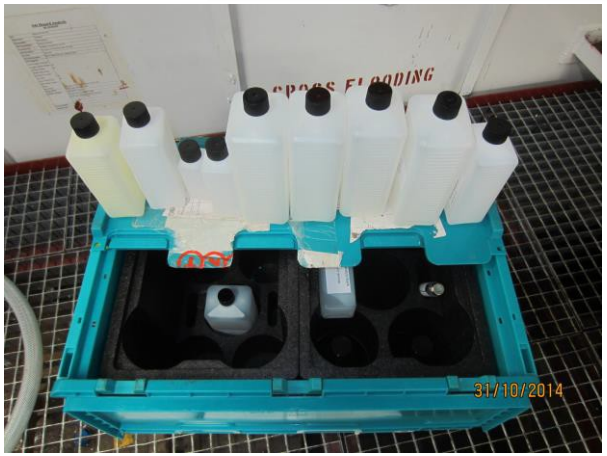
Chain of Custody

- Time/signature Chain of Custody is maintained throughout the sampling, transfer, and laboratory analysis.

Laboratory Analysis

- The SGS labs analyse all samples utilizing US EPA approved methods and issues a final report with all required calibration, standardization, and limits of quantitation
- Upon receipt at the laboratory a checklist is created by SGS to document condition of sample kits, including temperature, breakage, custody seals, and confirmation that all samples are accounted for.
- Samples are analysed within the hold time required by the given method.
- Results provided by the SGS laboratories include the analysis methodology used and the relevant calibration and standardization procedures.
- SGS provides limits of quantitation for each result obtained.





Processing of sampling and analysis results

Documentation and process overview

- Final reports are issued by SGS upon completion of sample analysis.
- The reports and sampling process are reviewed by SGS, each operating line, in addition to an independent review.
- Results are evaluated to ensure that sampling procedure was followed, Chain of Custody was maintained, approved analytical methods were utilized, and that hold times were not exceeded.

Compilation of results

- The SGS laboratory reports are submitted to DNV GL to be compiled. DNV GL then reviews the data and makes the comparison to selected water quality standards.

Process adjustments

- To ensure the most standard laboratory treatment possible, Carnival has reduced the laboratories used for sample analysis to two: one in Europe and one In North America.
- Additionally, SGS has cooperatively reduced the detection limits to the lowest level possible for each parameter, with identical limits at both labs.

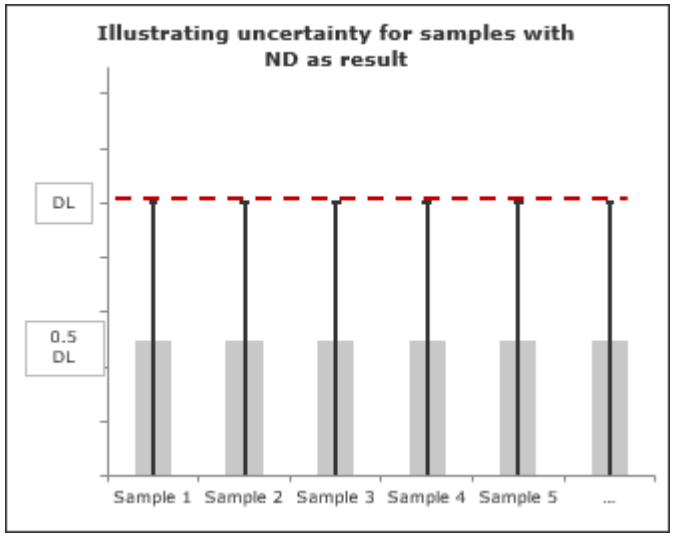
Parameters analysed by SGS

PAHs	Metals*	Other parameters
1-Methylnaphthalene	Aluminum (Al)	C10 – C40 Hydrocarbons
2-Methylnaphthalene	Cadmium (Cd)	Chloride
Acenaphthene	Chromium (Cr)	Total Dissolved Solids
Acenaphthylene	Copper (Cu)	Total Suspended Solids
Benzo(a)anthracene	Iron (Fe)	Ammonia as N
Benzo(a)pyrene	Lead (Pb)	Total Phosphate as PO4
Benzo(b)fluoranthene	Nickel (Ni)	Total Phosphorus as P
Benzo(g,h,i)perylene	Thallium (Tl)	Total Organic Carbon
Benzo(k)fluoranthene	Vanadium (V)	Total Kjeldahl Nitrogen
Chrysene	Zinc (Zn)	Chromium (VI)
Dibenz(a,h)anthracene	Arsenic (As)	pH
Fluoranthene	Selenium (Se)	Nitrate + Nitrate as N
Fluorene	Mercury (Hg)	Biological oxygen demand (BOD)
Indeno(1,2,3-cd)pyrene		Chemical oxygen demand (COD)
Naphthalene		Organic Nitrogen
Phenanthrene		Total Nitrogen
Pyrene		Ammonium
		Diesel Range Organics (DRO)

* Analysis was for both Total and Dissolved portion

Handling of “Non-Detects”

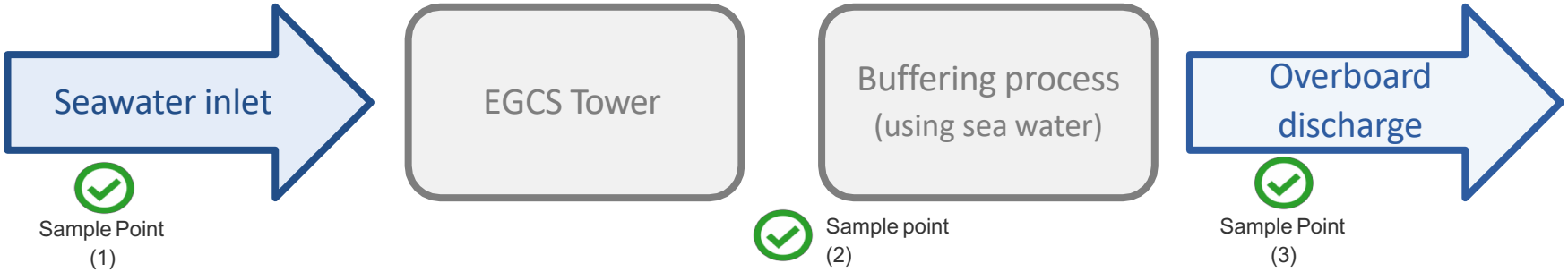
- A significant number of samples for each parameter are “non-detects” below the laboratory detection limits. In environmental testing, it is technically impossible to verify the complete absence of an analyte.
  - If the analyte is not present or present at a concentration below the detection limit, the lab will report a non detect (ND).
  - An analyte is only confidently reported as present when the test result is above the detection limit.
  - SGS provided the DL for each analyte and sample
  - For results reported as ND, it was assumed that the concentration of the analyte in the sample was half of the detection limit (DL).*
  - This means the concentration of the analyte is most likely inflated when calculating the average concentration since a ND can actually be zero, while from a chemical analytical point of view, it cannot be identified definitively as zero.



- Certain parameters are nearly always below the detection limit at the post tower outlet sample.
  - An ND is considered to be half the DL, so the result has more uncertainty, although the margin of error rests below the DL
  - For a given parameter, the lower the rate of detection rate, the more likely the average concentration is below the DL but the greater the margin of error.

* US EPA *Ref. Statistical analysis of groundwater monitoring data at RCRA facilities: unified guidance* (2009)

Calculation of "net Post-EGCS" concentrations



- If the ambient seawater already has a high concentration of the parameter in question, the concentration after the EGCS tower (and in the overboard discharge) may be elevated, but not necessarily due to the EGCS process.
- In order to understand how the EGCS process affects water quality*, a distinction is made between gross post EGCS concentration and net post-EGCS concentration.

Net post-EGCS concentration =

post-EGCS concentration (2) – Incoming seawater concentration (1)

- In some cases, the net concentration is negative. This negative result is taken at face value, assumed to be valid because there is a seawater filter between the seawater inlet and the EGCS tower.
- The intention of using the net concentration is to correct for the amount already present in the incoming seawater, giving a clearer idea of how the EGCS contributes to the change in concentration of the parameter

* Compliance with IMO washwater discharge criteria uses the gross post-EGCS concentration.

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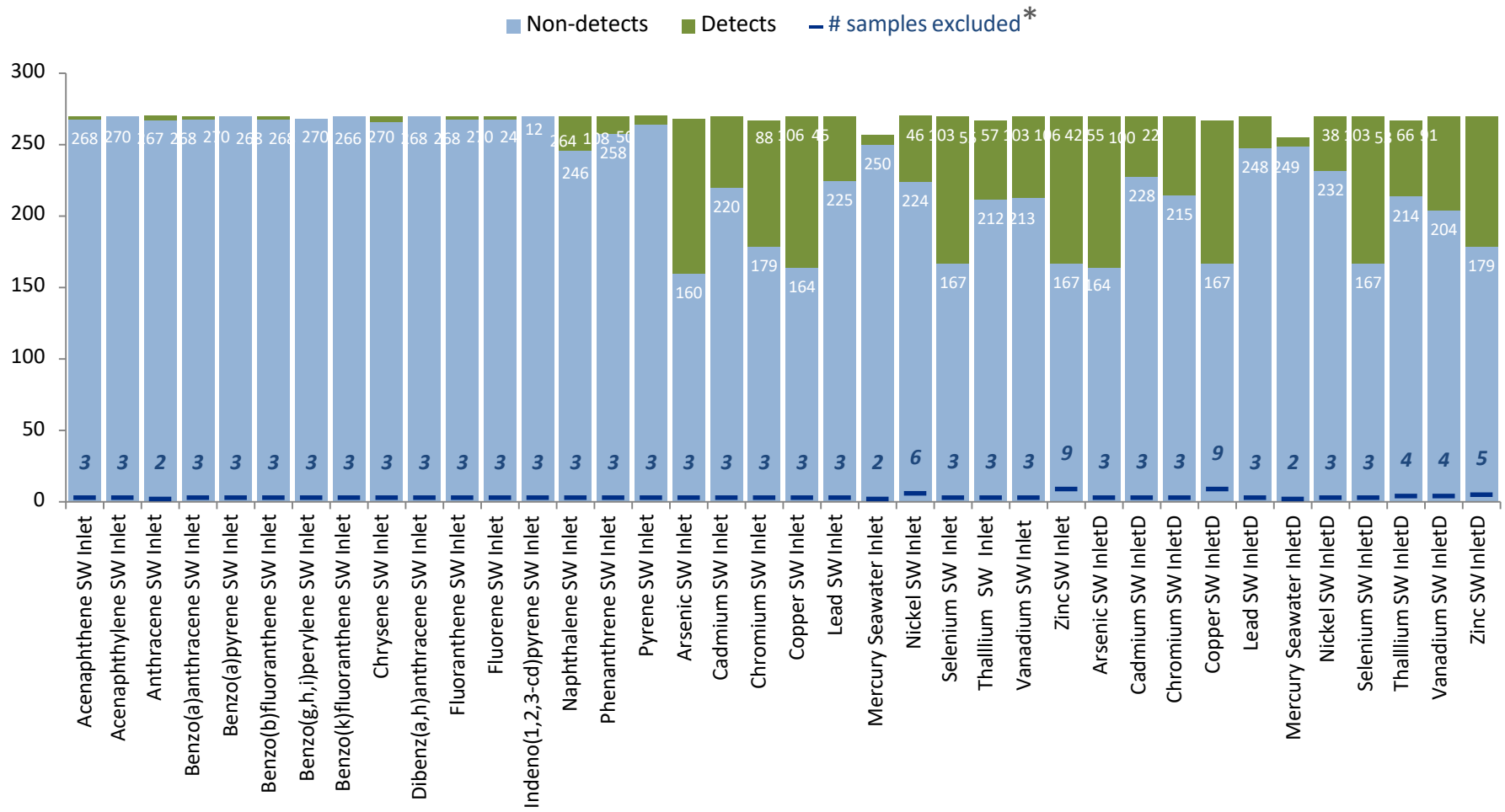
- Distribution of “non-detects” and statistical outliers.
- Inlet and post-EGCS sample distributions for Anthracene
- Inlet and post-EGCS sample distributions for Nickel

Observations From the lab results

- In both the 2016 and 2018 assessment sample sets, many parameters have a detection rate of less than 50%.
  - For certain parameters, the criteria in water quality standards can be below what is possible to measure using known laboratory techniques.
  - This does not mean that the results are invalid. The purpose of this assessment is to illustrate the quality of washwater, not definitively demonstrate compliance with the standards which are compared to.
- The detection limit for a particular sample parameter is dependent upon laboratory analyst, sample matrix, method used, and instrumentation utilized.
- The percentage of samples excluded as being more than three standard deviations from the mean varies between 0.4% (1 sample) and 3.2% (9 samples). For the majority of cases (considering all parameters at inlet and post-EGCS sampling points), 1.1% of the samples are excluded (3 samples).
- The following slides show:
  - Distribution of “detects”, “non-detects” and statistical outliers for inlet and post-EGCS samples.
  - Inlet and post-EGCS sample distributions for Anthracene and Nickel

Inlet samples: laboratory "detects" vs. "non-detects"

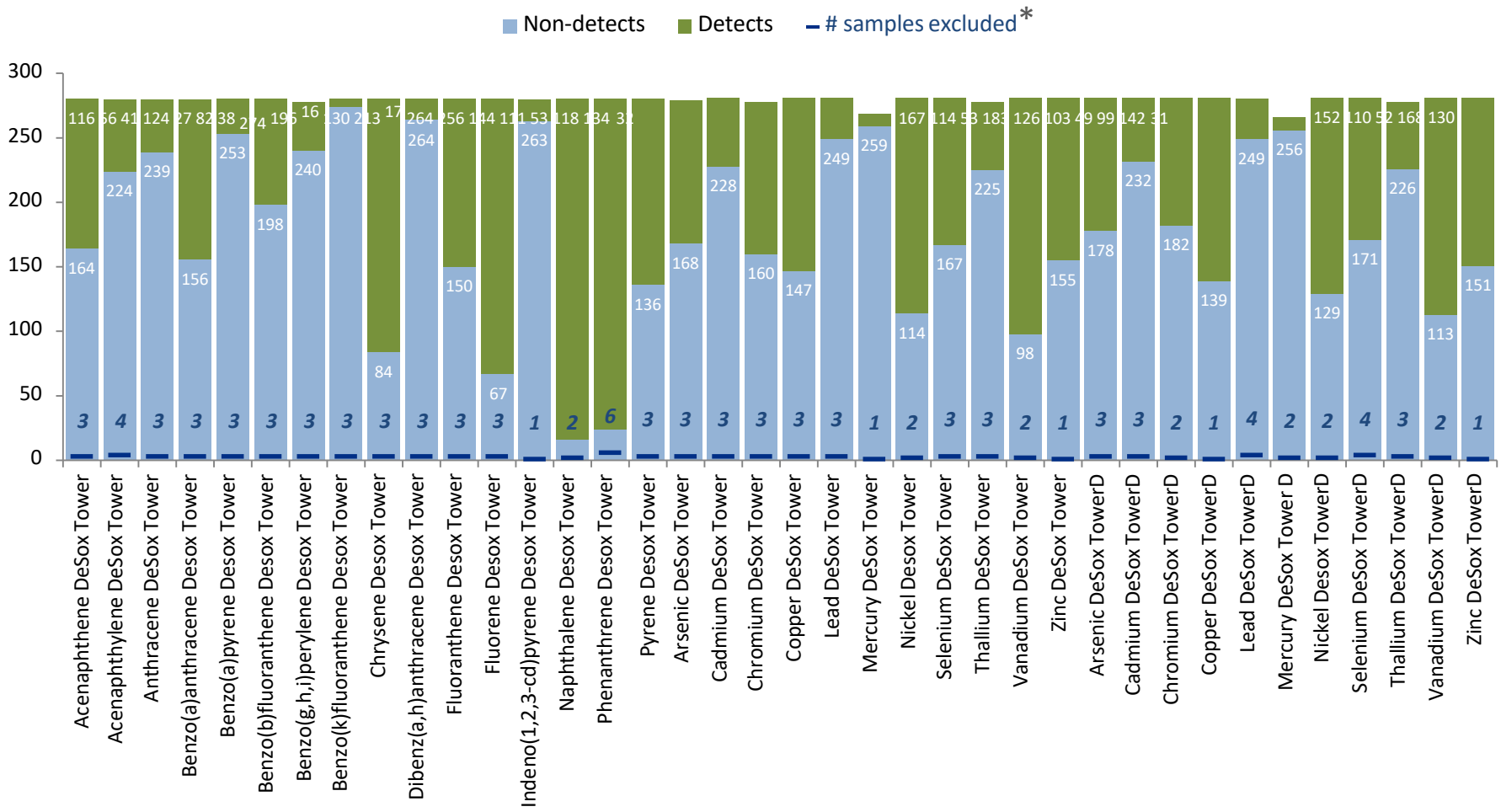
Between 60-100% of Inlet samples for each parameter are "non-detects"



*Statistical outliers > 3σ from the mean

Post-EGCS tower samples: laboratory "detects" vs. "non-detects"

Between 6-98% of post-EGCS samples for each parameter are "non-detects"



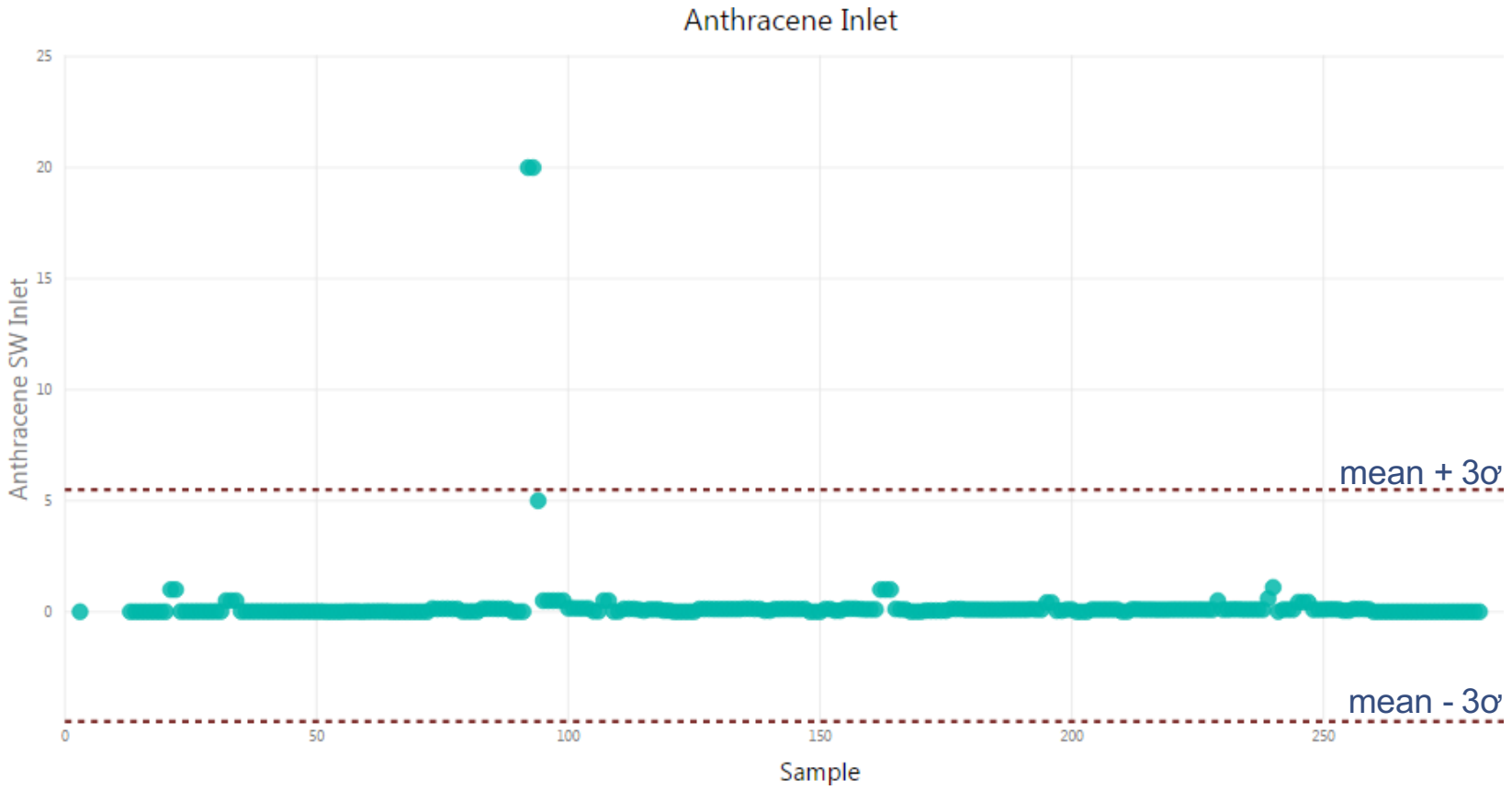
*Statistical outliers > 3σ from the mean

Anthracene Inlet Sample Distribution

0.7% of the samples are outside 3σ of the mean

- Average : 0.2780 µg/l
- Average excluding samples outside 3σ of the mean : 0.1308 µg/l
- # samples excluded : 2 out of 281 (0.7%)

3 samples above laboratory detect limit, including 2 outliers.

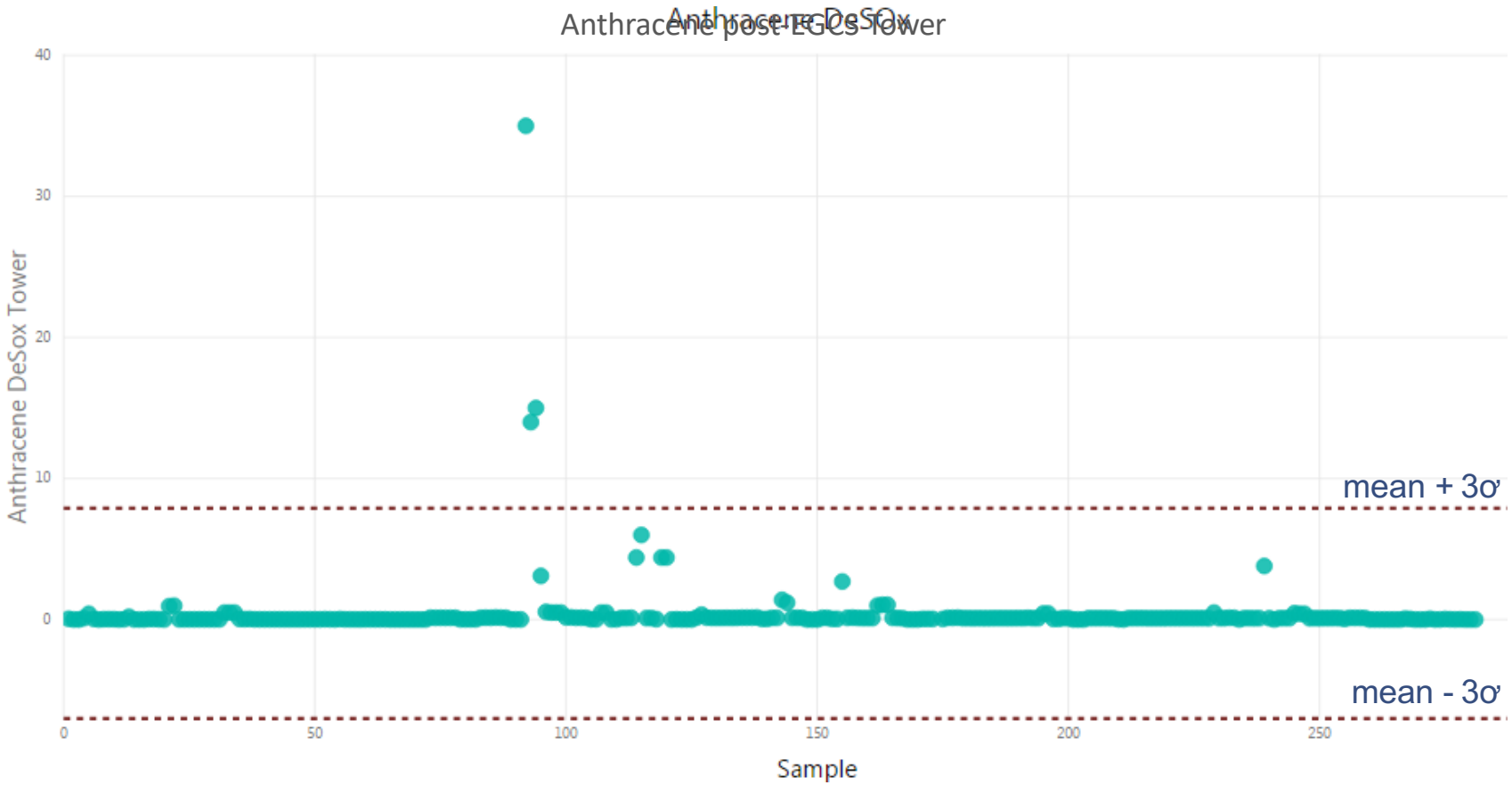


Anthracene Post-EGCS Tower Sample Distribution

1.1% of the samples are outside 3σ of the mean

- Average : 0.4439 µg/l
- Average excluding samples outside 3σ of the mean : 0.2176 µg/l
- # samples excluded : 3 out of 281 (1.1%)

41 samples above laboratory detect limit, including 3 outliers.

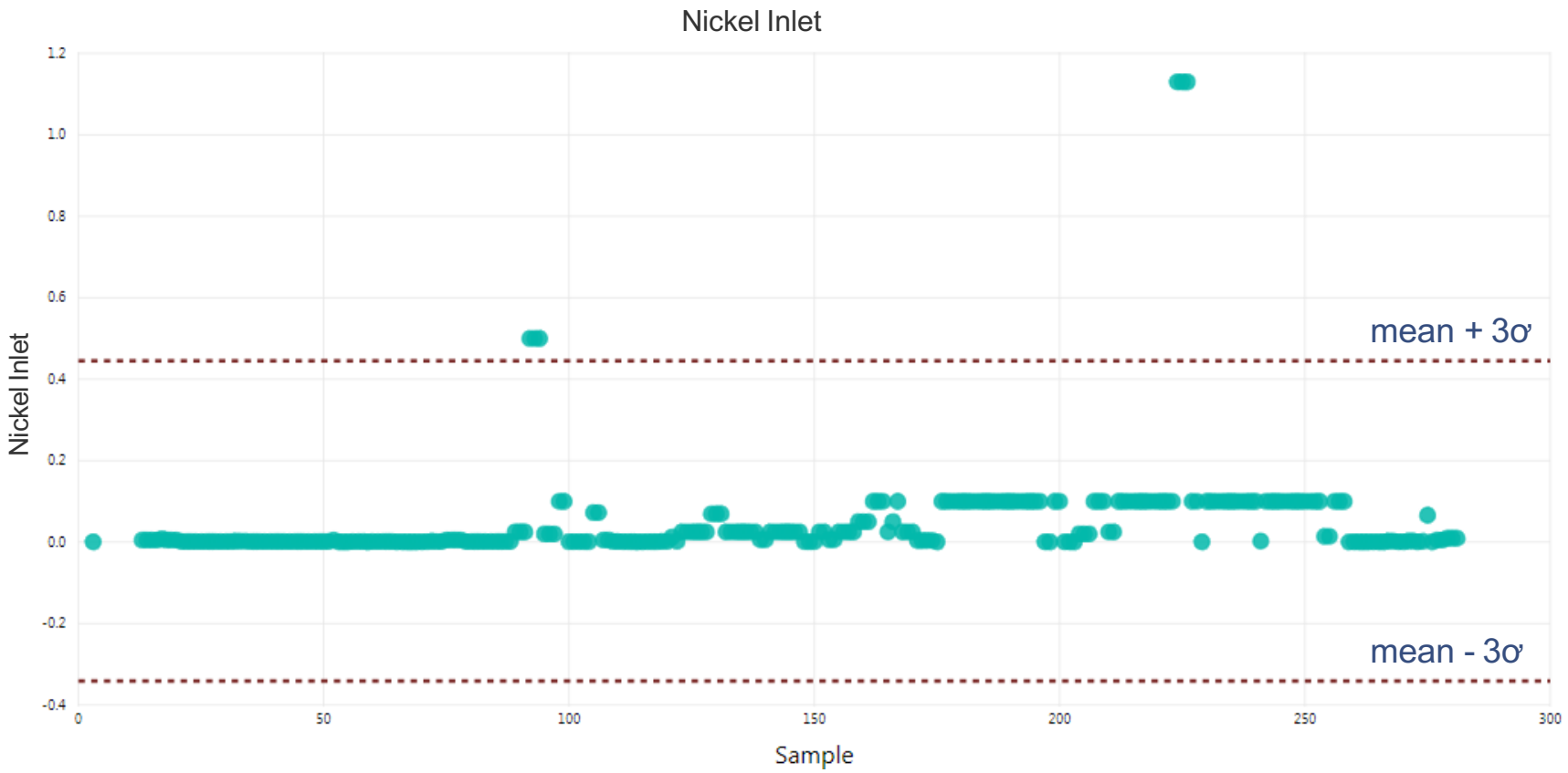


Nickel Inlet Sample Distribution

2.1% of the samples are outside 3σ of the mean

- Average : 0.05195 mg/l
- Average excluding samples outside 3σ of the mean : 0.0346 mg/l
- # samples excluded : 6 out of 281 (2.1%)

46 samples above laboratory detect limit, including 3 outliers. Remaining 3 outliers are non-detects.

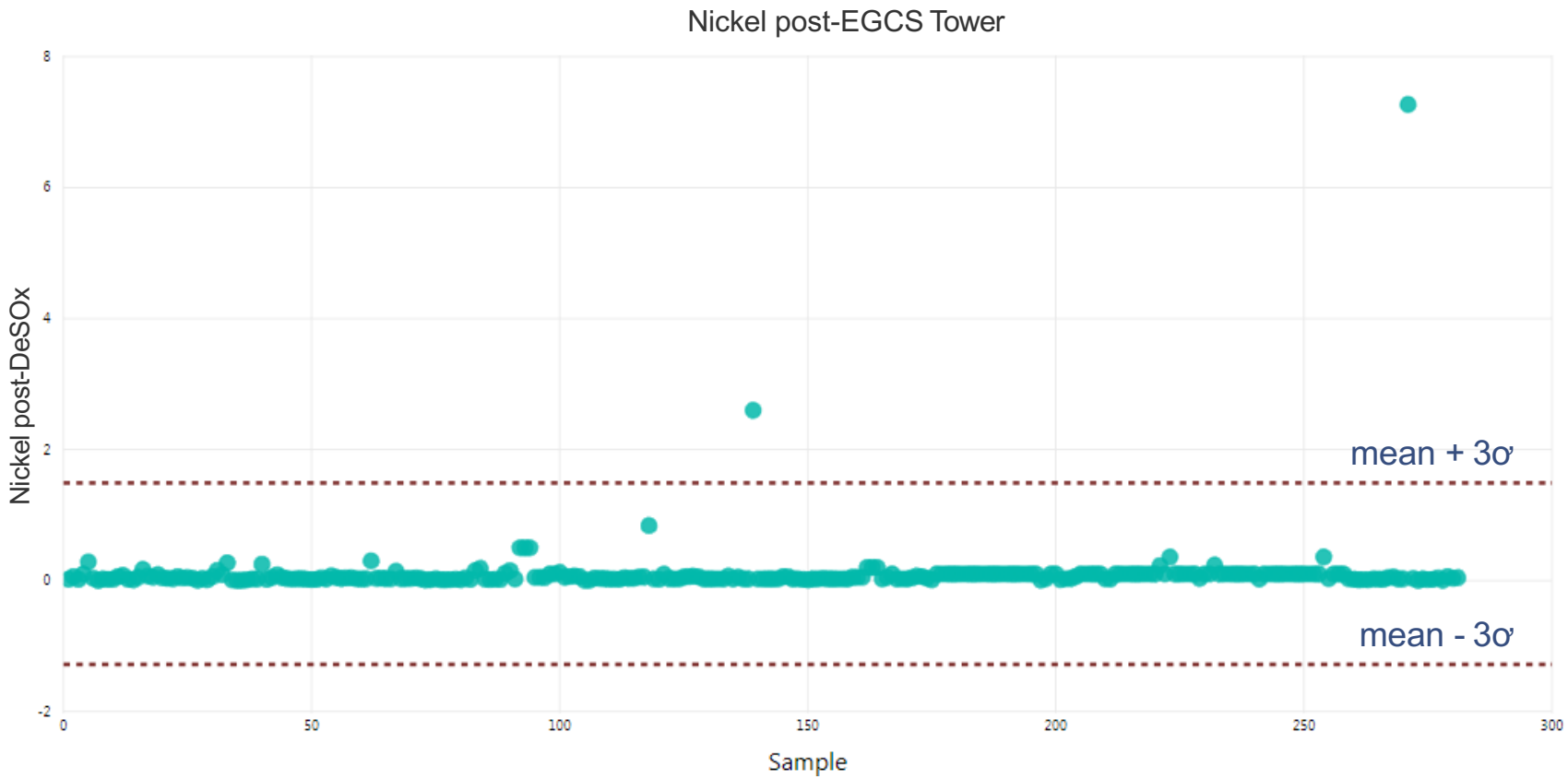


Nickel Post-EGCS Tower Sample Distribution

Post-DeSOx samples - 0.7% of the samples are outside 3σ of the mean

- Average : 0.10495 mg/l
- Average excluding samples outside 3σ of the mean : 0.07032 mg/l
- # samples excluded : 2 out of 281 (0.7%)

167 samples above laboratory detect limit, including 2 outliers.



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- IMO criteria for EGCS washwater
- Comparison to IMO PAH and Nitrate criteria
- Selection of water quality standards
- Average net post-EGCS analysis compared to:
  - German Wastewater Ordinance
  - EU Incineration Waste Water Standards
  - EU Surface Water Standards
- Positive preliminary results for washwater filtration

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IMO criteria for EGCS washwater

- **Nitrates** and **PAH** are regulated according to the output of the EGCS in terms of tons of water per mega watt hour (t/MWh) installed engine power, i.e. the limit is dependent on water output from the EGCS.*
- **pH** of the discharge point must be the value which will give at least 6.5 pH at four meters from the discharge point, while the ship is stationary.
  - All sampled pH values at discharge are above the calculated minimum pH
- **Turbidity** should not be greater than 25 FNU (formazin nephlometric units) or 25 NTU (nephlometric turbidity units) or equivalent units, above the incoming seawater turbidity.
- All washwater limits are **continuous;** these limitations must be upheld at any given time.

*In this assessment, the strictest Nitrate and PAH limits have been selected for comparison to all samples, rather than normalizing for operating conditions.

Nitrate washwater limits

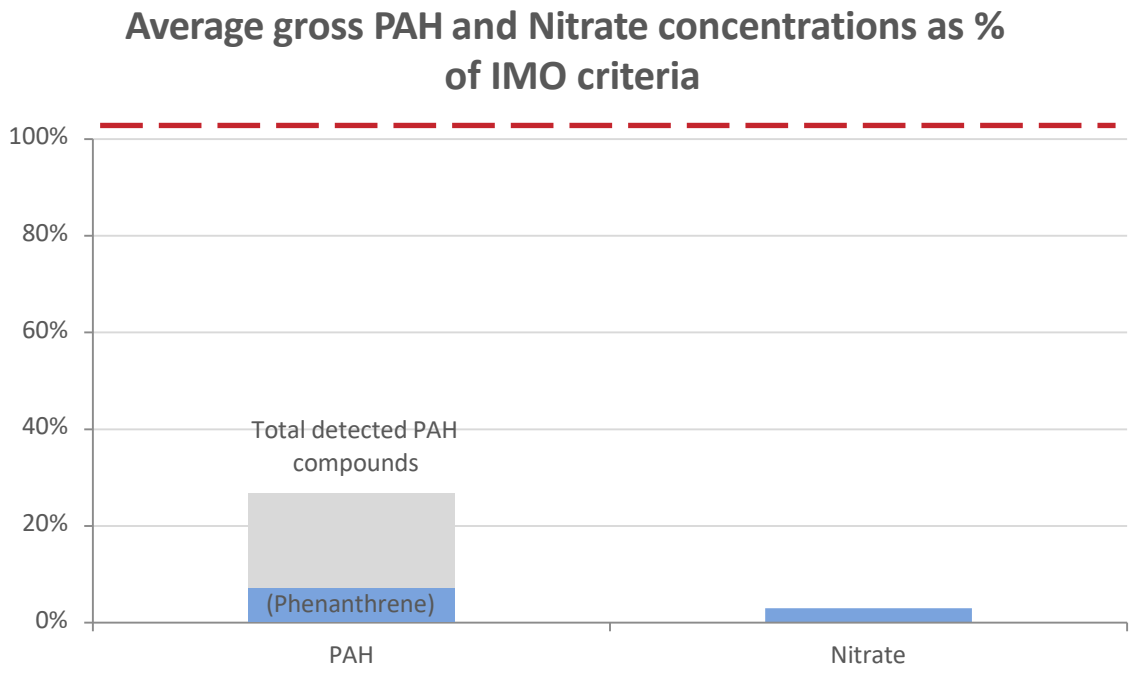
Flow rate from EGCS (t/MWh)	Discharge Concentration Limit (mg/L nitrate)
0 - 1	2700
2.5	1080
5	640
11.25	240
22.5	120
45	60
90	30

Strictest limits

PAHs washwater limits

Flow rate from EGCS (t/MWh)	Discharge Concentration Limit (µg/L PAH_{phe} equivalents)
0 - 1	2250
2.5	900
5	450
11.25	200
22.5	100
45	50
90	25

Comparison to IMO PAH and Nitrate criteria



Compound	Lowest IMO criteria (based on 90 t/MWh flow rate)		Average gross post EGCS concentration	
PAH	25	µg/L	1.77	µg/L *
Nitrate	30	mg/L	0.8	mg/L

*IMO requirements for PAH are based on phenanthrene equivalence, so the post-EGCS value given is for phenanthrene. Total detected PAH compounds are shown on the graph for information.

- The washwater discharge limitations vary according to the EGCS washwater output, i.e. the higher the washwater flow the lower the allowed concentration.
- Here, the weighted average **gross** post-EGCS concentrations are compared with the lowest theoretical requirements.
- Both the Post-EGCS PAH values for phenanthrene and the average sum of all detected PAH values are below the strictest IMO requirements.
- This comparison is for illustrative purposes, and does not constitute approval of any vessel with IMO requirements.

Selection of Water Quality Standards

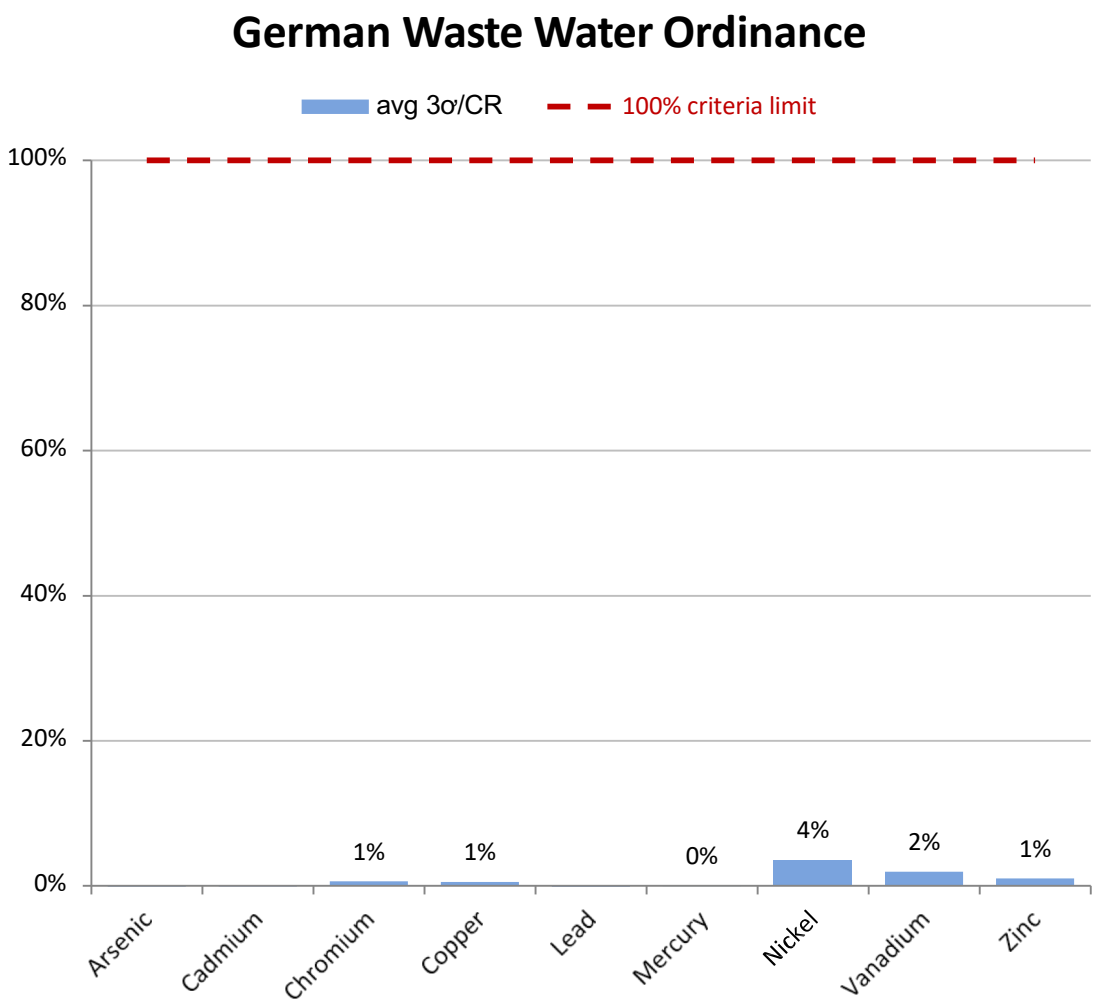
- As previously discussed, although not required for EGCS washwater, a comparison to other water quality standards provides a clearer perspective and understanding of the parameters:
  - German Waste Water Ordinance (Article 2 of 6th Ordinance for Amendment of Waste Water Ordinance, Federal Water Act)
  - EU Incineration Waste Water Standards (Directive 2010/75/EU, Industrial Emissions Directive)
  - EU Surface Water Standards (Directive 2013/39/EU, amending Water Framework Directive 2000/60/EU)
  - WHO Drinking Water Standards (Guidelines for Drinking-Water Quality, Fourth Edition)

- These water standards are not requirements to which EGCS washwater discharge must comply and are chosen because they provide relatable criteria for a number of the parameters of interest in this assessment. The surface water and drinking water standards in particular provide real world criteria for PAH concentrations.
- They illustrate the general quality of the wash-water discharge and provide a broader perspective than comparison to IMO requirements, or simply a compilation of the average concentration alone can provide.
- These comparisons do not constitute the basis for determining if water is compliant to the selected standards. In particular, the surface water and drinking water standards are not intended for use with industrial processes and should be seen as for reference only.
- Parameter results shown are non-weighted average net post-EGCS concentrations.

German Waste Water Ordinance, net post-EGCS analysis

Difference between the post-EGCS and Inlet averages

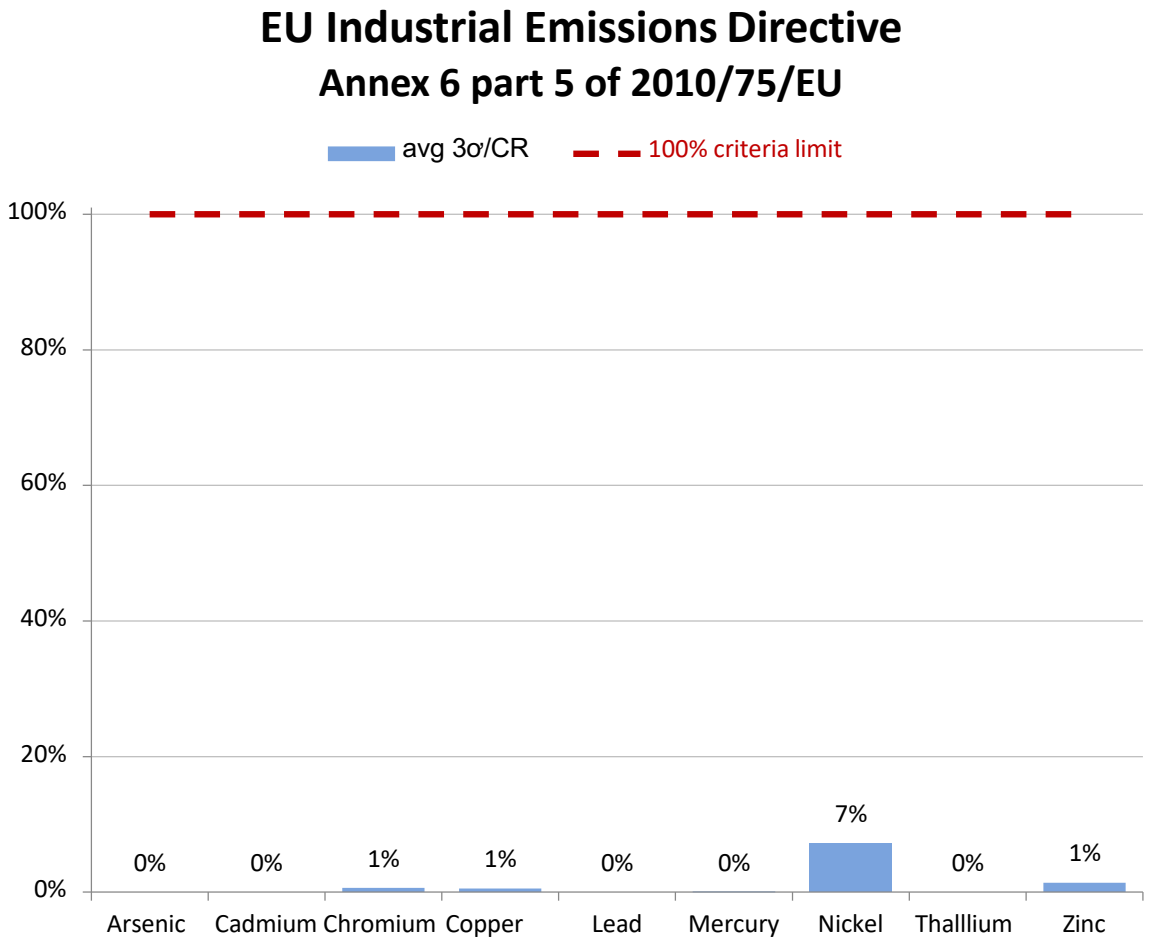
- This comparison uses the German Waste Water Ordinance (Article 2 of 6th Ordinance for Amendment of Waste Water Ordinance, Federal Water Act), waste water limitations from biological waste treatment.
- This ordinance was chosen as a point source discharge standard and due to the total metal criteria being well aligned with the tested parameters.
- The waste treatment criteria did not include vanadium limits, so this criteria limit is for steam generation (from the same ordinance), in order for vanadium to be included as a metal of interest.
- The standard contains no PAH criteria.



EU Industrial Emissions Directive, net post-EGCS analysis

Difference between the post-EGCS and Inlet averages

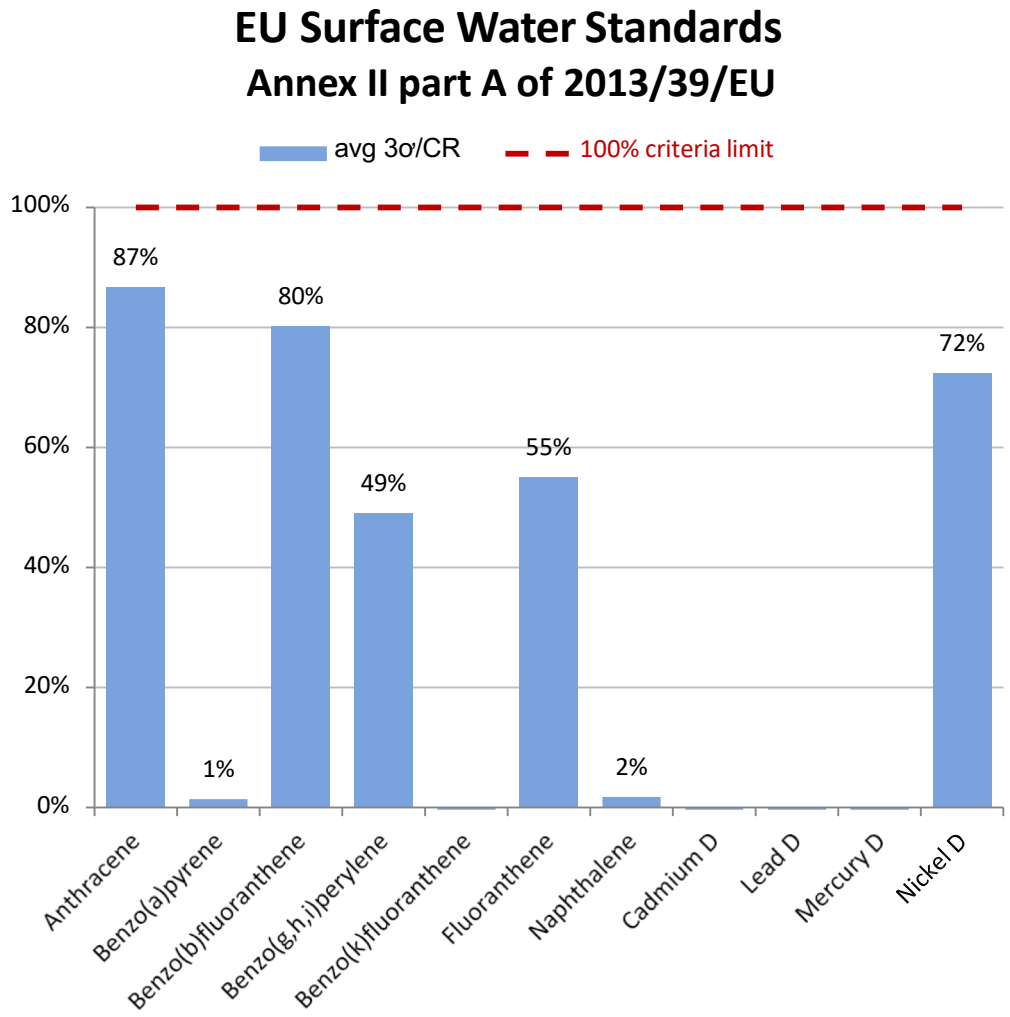
- The Waste Gas Cleaning Water Standards (part of EU Industrial Emissions Directive 2010/75/EU) refer to emission limit values applied to point source discharge from waste water from the cleaning of waste gases from incineration or co-incineration plants.
- The standard includes limits for trace metal parameters similar to the German Wastewater Ordinance. The criteria are generally somewhat stricter (there is no Vanadium criterion).
- The standard contains no PAH criteria.



EU Surface Water Standards, net post-EGCS analysis

Difference between the post-EGCS and Inlet averages

- The EU Surface Water Standards (as amended by Directive 2013/39/EU), part of the EU Water Framework Directive, refer to maximum allowed concentration* in inland surface waters.
- Surface water criteria imply that the concentrations shall not reach the maximum concentrations. This comparison does not account for any potential accumulation effect on ambient water.
- While as a water quality standard it is not intended for application to point source discharges such as EGCS washwater, it provides a useful point of reference for PAH concentrations.
- The metal concentration criteria are for dissolved (D) metals.

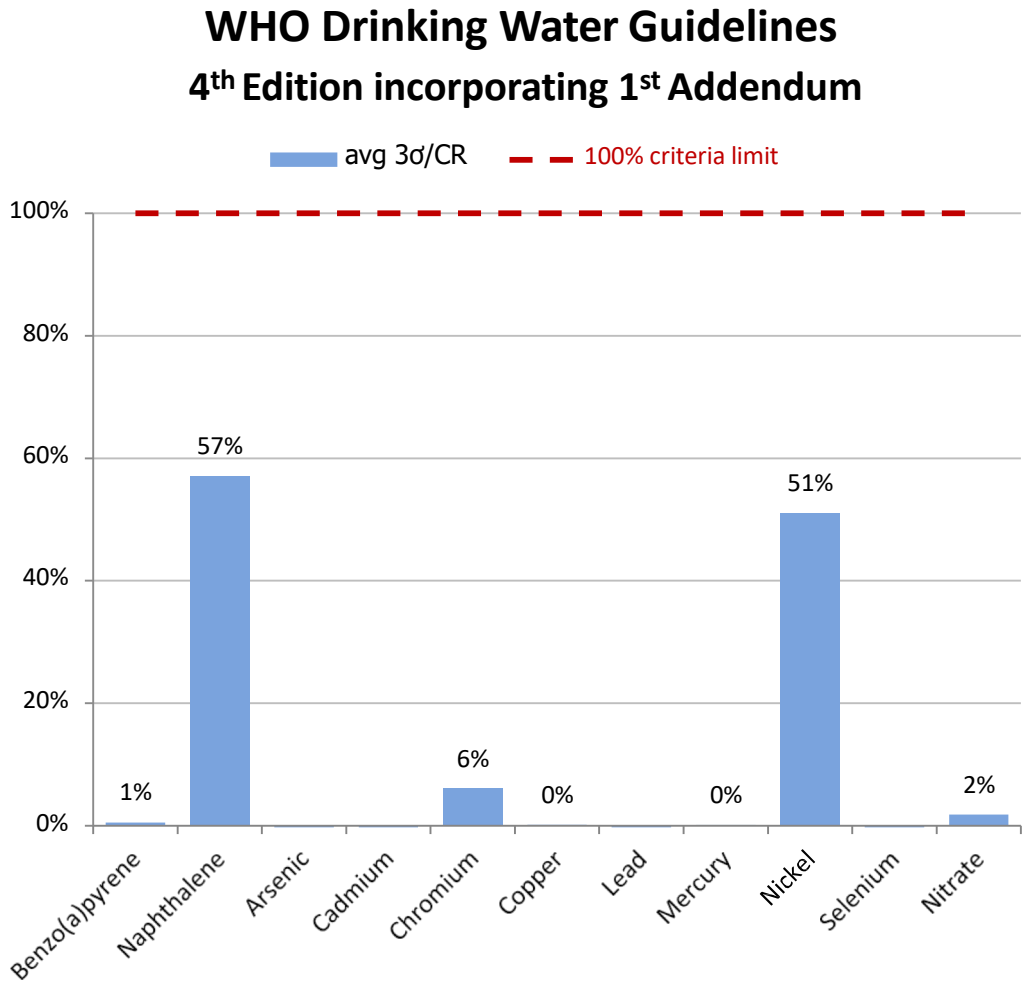


* Maximum allowable concentration is the maximum concentration a pollutant is recommended to have at any given time in the water body in question.

WHO Drinking Water Guidelines, net post-EGCS analysis

Difference between the post-EGCS and Inlet averages

- This comparison is for general interest only. These Guidelines are used as the basis for regulation and standard setting world-wide.
- The total metal criteria are stricter than for point source discharge standards (versus EU Surface Water Standards which use dissolved metal criteria).
- Value for **nitrate** is based on detected values only.



Positive preliminary results for washwater filtration

While not discussed further in this assessment, the results for 11 samples with discharge filtration were also reviewed. Initial tests and laboratory analysis of filtered material and post filtration washwater indicate an effective reduction potential for the following parameters:

Parameter	Effective Filtration	Parameter	Effective Filtration	Parameter	Effective filtration
Arsenic	✓	Anthracene	✓	Aluminium	✓
Cadmium	✓	Benzo(a)anthracene	✓	Boron	✓
Chromium	✓	Benzo(b)fluoranthene	✓	Cobalt	✓
Copper	✓	Benzo(g,h,i)perylene	✓	Manganese	✓
Iron	✓	Chrysene	✓	Selenium	✓
Lead	✓	Fluoranthene	✓	Thallium	✓
Mercury	✓	Fluorene	✓	Total Organic Carbon	✓
Nickel	✓	Naphthalene	✓		
Vanadium	✓	Phenanthrene	✓		
Zinc	✓	Pyrene	✓		

Further tests with filtration are being conducted to quantify the effectiveness of filtration. This includes operational trials to determine an optimum balance between filtration and EGCS effectiveness.

- Executive Summary
- Background
- Sampling and Analysis Methodology
- Observations from Lab Results
- Comparison to Water Quality Standards
- **Conclusions**

- Summary of results
- Handling of statistical outliers
- Conclusions
- Limitations

Summary of results of the Assessment

- As for the 2016 Assessment using the smaller sample set, a significant number of sample parameters are “non-detects” below laboratory detection limits.
- The average net post-EGCS for a number metal parameters is extremely low, with post-EGCS values close to inlet values: Arsenic, Cadmium, Lead, Mercury, Selenium, Thallium
- A number of PAH parameters also give a low net result: Benzo(a)pyrene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene.*
- As with the 2016 study, the 2018 samples are below the criteria for the German Wastewater Ordinance on all tested parameters. A new comparison to the stricter EU Industrial Emissions Directive similarly shows parameter concentrations well below reference point source emission limits.
- When comparing to the EU Surface Water Standard, the 2018 sample set is below the criteria when a three-sigma deviation and trimmed mean statistical methods is used to exclude statistical outliers. When outliers are not excluded, an unweighted average of sample parameters exceeds the EU surface water criteria for Anthracene and Dissolved Nickel.
- While the current sample size (11) is too small to reach definitive conclusions, washwater quality appears further improved by enhanced system filtration.

Handling of statistical outliers

- In the 2016 assessment, the Benzo(b)fluoranthene parameter exceeded the EU Surface Water Standard criteria. At the time it was hypothesised that this was due to a single outlier result.

- For the 2018 assessment, results outside a three-sigma deviation from the mean are excluded. This affects for only a small proportion of samples and a number of these statistical outliers are present in the inlet as well as post-EGCS samples.

- When comparing to the EU Surface Water Standard, the expanded 2018 sample set is below the criteria when statistical outliers are excluded. When these outliers are not excluded, an unweighted average of sample parameters exceeds the EU surface water criteria for Anthracene and Dissolved Nickel.

- It is not possible to reach definitive conclusions on the cause of outliers. However, typical contributions to occurrence of outliers may include:
    - Laboratory: Gross error, wrong analytical method, or insufficiently low detection limits.
    - Sample contamination/procedure: Error in sampling procedures introducing contamination.
    - Handling errors: Exceeding hold times, not maintaining temperature, breach of custody.

Conclusions

- Studied washwater parameter concentrations are below the emission limits for land-based industrial point source waste water standards. This is not evidence of compliance with these standards (which are intended for a different regime and include other controls and limits for compliance than quality criteria). The comparison does however establish a point of reference to understand the quality of EGCS washwater relative to other industrial discharges.

- Very low and negative net post-EGCS values for certain washwater parameters indicate a minimal contribution to the concentration of these parameters from the EGCS process (Arsenic, Cadmium, Lead, Mercury, Selenium, Thallium).

- The washwater parameter concentrations also compare favourably to stricter water quality standards such as the EU surface Water Standards for inland waters. These standards have very different application and this comparison is not a definitive assessment of point source washwater quality, however they provide a useful quantitative reference to understand washwater parameter concentrations, in particular for PAH compounds where there is a lack of more suitable standards.

Limitations

- The average net post-EGCS concentrations were calculated for ease of comparison, but this means that values may not be representative of an individual vessel, given the variance of the samples, and various operational conditions of each vessel.

- The study provides an objective evaluation of washwater quality as the basis for more informed debate. It does not:
  - Attempt to assess the cumulative effect of washwater parameters entering seawater or the potential environmental impact.
  - Make any conclusions regarding washwater parameter concentrations and fuel types, engine and flow conditions.

Appendices

- Parameter value summary table
- Water standards and application in this study
- Average net post-EGCS concentrations compared to German Wastewater Ordinance
- Average net post-EGCS concentrations compared to EU Industrial Emissions Directive
- Average net post-EGCS concentrations compared to EU Surface Water Standard

Parameter Summary Table

	Inlet				Post-EGCS Tower				Average net	
	avg	*avg 3σ*	*# samples excluded*	*%samples excluded*	*avg*	*avg 3σ*	*# samples excluded*	*%samples excluded*	*avg*	*avg 3σ*
Acenaphthene	0.18171	0.12758	3	1.1%	0.25662	0.20525	3	1.1%	0.07491	0.07767
Acenaphthylene	0.18048	0.12633	3	1.1%	0.20132	0.14228	4	1.4%	0.02083	0.01595
Anthracene	0.27801	0.13083	2	0.7%	0.44387	0.21763	3	1.1%	0.16586	0.08680
Benzo(a)anthracene	0.12208	0.06727	3	1.1%	0.23149	0.10764	3	1.1%	0.10941	0.04037
Benzo(a)pyrene	0.11746	0.06260	3	1.1%	0.11923	0.06637	3	1.1%	0.00177	0.00377
Benzo(b)fluoranthene	0.12144	0.06663	3	1.1%	0.13298	0.08027	3	1.1%	0.01154	0.01364
Benzo(g,h,i)perylene	0.12786	0.07270	3	1.1%	0.12986	0.07673	3	1.1%	0.00200	0.00403
Benzo(k)fluoranthene	0.12123	0.06641	3	1.1%	0.11794	0.06506	3	1.1%	-0.00329	-0.00135
Chrysene	0.12316	0.06836	3	1.1%	0.29627	0.24533	3	1.1%	0.17312	0.17697
Dibenz(a,h)anthracene	0.13486	0.08020	3	1.1%	0.12891	0.07615	3	1.1%	-0.00595	-0.00404
Fluoranthene	0.16575	0.11143	3	1.1%	0.25066	0.17756	3	1.1%	0.08491	0.06613
Fluorene	0.16641	0.11210	3	1.1%	0.59659	0.52363	3	1.1%	0.43018	0.41153
Indeno(1,2,3-cd)pyrene	0.13775	0.08312	3	1.1%	0.24845	0.13643	1	0.4%	0.11070	0.05331
Naphthalene	0.19390	0.13990	3	1.1%	3.33595	2.42469	2	0.7%	3.14205	2.28480
Phenanthrene	0.17797	0.12379	3	1.1%	2.03806	1.89087	6	2.1%	1.86009	1.76708
Pyrene	0.19935	0.10795	3	1.1%	0.35858	0.27221	3	1.1%	0.15924	0.16426
Arsenic	0.02507	0.01969	3	1.1%	0.02476	0.01960	3	1.1%	-0.00030	-0.00009
Cadmium	0.01060	0.00510	3	1.1%	0.01036	0.00508	3	1.1%	-0.00024	-0.00002
Chromium	0.01377	0.01297	3	1.1%	0.01960	0.01604	3	1.1%	0.00583	0.00307
Copper	0.10160	0.04600	3	1.1%	0.16653	0.04869	3	1.1%	0.06494	0.00269
Lead	0.01801	0.01259	3	1.1%	0.01713	0.01192	3	1.1%	-0.00087	-0.00067
Mercury	0.00403	0.00014	2	0.7%	0.00201	0.00014	1	0.4%	-0.00202	0.00001
Nickel	0.05195	0.03460	6	2.1%	0.10495	0.07032	2	0.7%	0.05300	0.03572
Selenium	0.04630	0.04120	3	1.1%	0.04564	0.04073	3	1.1%	-0.00066	-0.00047
Thallium	0.02492	0.01953	3	1.1%	0.02313	0.01793	3	1.1%	-0.00179	-0.00159
Vanadium	0.05265	0.04762	3	1.1%	0.14099	0.12623	2	0.7%	0.08834	0.07860
Zinc	0.05020	0.03447	9	3.2%	0.14000	0.05479	1	0.4%	0.08981	0.02032
Arsenic Dissolved	0.02452	0.01918	3	1.1%	0.02383	0.01869	3	1.1%	-0.00069	-0.00048
Cadmium Dissolved	0.01122	0.00572	3	1.1%	0.01087	0.00560	3	1.1%	-0.00034	-0.00013
Chromium Dissolved	0.01856	0.01315	3	1.1%	0.01942	0.01597	2	0.7%	0.00086	0.00282
Copper Dissolved	0.04424	0.03190	9	3.2%	0.29756	0.08362	1	0.4%	0.25332	0.05172
Lead Dissolved	0.01874	0.01334	3	1.1%	0.02005	0.01233	4	1.4%	0.00131	-0.00101
Mercury Dissolved	0.00407	0.00015	2	0.7%	0.00389	0.00014	2	0.7%	-0.00017	-0.00001
Nickel Dissolved	0.04164	0.03649	3	1.1%	0.09363	0.06111	2	0.7%	0.05199	0.02462
Selenium Dissolved	0.04422	0.03910	3	1.1%	0.04688	0.03871	4	1.4%	0.00266	-0.00038
Thallium Dissolved	0.02641	0.01921	4	1.4%	0.02468	0.01949	3	1.1%	-0.00174	0.00028
Vanadium Dissolved	0.05718	0.04863	4	1.4%	0.11724	0.10575	2	0.7%	0.06006	0.05712
Zinc Dissolved	0.04418	0.03543	5	1.8%	0.12217	0.05118	1	0.4%	0.07799	0.01575

Water standards and their application in this study

Standard name	Standard reference	Applicable waters	Application in study
German Waste Water Ordinance	Article 2 of 6th Ordinance for Amendment of Waste Water Ordinance, Federal Water Act	The ordinance covers waste water from different industrial processes. Criteria for waste water from biological waste treatment and steam generation are used in this study.	All parameters tested by SGS relevant to the standard are compared to biological waste water criteria. Vanadium concentration is compared to criteria for waste water from steam generation.
EU Waste Gas Cleaning Water Standards	Directive 2010/75/EU	Waste water resulting from the cleaning of waste gases from waste incineration and waste co-incineration plants.	All parameters tested by SGS relevant to the standard are compared to these criteria
EU Surface Water Standards	Directive 2013/39/EU	Surface waters in the EU are defined as inland water, except groundwater, transitional or coastal waters. 2013/39/EU defines the priority substances and limitation criteria for the Water Framework Directive	All parameters tested by SGS relevant to the standard are compared to these criteria. In particular the standards provide PAH criteria limits and stricter trace metal concentrations.
WHO Drinking Water Standards	Guidelines for Drinking-Water Quality (Fourth Edition)	Drinking water standards which are considered to be within the reach of all countries throughout the world	All parameters tested by SGS relevant to the standard are compared to these criteria. This provides stricter criteria than point source discharge concentration limits for trace metals.

Comparison to German Waste Water Ordinance criteria

Parameter	Criteria	Net Post-EGCS results		Unit	Avg. 3σ % of criteria limit
		Avg.	Avg. 3σ		
Arsenic	**0.1**	-0.00030	-0.00009	mg/L	0%
Cadmium	**0.1**	-0.00024	-0.00002	mg/L	0%
Chromium	**0.5**	0.00583	0.00307	mg/L	1%
Copper	**0.5**	0.06494	0.00269	mg/L	1%
Lead	**0.5**	-0.00087	-0.00067	mg/L	0%
Mercury	**0.05**	-0.00202	0.00001	mg/L	0%
Nickel	**1**	0.05300	0.03569	mg/L	4%
Vanadium	**4**	0.08834	0.07860	mg/L	2%
Zinc	**2**	0.08981	0.02032	mg/L	1%

- The standards are taken from the German Waste Water Ordinance; these are waste water limitations from biological waste treatment (the Vanadium criterion comes from steam generation waste water standards from the same ordinance).
- Ordinance is administered by the German Federal Ministry for the Environment.
- This ordinance was chosen because it had criteria limits for the highest number of relevant metal parameters of interest.
- The table shows concentrations of net post-EGCS discharge.

Comparison to EU Industrial Emissions Directive criteria

Parameter	Criteria	Net Post-EGCS results		Unit	Avg. 3σ % of criteria limit
		Avg.	Avg. 3σ		
Arsenic	**0.15**	-0.00030	-0.00009	mg/L	0%
Cadmium	**0.05**	-0.00024	-0.00002	mg/L	0%
Chromium	**0.50**	0.00583	0.00307	mg/L	1%
Copper	**0.50**	0.06494	0.00269	mg/L	1%
Lead	**0.20**	-0.00087	-0.00067	mg/L	0%
Mercury	**0.03**	-0.00202	0.00001	mg/L	0%
Nickel	**0.50**	0.05300	0.03572	mg/L	7%
Thallium	**0.05**	-0.00179	-0.00159	mg/L	0%
Zinc	**1.50**	0.08981	0.02032	mg/L	1%

- The criteria are based on Annex 6 Part 5 of 2010/75/EU Industrial Emissions Directive - *Emission limit values for discharges of waste water from the cleaning of waste gases from incineration plants.*
- The Directive provides some different trace metal criteria than the German Wastewater Ordinance and is overall somewhat stricter for common metals.
- The directive was selected due to the similar nature of the process associated with the waste water discharge.
- The table shows concentrations of net post-EGCS discharge.

Comparison to EU Surface Water Standards

Parameter	Criteria	Net Post-EGCS results		Unit	Avg. 3σ % of criteria limit
		Avg.	Avg. 3σ		
Anthracene	**0.1**	0.16586	0.08680	µg/L	87 %
Benzo(a)pyrene	**0.270**	0.00177	0.00377	µg/L	1 %
Benzo(b)fluoranthene	**0.017**	0.01154	0.01364	µg/L	80 %
Benzo(g,h,i)-perylene	**0.0082**	0.00200	0.00403	µg/L	49 %
Benzo(k)fluoranthene	**0.017**	-0.00329	-0.00135	µg/L	0 %
Fluoranthene	**0.120**	0.08491	0.06613	µg/L	55 %
Naphthalene	**130**	3.14205	2.28480	µg/L	2 %
Cadmium (Dissolved)	**0.00045**	-0.00034	-0.00013	mg/L	0 %
Lead (Dissolved)	**0.014**	0.00131	-0.00101	mg/L	0 %
Mercury (Dissolved)	**0.00007**	-0.00017	-0.00001	mg/L	0 %
Nickel (Dissolved)	**0.034**	0.05199	0.02462	mg/L	72 %

- The criteria are based on Environmental Quality Standards (EQS) in Directive 2013/39/EU, amending the Water Framework Directive (2000/60/EC) – *Maximum allowable concentration for inland surface waters.*
- Inland surface waters encompass rivers and lakes and related artificial or heavily modified water bodies.
- The standard was chosen because it has limits for a number of the PAH parameters of interest.
- The cadmium criteria is lower than what is possible to measure during standard lab testing.
- The table shows concentrations of net post-EGCS discharge.
- Criteria are only shown for parameters for which Carnival tested.

Comparison to WHO Drinking Water Guidelines

Parameter	Criteria	Net Post-EGCS results		Unit	Avg. 3σ % of criteria limit
		Avg.	Avg. 3σ		
Benzo(a)pyrene	**0.7**	0.00177	0.00377	µg/L	1%
Arsenic	**0.01**	-0.00030	-0.00009	mg/L	0%
Cadmium	**0.003**	-0.00024	-0.00002	mg/L	0%
Chromium	**0.05**	0.00583	0.00307	mg/L	6%
Copper	**2**	0.06494	0.00269	mg/L	0%
Lead	**0.01**	-0.00087	-0.00067	mg/L	0%
Mercury	**0.006**	-0.00202	0.00001	mg/L	0%
Nickel	**0.07**	0.05300	0.03572	mg/L	51%
Selenium	**0.04**	-0.00066	-0.00047	mg/L	0%
Nitrate	**50**	1.2827	0.9030	mg/L	2%

- The criteria are based on the WHO's Guidelines for drinking-water quality, 4th edition, incorporating the first addendum.
- These are not national primary drinking water regulations and are selected as a representative international baseline for acceptable criteria.
- The comparison is for general interest only as these Guidelines contain significantly stricter criteria for total trace metals than major point-source discharge standards .
- The table shows concentrations of net post-EGCS discharge.
- Criteria are only shown for parameters for which Carnival tested.