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## **POLLUTION PREVENTION AND RESPONSE**

### **Study report on analyses of water samples from exhaust gas cleaning systems**

**Submitted by CESA**

#### **SUMMARY**

*Executive summary:* This document provides the results of a sampling campaign of washwater from exhaust gas cleaning systems on a series of ships and the subsequent analysis performed jointly by EGCSA (the Exhaust Gas Cleaning Systems Association) and Euroshore (the association representing port waste reception facility providers)

*Strategic direction, if applicable:* 1

*Output:* 1.12

*Action to be taken:* Paragraph 2

*Related documents:* MEPC 73/11 and PPR 5/24

#### **Introduction**

1 This document reports on the analysis of 238 samples of exhaust gas cleaning system overboard discharges and of seawater from 20 ships in the Baltic and North Sea ECAs and two ships in the Mediterranean in a joint campaign run by EGCSA (the Exhaust Gas Cleaning Systems Association) and Euroshore (the Association representing port waste reception facility providers). The report is set out in the annex.

#### **Action requested of the Committee**

2 The Committee is invited to note the information provided.

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ANNEX

# Report on analyses of water samples from Exhaust Gas Cleaning Systems

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## SUMMARY

This paper reports on the analysis of 238 samples of scrubber overboard discharges and of seawater from 20 vessels in the Baltic and North Sea ECAs and two vessels in the Mediterranean in a joint campaign run by EGCSA (the Exhaust Gas Cleaning Systems Association) and Euroshore (the Association representing port waste reception facility providers). All vessels were using IF 380 residual fuel.

Samples were collected in two programmes. For reasons of cost control two laboratories were used. Samples were analysed for US EPA 16 Polycyclic Aromatic Hydrocarbons (PAH), metals, BTEX (in Programme 1 only) and nitrates/nitrites (in Programme 1 only).

The concentrations of PAH normalized <sup>[1]</sup> at 45m<sup>3</sup>/MWh washwater flow rate were below 43µg/l in the discharges from all 22 vessels. The average concentration was less than 12µg/l. PAH composition and comprised an average of 47% naphthalene, the lightest PAH, which readily volatilizes from surface waters and has a half-life of less than one day in the atmosphere.

The concentration of benzo(a)pyrene (BaP), a marker for PAH used by the World Health Organization was found to be below the WHO drinking water guideline limit in all but one sample when normalized at a washwater flow rate of 45m<sup>3</sup>/MWh; (0.74µg/l compared with 0.7µg/l). The average normalized BaP concentration was 0.06µg/l and unnormalized concentrations were all below the WHO limit.

BTEX concentrations were found to be low (maximum 4 parts per billion in one sample). Concentrations were below limits of detectability in 11 of 15 overboard samples and concentrations in the other four samples were below the WHO guideline limits for drinking water.

Of the metals analysed vanadium was the most prevalent in the overboard samples. Concentrations of chromium, copper, lead, nickel and zinc have been compared with European Union limits for discharges of waste water from cleaning of waste gases from incineration plant. Of 195 individual test results, three (two lead and one zinc) were found to be above the EU limits on two ships. Samples taken from the first vessel at a later date found lead to be below detectable limits. On the second vessel, elevated levels of zinc were also reported at sea water inlet to the scrubber system and in general there is evidence of contribution of zinc and copper probably from anodic protection and marine growth inhibition systems. These metals are likely to be seen on many ships regardless of whether scrubbers are installed.

Arsenic and cadmium were below limits of detectability in 32 of 34 seawater samples and 35 of 39 overboard samples. Mercury was reported in one seawater sample. Concentrations were below detectable limits in all other samples. It is considered that the arsenic and mercury reported in the three seawater samples may have resulted from either cross contamination during sampling or erroneous analysis. Where reported as present, the normalized concentrations of arsenic, cadmium and mercury were all sub parts per billion.

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[1] For an explanation of normalization see section 2.1

Current EGCS systems are not designed to scrub NO<sub>x</sub> and all normalized nitrate levels at overboard discharge were below the 2015 Exhaust Gas Cleaning System Guidelines' limit of 60mg/l. Concentrations of nitrite were found to be negligible. Analysis of seawater samples showed that nitrate in the clean seawater supply to open loop scrubbers contributed significantly to nitrate at the discharge. A maximum normalized concentration of 7mg/l was found by deducting the concentration at system inlet from the concentration at overboard. It is therefore suggested that should it be needed for compliance confirmation, there should be an option to take into account the nitrate at inlet to open loop scrubbers when reporting in accordance with MEPC.259(68), 10.1.5. Alternatively, that consideration be given to removing the need for nitrate testing for current scrubber designs.

Given the operational constraints of ships, it was found necessary to take a *practical and cost-effective approach* to sampling. A marine engineer experienced in exhaust gas cleaning systems and sampling sailed with all ships during the first programme and managed the campaign throughout. Based on learning from the first programme a step-by-step guide was developed for Programme 2, so that ship's crew could take samples. The guide is published on the EGCSA website.

The main challenges for sampling are cleanliness, as concentrations of some analytes are often extremely low (PAH: parts per billion or less), and availability of suitable points to take samples. To promote sampling best practice EGCSA has developed and published on its website a specification for sample points based on offshore industry methodology.

There is a need for good communication and planning during a campaign such as this. Sampling requires the use of specially prepared sample bottles in cooler boxes with ice packs, which must be supplied to the ship by the laboratory. The allowable time between sampling, which is undertaken at sea, and analysis in the laboratory can be challenging. Ships can be held at anchor after sampling, berths may be geographically remote from laboratories and, unlike ship operations, courier collections and laboratory opening hours are not 24/365. This is particularly relevant when sampling for nitrates and BTEX tests at the same time. Samples for nitrates must be received at the laboratory within 24 hours, unless the sample remains frozen in transit, and sample freezing takes time. However, BTEX samples must be received at the laboratory within 48 hours and cannot be frozen.

It is therefore recommended that any future programmes and protocols take the need for practicality into account. The use of specialised equipment, laboratories and test methodologies, should be carefully considered to facilitate rather than constrain sampling, particularly if it is to be undertaken by ship's crew.

## 1 SAMPLING CAMPAIGN

### 1.1 Background

Following a meeting of the EC's European Sustainable Shipping Forum scrubber sub-group (ESSF EGCS SG) on the 2<sup>nd</sup> July 2014, it was agreed the Exhaust Gas Cleaning Systems Association, EGCSA and the Association representing port reception facility providers, Euroshore would run a joint campaign of washwater sampling to establish a better understanding of the components in open and closed loop overboard discharges and to determine the likely concentrations.

During 2015, EGCSA and Euroshore worked with ship operators and scrubber manufacturers to sample the overboard discharges from exhaust gas cleaning systems of 10 ships. For comparison samples were also taken at seawater inlet to the exhaust gas cleaning systems during open loop scrubbing or at other locations (typically from the supply to the EGCS coolers) during closed loop scrubbing. Samples were analysed for US EPA 16 PAH, BTEX, metals and nitrate/nitrite.

Following review of the analytical data from the first programme, it was agreed that a second programme would be undertaken during 2016/17, which would focus on the concentration of PAH and metals.

Analysis results and related data are available at Appendix 2 of this report.

### 1.2 Ships

All ship-owners and ships taking part in the sampling campaign have been given complete anonymity with respect to the sample source. Table 2 provides a summary of the ships sampled in both programmes, the ship codes for the data table in Appendix 2 and an overview of the exhaust gas cleaning configurations.

Twenty ships were sampled in the North Sea and Baltic Emission Control Areas and two in the Mediterranean; half were RoRo/RoPax vessels as shown in Table 1. Appendix 1 has maps with ship positions at the end of each sampling exercise.

Ship type	Number
RoRo/RoPax	11
Cruise	3
Oil tanker	3
Vehicles carrier	2
Multi-purpose	1
RoRo container	1
Container	1

Table 1: ship types sampled

The initial aim was to sample scrubber systems at maximum engine load, however this approach was quickly found to be impractical for a variety of reasons including:

- Variable weather and sea conditions

- Reduced speed operation for fuel cost savings
- Waiting for orders for spot market vessels
- Meeting exact passage timings on regular routes
- Berthing delays

As a result, samples were taken at engine powers ranging from manoeuvring in a river delta i.e. approximately 10% of maximum continuous rating (MCR) to full power i.e. 92% MCR. This range of operating powers represents the reality of ship and scrubber system operation. The average engine power during sampling was 59% MCR.

All ships were using IF380 residual fuel in engines and boilers during sampling. Sulphur contents of the fuel varied between and 0.96% and 3.14% with an average of 2.38%.

Vessel	Codes	Type	Scrubber overview
1	A, O	RoRo/RoPax	Two single entry hybrid scrubbers port and starboard. One main engine per scrubber. (Starboard engine not in operation during first sampling).
2	B, Q, W	Multi-Purpose	One single entry hybrid scrubber for main engine
3	C	RoRo/RoPax	One multi-entry open loop scrubber for two main engines
4	D	RoRo/RoPax	One multi-entry open loop scrubber for two main engines
5	E	Container	One single entry closed loop scrubber for main engine
6	F	Vehicles Carrier	One multi-entry hybrid scrubber for one main engine & three auxiliary engines
7	G	RoRo/RoPax	Four single entry open loop scrubbers; two port and two starboard. One main engine per scrubber.
8	H, R	Tanker	One multi-entry hybrid scrubber for two main engines, five auxiliary engines, two auxiliary boilers and one donkey boiler
9	I	Tanker	One multi-entry hybrid scrubber for one main engine & three auxiliary engines
10	J, V, X	RoRo/RoPax	Two single entry hybrid scrubbers, one main engine per scrubber
11	K	RoRo/RoPax	Two single entry hybrid scrubbers, one main engine per scrubber
12	L	RoRo/RoPax	One single entry hybrid scrubber for main engine
13	M	RoRo/RoPax	One single entry hybrid scrubber for main engine
14	N	RoRo/RoPax	One multi-entry hybrid scrubber for two main engines
15	P	RoRo Container	One single entry open loop scrubber for one main engine
16	S	Tanker	One multi-entry hybrid scrubber for two main engines, five auxiliary engines, two auxiliary boilers and one donkey boiler

17	T	RoRo/RoPax	Four single entry open loop scrubbers; two port and two starboard. One main engine per scrubber.
18	U	RoRo/RoPax	Two multi-entry hybrid scrubbers; one port & one starboard. Two main engines per scrubber.
19	Y	Vehicles Carrier	One multi-entry hybrid scrubber for one main engine and three auxiliary engines
20	Z	Cruise	One single entry hybrid scrubber for auxiliary engine
21	AA	Cruise	One single entry hybrid scrubber for auxiliary engine
22	BB	Cruise	One single entry hybrid scrubber for auxiliary engine

Table 2: vessel and exhaust gas cleaning system overview

### 1.3 Exhaust Gas Cleaning Systems

Tables 2 and 3 illustrate the variety of exhaust gas cleaning system configurations on the 22 vessels sampled, with scrubbers serving both single and multiple combustion units. Depending on the vessel type and arrangement there may be one or more exhaust cleaning units with integrated or separated piping and control arrangements.

EGCS type	Number of vessels
Hybrid (i.e. can operate in both open and closed loop mode)	16
Open loop	5
Closed loop	1

Table 3: exhaust gas cleaning system types on sampled vessels

Of the 16 vessels with hybrid systems, 13 were sampled with the system operating in open loop mode only, two were sampled both in open and closed loop mode and one was sampled in closed loop mode only.

### 1.4 Sampling

To prevent analyte losses between the ship and laboratory, samples for analysis of PAH, BTEX, metals and nitrate/nitrite require properly prepared bottles and cooler boxes with ice packs for transport of the filled bottles as shown in Figure 1. One litre sample bottles for PAH analysis, for example, are of dark glass and contain a small quantity of concentrated hydrochloric acid. The bottles must be 100% filled to avoid losses, particularly of naphthalene, through volatilization and photochemical and biological processes.



Figure 1: sample bottles for PAH and metals analysis with cooler box for transport used in Programme 1

The time in transit between ship and laboratory as shown in Table 4 is also important in mitigating analyte losses and can pose logistical problems and can be expensive for ships if not planned carefully.

Analyte	Test method	Maximum time from sampling to analysis
Nitrate + Nitrite	EN ISO 10304-1	Cool to between 1C and 5C: <b>24 hours</b> Frozen to -20C: 1 month
BTEX	DIN 38407-9-2	<b>48 hours</b> (glass sample bottles – do not freeze; cool only)
PAH	EPA 8270D	7 days (glass sample bottles – do not freeze; cool only)
Metals	EN ISO 11885	1 month

Table 4: Programme 1 maximum times between sampling and laboratory analysis

For integrity assurance a marine engineer experienced with exhaust gas cleaning systems and sampling sailed with all ships during Programme 1 and managed the campaign throughout. A practical step-by-step guide was developed using the hands-on learning and observations of ship staff landing samples during the first programme, so that ships could safely and properly take and despatch samples for Programme 2 with ongoing support from shore. (An example of the guide is freely available to download from the EGCSA website - [http://www.egcsa.com/wp-content/uploads/EGCSA-Euroshore-scrubber-water-sampling-Ship-Guide-2016\\_17.pdf](http://www.egcsa.com/wp-content/uploads/EGCSA-Euroshore-scrubber-water-sampling-Ship-Guide-2016_17.pdf)).

Given the very low concentrations of analytes, the ship guide puts particular emphasis on sample point preparation and cleanliness. It was found during Programme 1 that although many EGCS instrumentation stations have valves of various types that can be used for sampling, this is not always the case and alternatives have to be found. In

addition, while the instruments provide continuous remote readings on a dedicated screen in the engine room control room (and sometimes a dedicated scrubber room), the instrumentation stations can be in unexpected places and are not necessarily in the engine room. Although access to instruments and alternative sample points may be acceptable for normal maintenance etc., it may not be so for sampling of water which is to be analysed for substances in the parts per billion range.

To address this issue and promote best practice while keeping in mind the need to be practical and cost effective, EGCSA has developed a sample point specification based on a UK government published methodology for sampling in the offshore industry (UKDECC, 2014), which is freely available at the EGCSA website - <http://www.egcsa.com/wp-content/uploads/EGCSA-Scrubber-Water-Sampling-Point-Specification-v1.pdf>

## 1.5 Laboratories

Two European laboratories (both ISO 17025 accredited, but with different parent organizations) were used for the campaign – Laboratory A for all of Programme 1 and the first part of Programme 2 and Laboratory B for the later part of Programme 2. The change was made for cost control reasons, but also deemed useful for comparison purposes as internationally trading ships are quite likely to have to use different analytical facilities employing different test methodologies and techniques.

Analyte	Laboratory A	Laboratory B
PAH	EPA 8270D, GC-MS	<ol style="list-style-type: none"> <li>1. In house method, GC-MS (based on EPA 8270C - allowed for EPA VGP)</li> <li>2. In house method, HPLC-FLD (based on ISO 7981-2 and comparable with EPA 8310 – allowed for EPA VGP). HPLC only used during parallel comparison tests.</li> </ol>
Metals	EN ISO 11885, ICP-OES	EN-ISO 17294-2, ICP-MS

Table 5: Test methods of Laboratories A and B

Parallel samples were taken for comparison tests from two vessels (Ship codes: Q/W, when closed loop scrubbing and X, when open loop scrubbing). Results of metals analyses of overboard samples were found to be in close agreement. The *percentage* of each EPA 16 PAH species reported by Laboratory A and B was found to be in close agreement. However, Laboratory A reported a lower *total concentration* of EPA 16 PAH than Laboratory B in the overboard samples from both vessels; (lower by 4µg/l to 9µg/l).

It is a complex subject and was beyond the scope of the sampling campaign to quantify what may have caused these differences in total PAH concentration. However, influencing factors when parallel sampling for comparison of laboratories could include:

- The technique used for sampling. If consecutive samples are taken and the sample point is not thoroughly flushed, analyte concentrations may be greater

in the first sample when compared to the second. It is also important that sample bottles be filled completely for reasons described below.

- Sample homogeneity. If a single sample is taken and decanted into two bottles, particle bound PAH may not be evenly distributed between the two samples.
- Carriage conditions and time of transit from ship to the two laboratories. As discussed in section 1.4, sampling requires specially prepared bottles and cooler boxes with ice packs for sample transport. Samples must be received at the laboratory within the required timeframe to avoid losses of volatile PAH species. While laboratories typically check that the temperatures of samples are within limits when received, these may vary depending on ambient temperatures and transit times. (A courier van with a long journey and several stops in hot weather, will expose the samples to higher temperatures than a courier on a short overnight journey with no stops). Some analytes may volatilize into the space above the liquid surface of the sample if the bottles are not completely full.
- Laboratory methods, which can be considered in two parts for PAH analysis (Restek ,2002):
  - Sample preparation when PAH are extracted from the water and any particles that may be present. The preparation method is often not quoted on analysis reports and more than one preparation method may be allowable under some test standards. Research (Mahgoub, 2016) suggests the rates of PAH recovery from samples can be variable depending on the preparation method used and the efficacy of PAH extraction from particles
  - Determination of the concentration of PAH extracted from the water and any particles. Gas Chromatography – Mass Spectrometry (GC-MS) or High Performance Liquid Chromatography with fluorescence and/or UV detection (HPLC-FLD-UV) may yield different results (Diaz-Moroles et al., 2007).

## 2 SAMPLE ANALYSES

### 2.1 Normalization of results

The water flow rate at the sample point and power of the combustion unit(s) being scrubbed is different at each sampling. A sample taken at a higher specific water flow rate will have a relatively lower concentration of analytes than the same sample taken at a lower specific water flow rate. To enable a comparison of concentrations on a like-for-like basis, concentrations in this report have been normalized i.e. adjusted using both flow and power using a factor of 45m<sup>3</sup>/MWh as follows:

$$\text{Normalized concentration} = \frac{\left[ \text{Laboratory reported (unnormalized) concentration} \right] \times \left[ \text{Specific water flow rate at time and point of sampling (m}^3\text{/MWh)} \right]}{45 \text{ m}^3\text{/MWh}}$$

Where:

$$\text{Specific water flow rate at time and point of sampling (m}^3\text{/MWh)} = \frac{\text{Water flow rate at sampling point (m}^3\text{/h)}}{\text{Power of the combustion unit(s) being scrubbed at time of sampling (MW)}}$$

## 2.2 Polycyclic Aromatic Hydrocarbons(PAH)

Polycyclic Aromatic Hydrocarbons are compounds comprising 2 to 8 joined benzene ring molecules (Pampanin and Sydnese, 2013). PAH's in the marine environment can be divided into two groups depending on their origin - pyrogenic PAHs, generally larger ring systems formed by incomplete combustion of organic material, for example fuel and a very minor proportion of lubricating oil in engines, which tend to condense and adsorb onto soot particles, and petrogenic PAHs, generally smaller ring systems that are naturally present in oil and oil products.

US EPA has identified 16 PAHs as priority pollutants. These include naphthalene, the lightest EPA 16 PAH, which rapidly volatilizes from surface waters and degrades through photochemical processes in the atmosphere with a half-life of < 1 day (ATSDR, 2015), phenanthrene, on average the second most common EPA 16 PAH found in fuel oils after naphthalene (Stout and Wang, 2016) and benzo(a)pyrene, which is often used as a marker for other PAHs (WHO, 2017, SEPA, 2015)

### 2.2.1 PAH and the Exhaust Gas Cleaning System Guidelines

MEPC.259(68), 2015 Guidelines for Exhaust Gas Cleaning Systems paragraph 10.2.1 states that the *oil content* of scrubber washwater overboard discharges must be monitored by the continuous monitoring and recording of PAH levels. In order to limit the quantity of oil discharged to sea online instruments are used to measure the concentration of PAHs at system inlet and overboard discharge at the wavelength phenanthrene fluoresces. Paragraph 10.1.3.3 gives the maximum allowable PAH concentration as *phenanthrene equivalents* depending on the washwater flow rate after inlet concentration has been deducted from overboard concentration.

The rationale for measuring PAH rather than oil is due to the lack of instrumentation capable of measuring the very low concentrations of oil in scrubber washwater. The concentrations are below the detection capabilities of traditional marine 15 parts per million oil-in-water monitors. Oil, however contains many species of hydrocarbons, including polycyclic aromatic hydrocarbons. PAHs fluoresce when exposed to ultra violet light energy, even at low parts per billion concentrations and there are several online instruments suitable for accurate measurement in water streams using this property.

The monitoring of oil in overboard discharges by using PAH measurement and the limits at various washwater flow rates were developed from a number of submissions to IMO, including MEPC 55/4/5 (Annex I, section 7.2) and by subsequent working and correspondence groups. References include BLG 12/6 (paragraph 8.3), BLG 12/6/Add.1(section 10.1.3), BLG 12/WP.6/Add.4, BLG 12/17 Annex 6 and MEPC 57/21 Annex 4.

## 2.2.2 PAH analytical results

Figure 2 shows the concentration of EPA 16 PAH normalized to 45m<sup>3</sup>/MWh washwater flow rate in 41 overboard discharge samples <sup>[2]</sup> to be below 43µg/l and at an average of 11.8µg/l. (No discharges were diluted by additional water, for example for pH adjustment, at the sampling points).

These concentrations do not have PAH at the seawater inlet of open loop scrubbers deducted. Unnormalized concentrations in Figure 3 show that while most samples of seawater taken both during open and closed loop scrubbing contained little PAH (less than 0.1µg/l) as might be expected, five results (and particularly those from Ship U) suggest the possibility of some contamination during sampling. PAH can be detected at the seawater inlet, for example because of sediment disturbance during shallow water manoeuvring (MEPC 55/4/5, 2006), however the locations of the ships at the time of sampling would suggest this to be unlikely in these cases.

Concentrations of the heavier molecular weight benzo(a)pyrene at scrubber overboard are shown at Figures 4 (normalized) and 5 (unnormalized). Of 41 samples, one normalized result exceeds the World Health Organization guideline value of 0.7µg/l (WHO, 2016) by 0.04µg/l <sup>[3]</sup>. No unnormalized results exceed the WHO guideline value. For comparison one unnormalized result exceeds the US EPA limit of 0.2µg/l (US EPA, 2009.). The average concentrations are 0.03µg/l (unnormalized) and 0.06µg/l (normalized).

The average concentration of each EPA 16 PAH, shown in Figure 6, is dominated by three species. Naphthalene at 47% is the most prevalent, followed by Phenanthrene at 25% and Fluorene at 8%. This can be compared with respective average figures of 61%, 21% and 10% for 48 crude oils reported by Pampanin and Sydnes (2013) and 65%, 11% and 5% for 71 IF380 fuel oils by Stout and Wang (2016), which suggests the majority PAH are petrogenic in source (see also Stogiannidis and Laane, 2014).

## 2.3 BTEX

BTEX is an acronym for benzene, toluene, ethylbenzene, and xylene, a group of volatile organic compounds (VOCs) found in petroleum. While BTEX have a high vapour pressure and volatilize to gases at ambient temperatures and pressures, the compounds can be dissolved in the water phase (Eugris.info, n.d.). Although the hydrophilic nature and persistence in the right conditions of reduced oxygen can facilitate transport over rather long distances, BTEX are highly biodegradable under aerobic conditions.

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[2]: The difference between number of samples and ships arises as some vessels were sampled more than once at different dates and times, some vessels have multiple scrubbers with discharges at the port and starboard sides and parallel samples were taken from two vessels (Ship codes: Q/W and X) when changing from Laboratory A to Laboratory B.

[3]: The guideline value normally represents the concentration of a constituent that does not result in any significant risk to health over a lifetime of consumption.

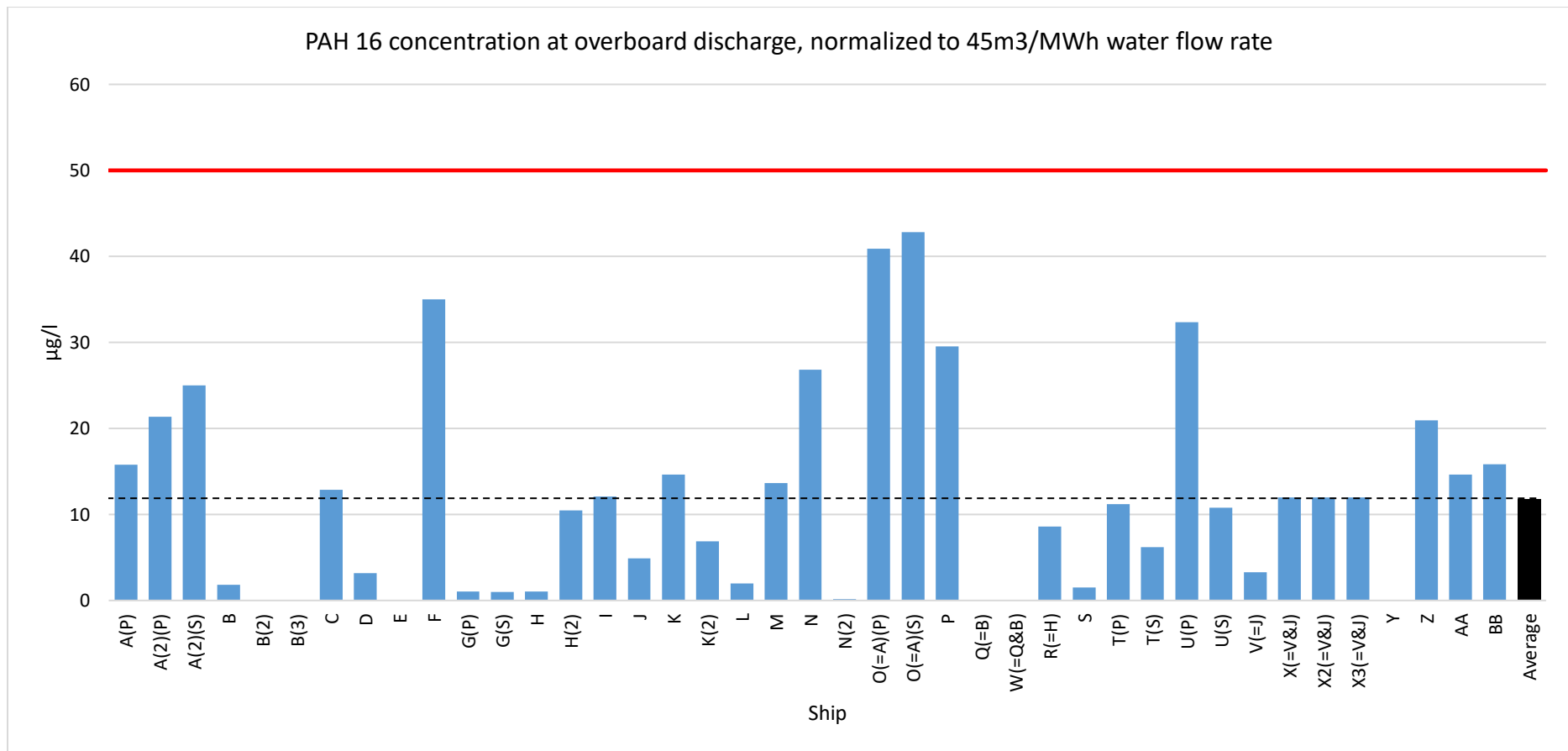


Figure 2: PAH 16 concentration at overboard discharge, normalized to 45m<sup>3</sup>/MWh water flow rate. All below 50µg/l.

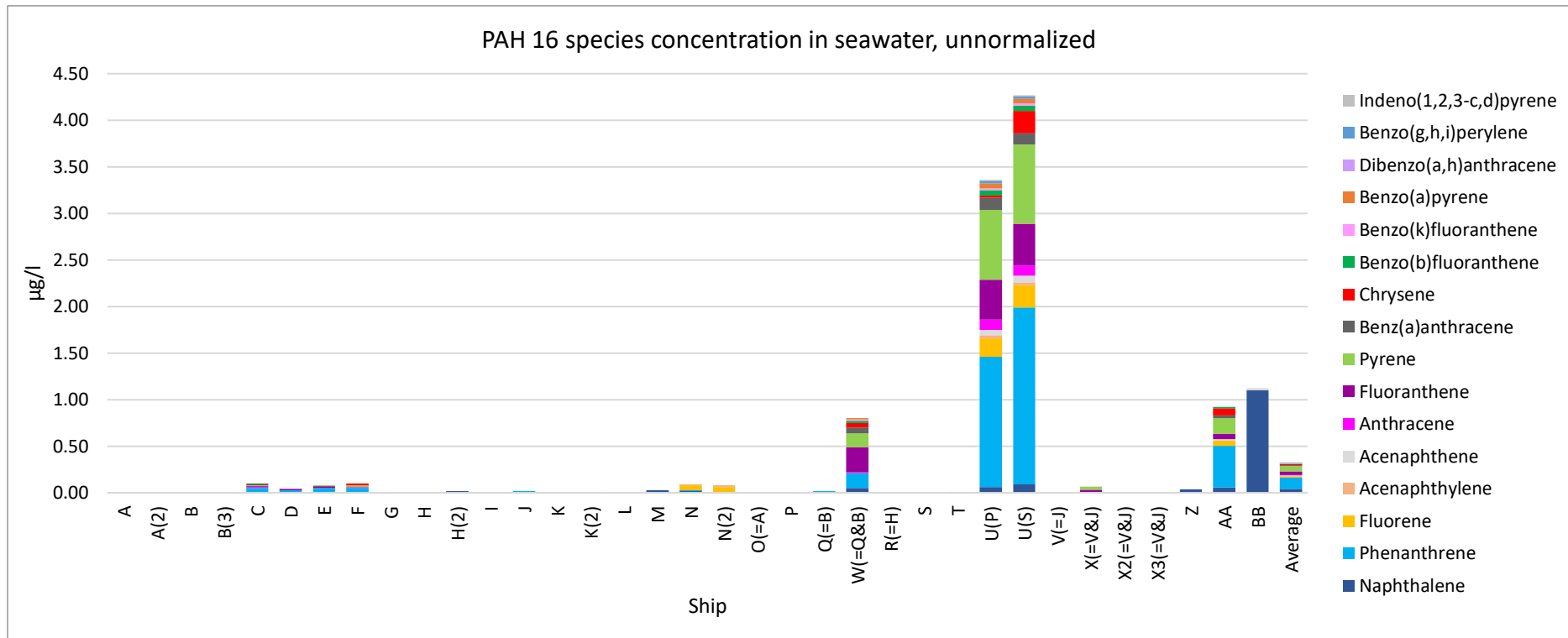


Figure 3: PAH 16 species concentration in seawater, unnormalized. Samples taken at seawater inlet to the exhaust gas cleaning systems during open loop scrubbing or at other locations (typically from the supply to the EGCS coolers) during closed loop scrubbing

Results from Ship: U suggest that some contamination may have occurred during sampling of the port and starboard seawater inlets, although it should also be noted that the PAH concentration is between 3.0 and 4.5 parts per billion.

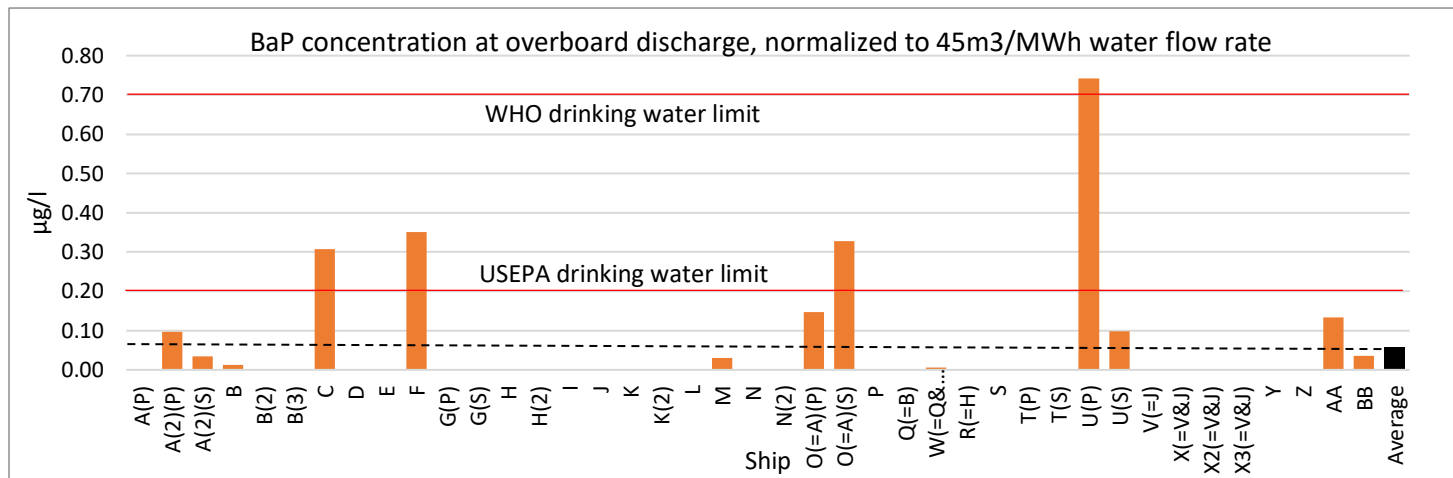


Figure 4: Normalized benzo(a)pyrene concentration at overboard and drinking water limits

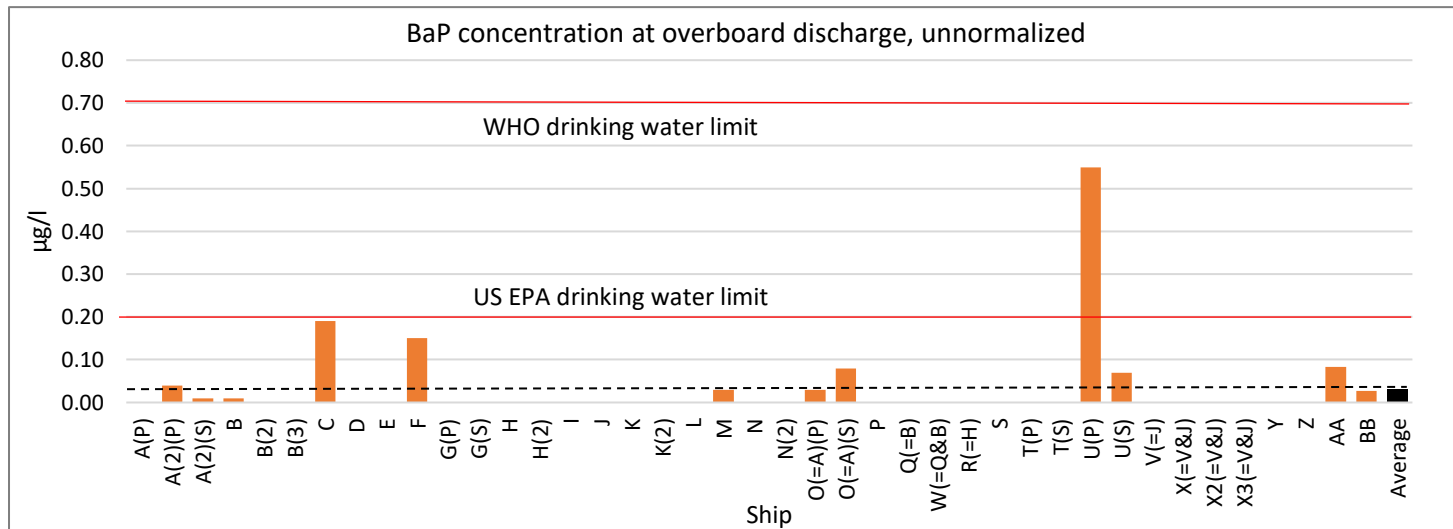


Figure 5: Unnormalized benzo(a)pyrene concentration at overboard and drinking water limits

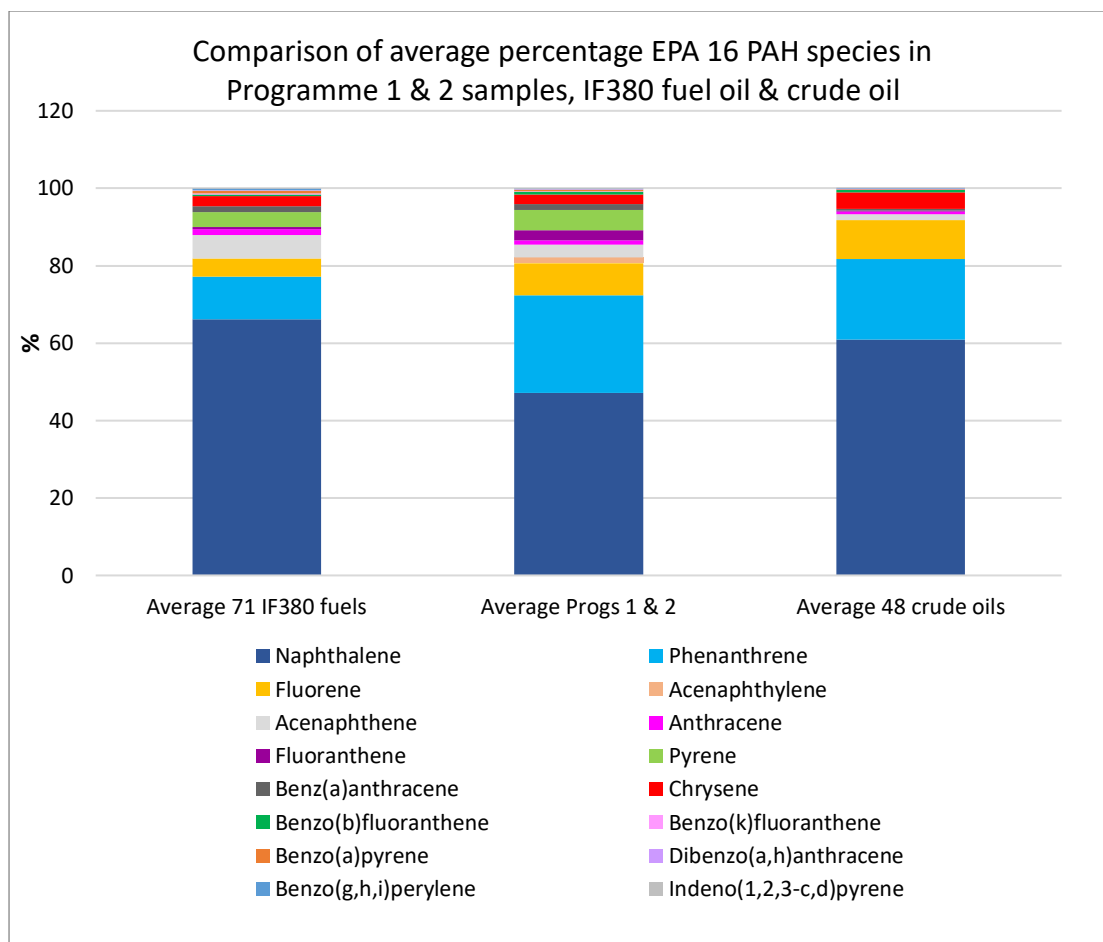


Figure 6: comparison of average percentage EPA 16 PAH species in Programme 1 and 2 samples, 71 IF380 fuel oil samples (Stout and Wang, 2016) and 48 crude oil samples (Pampanin and Sydnes, 2013)

### 2.3 BTEX (continued)

The World Health Organization Guidelines for drinking-water quality (WHO, 2017) give guideline values of:

- 10µg/l (0.01mg/l) for benzene,
- 700µ/l (0.7mg/l) for toluene,
- 300µ/l (0.3mg/l) for ethylbenzene; and
- 500µ/l (0.5 mg/l) for xylene.

#### 2.3.1 BTEX analytical results

Of 15 analyses by method DIN 38407-9-2:

- A maximum unnormalized benzene concentration of 2µ/l was reported in 2 samples
- Benzene concentration was below the test method detectable limit in 11 samples
- A maximum unnormalized toluene concentration of 2µ/l was reported in 2 samples

- Toluene concentration was below the test method detectable limit in 11 samples
- Ethylbenzene, o-xylene, m-, p-xylene concentrations were below the test method detectable limit in all 15 samples
- Total BTEX concentration was below the test method detectable limit in 11 samples

As the concentrations reported during Programme 1 were consistently low, sample analysis for BTEX was not continued under Programme 2.

## 2.4 Metals

Appendix 3 of MEPC.259(68) requests that samples are analysed for the metals arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), vanadium (V) and Zinc (Zn). These were reported in both programmes 1 and 2, together with mercury (Hg) in Programme 1.

These metals can be found in residual fuel oils (Handbook.ifrf.net, 2001), however there are other potential sources; combusted lubricating oil may contribute minor quantities of zinc for example.

Scrubber manufacturers are knowledgeable and experienced in the application of high performance corrosion resistant materials. Very high PREN<sup>[4]</sup> stainless steels are typically used for EGCS unit construction and there is extensive use of inert glass-reinforced-epoxy (GRE) for EGCS pipework. However, an EGCS system may not be totally segregated from other systems on the ship. On the seawater supply side, sea chests may be shared with other systems where more traditional materials are used for piping, filtration, pumps, valves and instrumentation fittings. Anti-corrosion anodes and marine growth suppression systems are likely to contribute metals such as zinc and copper. Analysis of samples of seawater either supplying open loop scrubbers or coolers on closed loop systems, reflect these materials as shown in Figure 7 and are likely to be seen on all ships regardless of whether scrubbers are installed.

Figure 8 illustrates the multiple pathways of marine fuel combustion and particulate emission without scrubbing and how some metals are bound to particulate matter or deposited as ash while others remain in the vapour phase and condense in the exhaust and beyond if a scrubber is not installed. Other than vanadium, differentiating and quantifying these metals from other sources in scrubber water overboard discharges is potentially complex and dependent not only on fuel composition, but also factors including overall system arrangements, sample point location within the system, sampling technique (e.g. thorough flushing of the sample point, cleanliness of sampling equipment etc.), rates of dissolution and rates of removal by treatment systems.

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[4] Pitting resistance equivalent numbers (PREN) are a theoretical way of comparing the pitting corrosion resistance of various types of stainless steels, based on their chemical compositions. (Bssa.org.uk, n.d.)

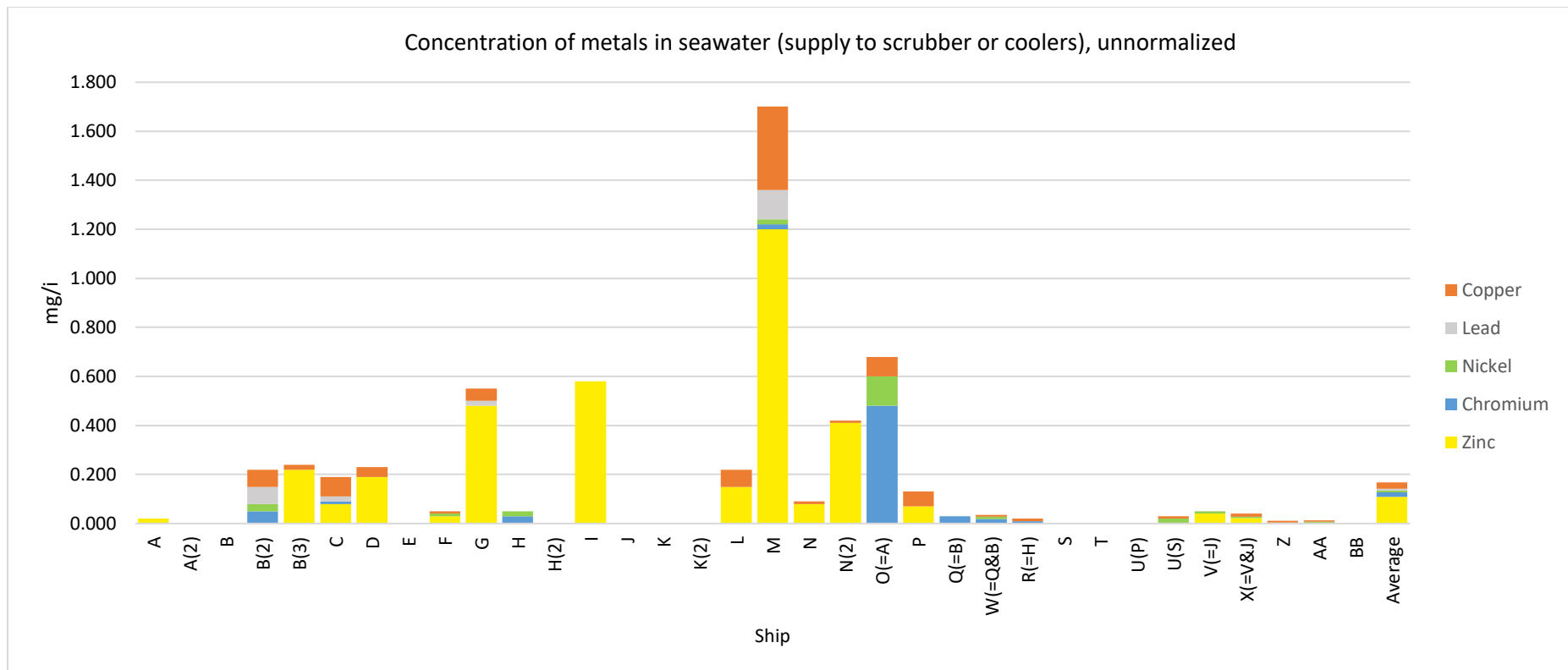


Figure 7: concentration of metals in seawater (supply to scrubber or coolers), unnormalized. Note prevalence of zinc and copper.

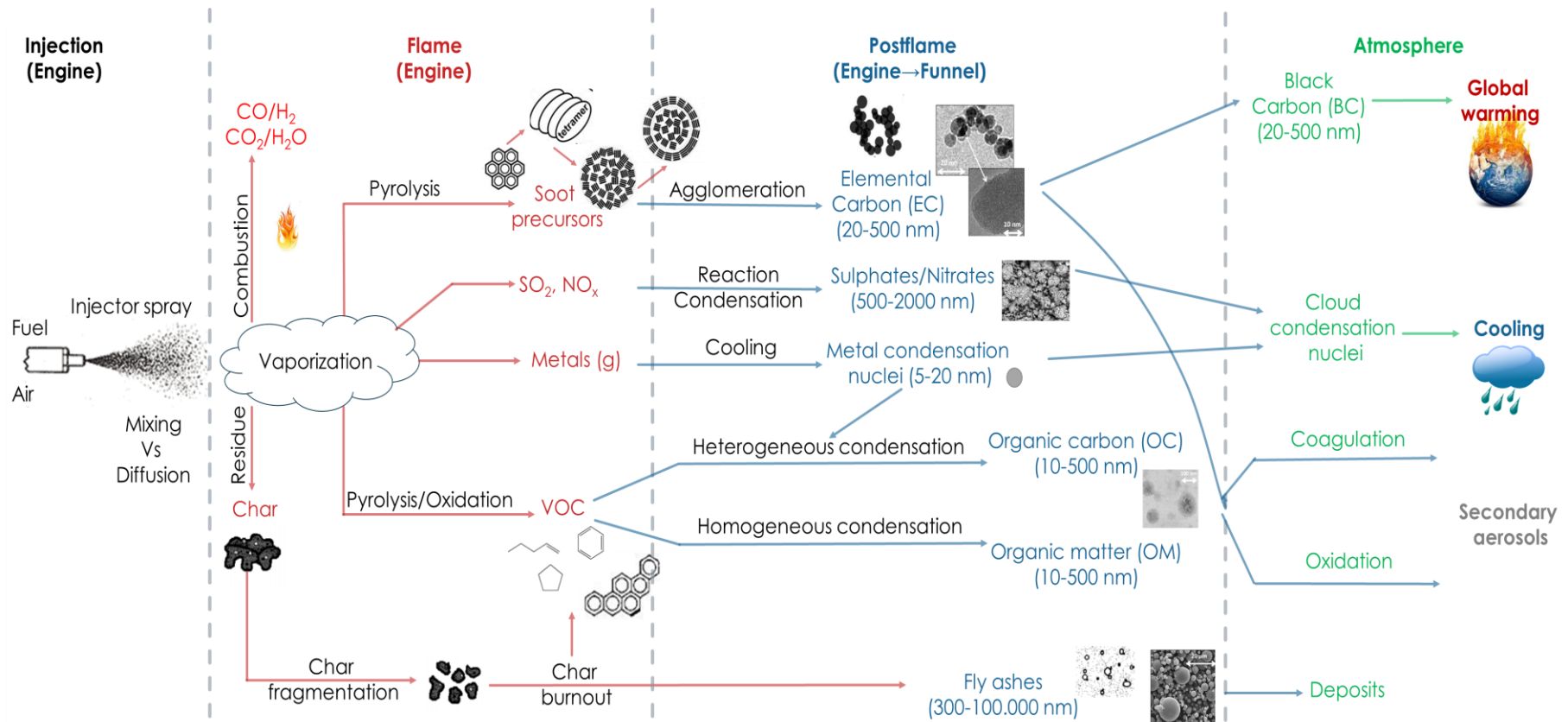


Figure 8: Origin of particulate matter in engine exhausts (graphic courtesy of Asst. Professor Di Natale, Unina). Metal vapours condense post flame and are also associated with carbonaceous particulate matter, char and fly ash (Moldanová et al., 2009).

#### 2.4.1 Metals analytical results

Figures 9-14 show concentrations of chromium, copper, nickel, lead, vanadium and zinc in 39 samples from overboard discharges.

Of the metals analysed vanadium was the most prevalent in the overboard samples (normalized average 0.36mg/l). Other than for vanadium, a comparison is made with emission limit values for discharges of waste water from the cleaning of waste gases from waste incineration plants and waste co-incineration plants given in Annex VI Part 5 of European Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control). Note: Directive 2010/75/EU has no limit value for vanadium.

Of 195 results, three exceeded the limits - two lead, although the concentration in samples taken from the same vessel at a later date were below detectable limits, and one zinc, although this coincides with the highest level of zinc reported at seawater inlet; Ship M.

Of the other metals: arsenic was below detectable limits in 36 of 39 overboard samples and reported in three at trace concentrations – the duplicates taken from a closed loop system during the laboratory changeover (0.020 and 0.024 mg/l, unnormalized) and one sample taken from a closed loop system on another vessel during Programme 1 (0.03 mg/l, unnormalized). Normalizing to 45m<sup>3</sup>/MWh water flow rate reduces the concentrations to sub parts per billion levels.

Arsenic was also reported in two seawater samples: 0.0033mg/l unnormalized, in a sample taken on the same vessel at the same time as the duplicate overboard samples referenced above, which may suggest some cross contamination and 0.03mg/l unnormalized – see below regarding potentially contaminated sample or erroneous reporting of Mercury.

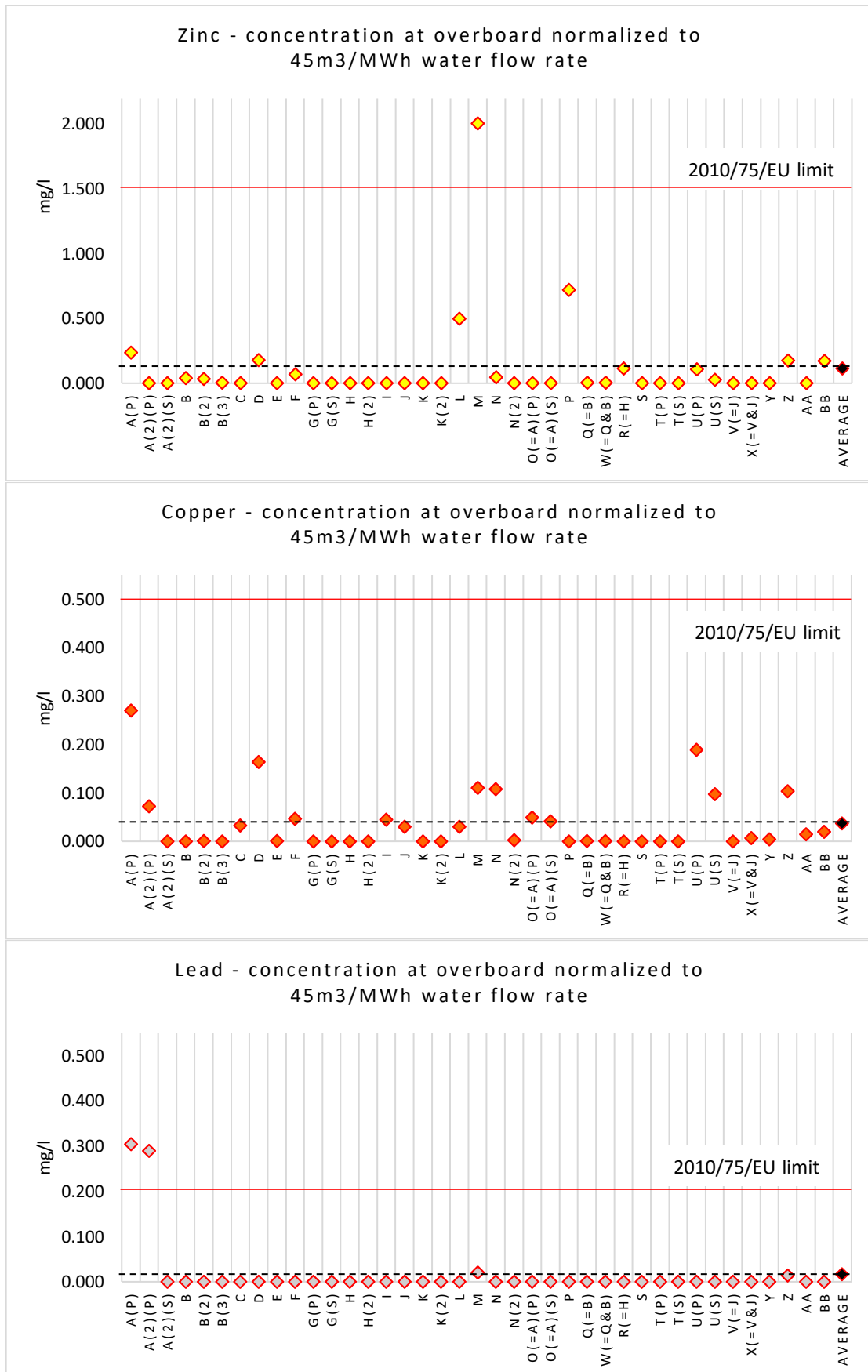
Cadmium was reported in one of the duplicate overboard samples during the laboratory changeover referenced above (0.00096mg/l, unnormalized, i.e. 0.96 ppb), but below detectable limits in all other samples.

Mercury by method BS EN 1483 was below detectable limits in all Programme 1 samples except one seawater sample (0.0004mg/l, unnormalized). It was considered that like arsenic reported in the seawater samples this could have resulted from either contamination during sampling or an erroneous analysis. Analysis for mercury was not continued under Programme 2.

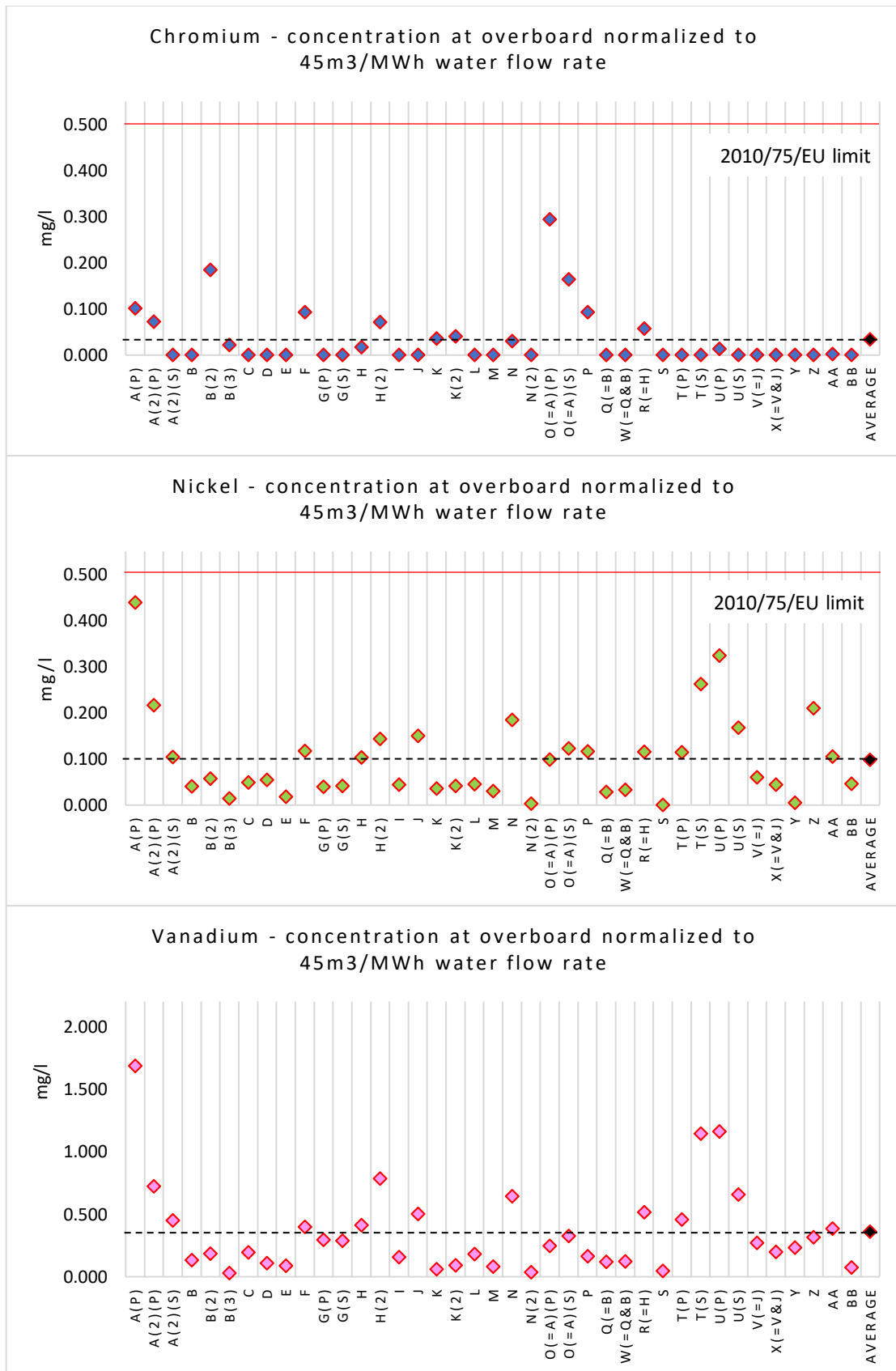
#### 2.5 Nitrate/nitrite

In an engine combustion chamber a series of reactions occur that oxidise a small part of the nitrogen in the charge air and most of the nitrogen in the fuel oil so that nitric oxide (NO) is formed. In the cooler exhaust after the combustion chamber approximately 5% to 10% of the NO is then converted to nitrogen dioxide (NO<sub>2</sub>) in the presence of excess oxygen (Wright, 2000).

While NO has a poor solubility in water, NO<sub>2</sub> readily dissolves to produce HNO<sub>3</sub> and HNO<sub>2</sub>. These decompose, and oxidise in the case of HNO<sub>2</sub>, then ionize to primarily form nitrate (NO<sub>3</sub><sup>-</sup>) and some nitrite (NO<sub>2</sub><sup>-</sup>).



Figures 9-11: normalized zinc, copper, lead at overboard and for comparison the 2010/75/EU limit for these metals.



Figures 12-14: normalized chromium, nickel, vanadium at overboard and for comparison the 2010/75/EU limit for chromium and nickel. (There is no 2010/75/EU limit for vanadium).

## 2.5 Nitrate/nitrite (continued)

Because current sulphur oxide scrubbers are not designed to remove nitrogen oxides, the Exhaust Gas Cleaning Guidelines require that nitrate data based on laboratory analysis of an overboard discharge sample is available at each renewal survey, rather than continuous monitoring. In order to mitigate the potential for eutrophication MEPC.259(68), paragraph 10.1.5.1 places a limit on nitrate concentration based on “12% removal of NOX from the exhaust, or beyond 60 mg/l normalized for washwater discharge rate of 45 tons/MWh whichever is greater”

### 2.5.1 Nitrate/nitrite analytical results

Concentrations of nitrite ( $\text{NO}_2^-$ ) by ISO 10304-1 were below limits of detectability in 23 of 28 samples. Very low levels were found in four overboard samples (maximum 0.12mg/l) and one seawater sample (0.06mg/l).

Figure 15 shows the normalized concentrations of nitrate ( $\text{NO}_3^-$ ) by ISO 10304-1 at scrubber overboard and for the systems operating in open loop mode concentrations at overboard with the concentration at seawater inlet deducted <sup>[4]</sup>.

Without taking the inlet concentration of nitrate into account, a maximum normalized concentration of 49mg/l was reported for Ship A from the starboard discharge (i.e. below the 60mg/l limit). This vessel was sampled twice in Programme 1. In both cases, it was necessary for operational and logistical reasons to take the samples while the vessel was transiting the Rhine-Meuse delta in Holland and all three overboard samples show an elevated level of nitrate.

A comparable level was reported for Ship B overboard discharge, when scrubbing in open loop mode approximately 25 km off the coast of Belgium, south west of Antwerp (see Figure 16). However, seawater samples taken during the same exercises also showed elevated levels of nitrate on both vessels. Deducting these concentrations from the concentrations at overboard, as shown in Figure 15, effectively reduces the nitrate produced by exhaust gas scrubbing to near zero.

Taking the same approach for the other ships using open loop scrubbing in Programme 1 shows a maximum normalized concentration of 7mg/l nitrate at the overboard discharges and a normalized average of less than 1mg/l <sup>[5]</sup>.

Given the foregoing it is suggested that should it be needed for compliance confirmation, there should be an option to take into account the nitrate at inlet to open loop scrubbers when reporting in accordance with MEPC.259(68), 10. 1.5. Alternatively, that for current scrubber designs consideration be given to removing the need for nitrate testing from the Guidelines.

As the concentrations reported during Programme 1 were all below limits, sample analysis for nitrate and nitrite was not continued under Programme 2.

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[5] For the two overboard samples taken when Ship B was scrubbing in closed loop mode (B(2) and B(3)), the nitrate concentration in seawater has not been deducted in Figure 15 as closed loop washwater is not supplied from the sea. Normalized concentrations of approximately 1mg/l nitrate were reported for these overboard samples.

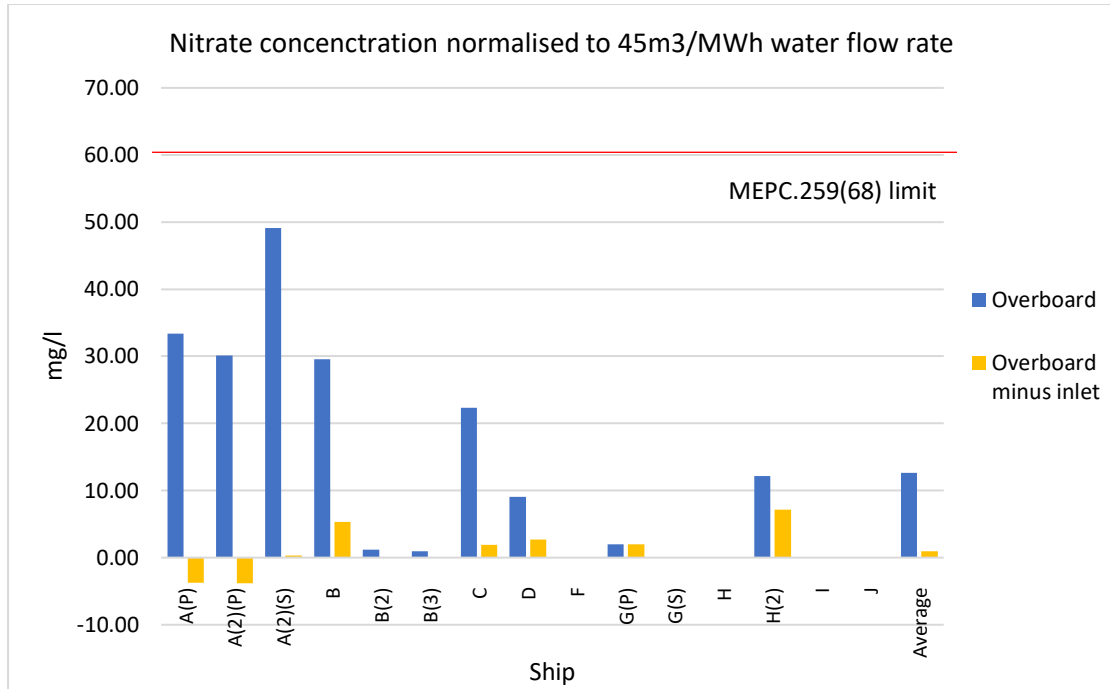


Figure 15: Normalized nitrate concentration at overboard and at overboard with inlet concentration deducted



Figure 16: Positions of Ships A & B with elevated nitrate concentrations at seawater inlet

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**APPENDIX 1 – Geographic positions of ships at end of each sampling**

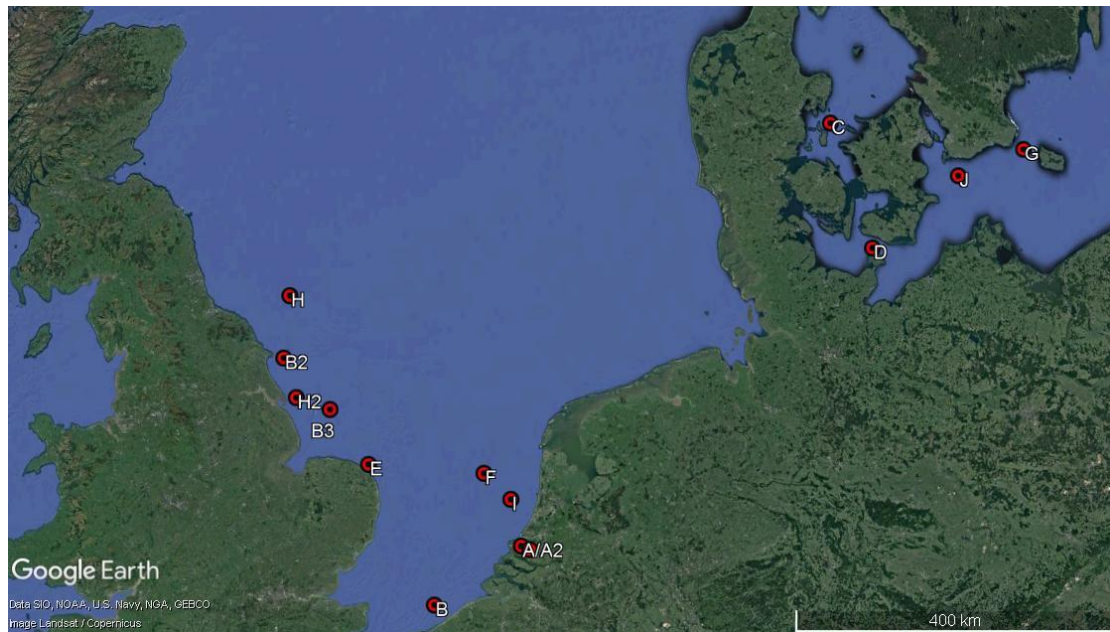


Figure A1.1: Programme 1

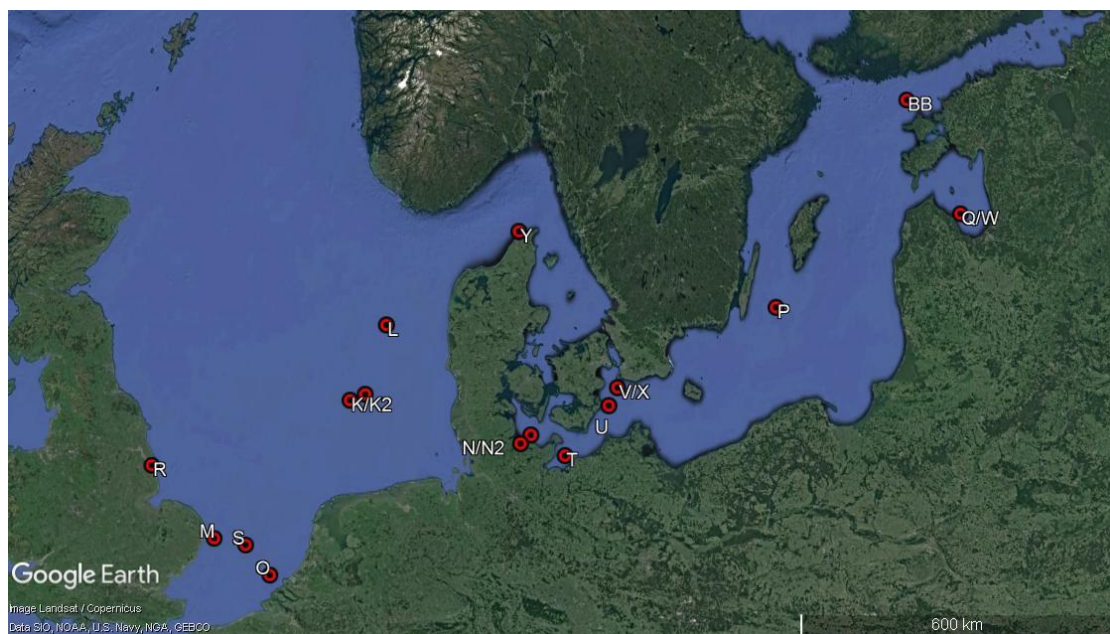


Figure A1.2: Programme 2 – North Sea & Baltic ECA



Figure A1.3; Programme 2 – Mediterranean

**APPENDIX 2 – Analysis results**

**Laboratory 1 Analyses**

Ship & engine details											
Ship	A		A(2)			B		B(2)		B(3)	
	RoRo/RoPax		RoRo/RoPax			Multi-Purpose		Multi-Purpose		Multi-Purpose	
Number of engines connected to the scrubber (just engines in operation)		1		1	1		1		1		1
Number of engines connected to the scrubber (all engines)		1		1	1		1		1		1
Combined rated power of all engines connected to the scrubber (MW)		10.8		10.8	10.8		8.4		8.4		8.4
Number of boilers in operation connected to the scrubber		0		0	0		0		0		0
Number of boiler connected to the scrubber (all boilers)		0		0	0		0		0		0
Rated output boiler(s) if connected (kg steam/hr)											

EGCS details											
Type of EGCS (open/closed/hybrid)		Hybrid		Hybrid	Hybrid		Hybrid		Hybrid		Hybrid
Mode of operation (open / closed loop) during sampling		Open		Open	Open		Open		Closed		Closed
Flow rate into the scrubber (m3/hr) - <i>Note may not be same as flow at sampling point</i>		164		468	471		180.5		Not recorded		Not recorded
Scrubber dilution water flow during sampling (m3/hr) - N/A = samples taken before any dilution		N/A		N/A	N/A		N/A		N/A		N/A

Sampling details												
ESSF programme number		Prog. 1		Prog. 1	Prog. 1		Prog. 1		Prog. 1		Prog. 1	
Sample description		Seawater	Port Scrubber Overboard	Seawater	Port Scrubber Overboard	Stbd Scrubber Overboard	Scrubber seawater in	Scrubber Overboard	Seawater	Scrubber overboard	Seawater	Scrubber overboard
Flow rate at sampling point (m3/h)		Not Recorded	164	Not Recorded	468	471	180.5	180.5	Not recorded	~1.5	Not recorded	~1.5
Engine load during sampling for each engine connected to the scrubber (%MCR)			~10% (manoeuvring)		40%	28%		36%		30%		78%

Fuel specification											
Fuel type		Residual		Residual	Residual		Residual		Residual		Residual
Viscosity		379cSt @50C		350cSt @50C	350cSt @50C		358cSt @50C		Not recorded		286cSt @50C
Sulphur content of the fuel (%m/m)		2.35		2.87	2.87		2.12		2.38		2.12
Method for determining Sulphur content (BDN/ Sampling etc).		BDN		Ship sample analysis report	Ship sample analysis report		Ship sample analysis report		Ship advice (source unknown)		Ship advice (source unknown)

Analysis results											
Ship	A		A(2)			B		B(2)		B(3)	
	Seawater	Port Scrubber Overboard	Seawater	Port Scrubber Overboard	Stbd Scrubber Overboard	Seawater inlet	Scrubber Overboard	Seawater	Scrubber overboard	Seawater	Scrubber overboard
<b>Metals Total</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>
Arsenic (As)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01
Cadmium (Cd)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Chromium (Cr)	<0.01	0.03	<0.01	0.03	<0.01	<0.01	0.05	<0.01	14.00	<0.01	4.30
Copper (Cu)	<0.01	0.08	<0.01	0.03	<0.01	<0.01	<0.01	0.07	0.03	0.02	<0.01
Lead (Pb)	<0.01	0.09	<0.01	0.12	<0.01	<0.01	<0.01	0.07	<0.01	<0.01	<0.01
Mercury (Hg)	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0004	<0.0002	<0.0002	<0.0002
Nickel (Ni)	<0.01	0.13	<0.01	0.09	0.03	0.03	0.03	0.03	4.30	<0.01	2.70
Vanadium (V)	<0.01	0.50	<0.01	0.30	0.13	<0.01	0.10	0.06	14.00	<0.01	6.00
Zinc (Zn)	0.02	0.07	<0.02	0.03	<0.02	<0.02	0.03	0.31	2.40	0.22	0.94
<b>PAH</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>
Naphthalene	<0.01	3.40	<0.01	6.00	5.00	<0.01	0.57	-	0.72	<0.01	0.21
Acenaphthylene	<0.01	0.05	<0.01	0.24	0.18	<0.01	0.07	-	0.03	<0.01	0.02
Acenaphthene	<0.01	0.12	<0.01	0.18	0.16	<0.01	0.02	-	0.25	<0.01	0.03
Fluorene	<0.01	0.35	<0.01	0.43	0.43	<0.01	0.10	-	0.57	<0.01	0.14
Phenanthrene	<0.01	0.62	<0.01	1.00	1.00	<0.01	0.39	-	2.20	<0.01	0.61
Anthracene	<0.01	<0.01	<0.01	0.11	0.04	<0.01	0.02	-	0.07	<0.01	<0.01
Fluoranthene	<0.01	0.03	<0.01	0.15	0.12	<0.01	0.06	-	0.44	<0.01	0.05
Pyrene	<0.01	0.04	<0.01	0.28	0.12	<0.01	0.05	-	0.50	<0.01	0.05
Benz(a)anthracene	<0.01	0.02	<0.01	0.15	0.07	<0.01	0.02	-	0.09	<0.01	<0.01
Chrysene	<0.01	0.04	<0.01	0.22	0.07	<0.01	0.04	-	0.16	<0.01	<0.01
Benzo(b)fluoranthene	<0.01	<0.01	<0.01	0.05	0.02	<0.01	0.01	-	0.06	<0.01	<0.01
Benzo(k)fluoranthene	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01
Benzo(a)pyrene	<0.01	<0.01	<0.01	0.04	0.01	<0.01	0.01	-	<0.01	<0.01	<0.01
Dibenzo(a,h)anthracene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01
Benzo(g,h)perylene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01
Indeno(1,2,3-cd)pyrene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01
Total detected PAH	0.00	4.67	0.01	8.87	7.22	0.00	1.36	-	5.09	0.00	1.11
<b>Additional Organic Compounds</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>
BTEX	3	4	1	4	4	-	2	-	2	-	2
Benzene	<1	1	<1	1	2	<1	<1	-	2	<1	<1
<b>Nitrate/Nitrite</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>
Nitrate	11	9.9	14.1	12.5	14.2	18.3	14.2	7.1	90.4	21.2	194
Nitrite	<0.02	<0.02	<0.02	<0.02	0.12	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Key: test methods	
Lab 1 - EN ISO 11885	
Lab 1 - EN 1483	
Lab 1 - EPA 8270D	
Lab 1 - DIN 38407-9-2	
Lab 1 - EN ISO 10304-1	

C		D		E		F		G		H		H(2)	
RoRo/RoPax		RoRo/RoPax		Container		Vehicles Carrier		RoRo/RoPax		Tanker		Tanker	
2		2		1		2		2	2		3		5
2		2		1		4		2	2		7		7
20		20		12.6		21.25		20.8	20.8		31.5		31.5
0		0		0		0		0	0		1 donkey boiler (intermittent firing)		1 donkey boiler (intermittent firing)
0		0		0		0		0	0		3		3
											2 x 25000kg/h 1 x 3000kg/h		2 x 25000kg/h 1 x 3000kg/h

	Open Loop Open		Open Loop Open		Closed Loop Closed		Hybrid Open		Open Loop Open	Open Loop Open		Hybrid Open		Hybrid Open
	756		953		Not recorded		537		1092	1054		930		930
	N/A		N/A		N/A		N/A		N/A	N/A		N/A		N/A

Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 1
Scrubber inlet	Scrubber overboard	Scrubber inlet	Scrubber overboard	Seawater	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Port Overboard	Stbd Overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard
756	756	953	953	Not recorded	3 (intermittent not continuous flow)	537	537	1092	1092	1054	930	930	930	930
	Port: 47% Stbd: 57%		Port: 75% Stbd: 78%		74%		24%		No.1: 60% No.2: 58%	No.3: 53% No.4: 57%		54%		~13% (manoeuvring)

	Residual 388cSt @50C		Residual 369 cSt @50C		Residual 380cSt @50C		Residual 380cSt @50C		Residual 368cSt @50C	Residual 368cSt @50C		Residual 380cSt @50C		Residual 380cSt @50C
	2.28		2.60		2.33		2.19		2.51	2.51		2.36		2.36
	Ship sample analysis report		Ship advice (source unknown)		Ship advice (source unknown)		Ship advice (source unknown)		Ship sample analysis report	Ship sample analysis report		Ship advice (source unknown)		Ship advice (source unknown)

C		D		E		F		G		H		H(2)		
Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Port Overboard	Stbd Overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.04	<0.01	<0.01	0.03	<0.01	0.01	0.01
0.08	0.02	0.04	0.12	<0.01	0.09	0.01	0.02	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
<0.01	0.03	<0.01	0.04	<0.01	4.90	0.01	0.05	<0.01	0.02	0.02	<0.01	0.06	<0.01	0.02
<0.01	0.12	<0.01	0.08	<0.01	25.00	0.03	0.17	<0.01	0.15	0.14	<0.01	0.24	<0.01	0.11
0.08	<0.02	0.19	0.13	<0.02	0.14	0.03	0.03	0.48	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
<0.01	0.58	<0.01	0.94	<0.01	0.06	<0.01	4.80	<0.01	0.34	0.32	<0.01	0.2	0.02	0.61
<0.01	0.23	<0.01	0.03	<0.01	0.01	<0.01	0.13	<0.01	0.03	0.03	<0.01	0.02	<0.01	0.04
<0.01	0.23	<0.01	0.10	<0.01	0.03	<0.01	0.28	<0.01	0.01	0.01	<0.01	0.04	<0.01	0.05
<0.01	0.40	<0.01	0.27	<0.01	0.09	<0.01	1.20	<0.01	0.04	0.04	<0.01	0.06	<0.01	0.16
0.05	2.20	0.03	0.81	0.05	0.49	0.05	2.90	<0.01	0.09	0.08	<0.01	0.22	<0.01	0.56
0.01	0.34	<0.01	0.02	<0.01	0.03	0.01	0.32	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01
0.01	0.62	<0.01	0.07	0.02	0.04	<0.01	0.76	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.02
0.01	1.40	<0.01	0.06	0.01	0.04	0.02	1.60	<0.01	0.01	0.01	<0.01	0.05	<0.01	0.03
0.02	0.88	<0.01	<0.01	<0.01	<0.01	<0.01	1.20	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.55	<0.01	0.02	<0.01	<0.01	0.02	1.30	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.21	<0.01	<0.01	<0.01	<0.01	<0.01	0.30	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.19	<0.01	<0.01	<0.01	<0.01	<0.01	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
0.10	7.96	0.04	2.32	0.08	0.79	0.10	14.98	0.00	0.52	0.49	0.00	0.62	0.02	1.47
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
<1	<1	<1	<1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
12.6	13.8	4.6	6.6	-	-	<0.5	<0.5	<0.5	1	<0.5	0.5	<0.5	0.7	1.7
<0.02	<0.02	<0.02	<0.02	-	-	<0.02	<0.02	0.06	0.11	0.1	<0.02	<0.02	<0.02	<0.02

I		J		K		K(2)		L		M		N		N(2)	
Tanker		RoRo/RoPax		RoRo/RoPax		RoRo/RoPax		RoRo/RoPax		RoRo/RoPax		RoRo/RoPax		RoRo/RoPax	
2	2	2	2	2	2	2	2	1	1	1	2	2	2	2	2
4	2	2	2	2	2	2	2	1	1	1	2	2	2	2	2
7.8	8.64	8.64	8.64	18.16	18.16	18.16	18.16	20.07	20.07	12.6	12.6	25.2	25.2	25.2	25.2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid
Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open
300	346	346	346	529	529	527	527	989	989	420	420	1332	1332	805	4.95
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Prog. 1	Prog. 1	Prog. 1	Prog. 1	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2
Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater	Scrubber overboard
300	300	346	346	529	535	527	527	989	989	420	420	1332	1332	805	4.95
38%			Forward: 89% Aft: 90%		Port: 56.5% Stbd: 53.5%		Port: 80% Stbd: 77.5%		72.5%		74%		76.50%		33%

Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual
Not recorded	343cSt @50C	387.8cSt @50C	387.8cSt @50C	380cSt @50C	377cSt @50C	380cSt @50C	380cSt @50C	377cSt @50C	380cSt @50C	377cSt @50C	380cSt @50C	380cSt @50C	380cSt @50C	380cSt @50C	380cSt @50C
2.24	2.32	2.55	2.55	2.84	2.10	2.84	2.84	2.10	2.84	2.10	2.84	2.84	2.60	2.60	2.60
Ship advice (source unknown)	BDN/certificate of quality	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)

I		J		K		K(2)		L		M		N		N(2)	
Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater	Scrubber overboard
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	0.05	<0.01	<0.01	<0.01	0.02	<0.01	0.02	<0.01	<0.01
<0.01	0.02	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	0.07	0.02	0.34	0.11	0.01	0.07	0.01	0.15
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	0.02	<0.01	<0.01	<0.01	<0.01
<0.0002	<0.0002	<0.0002	<0.0002												
<0.01	0.02	<0.01	0.15	<0.01	0.03	<0.01	0.05	<0.01	0.03	0.02	0.03	<0.01	0.12	<0.01	0.24
<0.01	0.07	<0.01	0.50	<0.01	0.05	<0.01	0.11	<0.01	0.12	<0.01	0.08	<0.01	0.42	<0.01	2.80
0.58	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.15	0.33	1.20	2.00	0.08	0.03	0.41	0.04
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
<0.01	3.7	<0.01	1.8	<0.01	8.8	<0.01	6	<0.01	0.32	0.03	7.2	0.02	14	<0.01	5.7
<0.01	0.17	<0.01	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	0.01	0.11	0.02	0.07
<0.01	0.21	<0.01	0.15	<0.01	0.46	<0.01	0.3	<0.01	0.06	<0.01	0.45	<0.01	0.25	<0.01	0.49
<0.01	0.26	<0.01	0.66	<0.01	0.77	<0.01	0.54	<0.01	0.17	<0.01	1.2	0.05	1.2	0.06	1.9
<0.01	0.79	0.02	1.9	<0.01	1.9	<0.01	1.3	<0.01	0.52	<0.01	3.4	0.01	1.6	<0.01	3.8
<0.01	0.02	<0.01	0.08	<0.01	0.02	<0.01	0.02	<0.01	0.03	<0.01	0.07	<0.01	0.02	<0.01	0.03
<0.01	0.05	<0.01	0.07	<0.01	0.08	<0.01	0.06	<0.01	0.03	<0.01	0.22	<0.01	0.1	<0.01	0.25
<0.01	0.11	<0.01	0.07	<0.01	0.21	<0.01	0.12	<0.01	0.1	<0.01	0.44	<0.01	0.05	<0.01	0.21
<0.01	0.07	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	0.11	<0.01	0.06	<0.01	0.05
<0.01	0.07	<0.01	0.04	<0.01	0.05	<0.01	0.05	<0.01	0.04	<0.01	0.32	<0.01	0.06	<0.01	0.06
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	0.02	<0.01	0.02
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
0.00	5.45	0.02	4.89	-	12.29	0.01	8.39	-	1.32	0.03	13.62	0.09	17.47	0.08	12.58
µg/L	µg/L	µg/L	µg/L												
<1	<1	<1	<1												
mg/L	mg/L	mg/L	mg/L												
<0.5	<0.5	<0.5	<0.5												
<0.02	0.03	<0.02	<0.02												

O (=A)		P		Q (=B)		R (=H)		S		T	
RoRo/RoPax		RoRo Container		Multi-Purpose		Tanker		Tanker		RoRo/RoPax	
1	1	1	1	1	1	5	7	3	7	2	2
1	1	1	1	1	1	7	7	7	7	2	2
10.8	10.8		15.6		8.4		31.5		31.5	20.8	20.8
0	0		0		0		1		1	0	0
0	0		0		0		3		3	0	0
						2 x 25000kg/h 1 x 3000kg/h			2 x 25000kg/h 1 x 3000kg/h		

	Hybrid	Hybrid	Open Loop		Hybrid		Hybrid		Hybrid		Open Loop	Open Loop
	Open	Open	Open		Closed		Open		Open		Open	Open
	870	872	850		163		821		876		1039	1044
	N/A	N/A	N/A		N/A		N/A		N/A		N/A	N/A

Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2
Seawater	Port scrubber overboard	Stbd scrubber overboard	Seawater inlet	Scrubber overboard	Seawater	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater	Port Overboard	Stbd Overboard
Not recorded	870	872	850	850	130	~1.5	821	821	876	876	Not recorded	1039	1044
	37%	44%		52%		81%		~13% (manoeuvring)		39%		58%	59%

	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	Residual	
	378.7cSt @50C	378.7cSt @50C	334cSt @50C		376cSt @50C		370cSt @50C		347cSt @50C		Not recorded	Not recorded
	2.05	2.05	2.38		2.41		2.60		0.96		2.40	2.40
	Ship advice (source unknown)	Ship advice (source unknown)	Ship advice (source unknown)		Ship advice (source unknown)		Ship advice (source unknown)		Ship advice (source unknown)		Ship advice (source unknown)	Ship advice (source unknown)

O (=A)		P		Q (=B)		R (=H)		S		T			
Seawater	Port scrubber overboard	Stbd scrubber overboard	Seawater inlet	Scrubber overboard	Seawater	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater	Port Overboard	Stbd Overboard
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
0.48	0.06	0.04	<0.01	0.04	0.03	0.18	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
0.08	0.01	0.01	0.06	<0.01	<0.01	0.06	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
0.12	0.02	0.03	<0.01	0.05	<0.01	5.70	<0.01	0.02	<0.01	<0.01	<0.01	0.06	0.14
<0.01	0.05	0.08	<0.01	0.07	<0.01	24.00	0.01	0.09	<0.01	0.02	<0.01	0.24	0.61
<0.02	<0.02	<0.02	0.07	0.31	<0.02	0.61	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
<0.01	2.4	2.8	<0.01	10	0.01	0.88	<0.01	0.8	<0.01	0.02	0.01	3.5	2.2
<0.01	0.1	0.1	<0.01	0.02	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.37	0.38	<0.01	<0.01	<0.01	0.18	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.88	0.91	<0.01	0.97	<0.01	0.77	<0.01	0.18	<0.01	0.17	<0.01	0.71	0.36
<0.01	3.4	3.9	<0.01	1.6	0.01	2.1	<0.01	0.5	<0.01	0.42	<0.01	1.6	0.72
<0.01	0.04	0.11	<0.01	0.02	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	0.02
<0.01	0.27	0.53	<0.01	0.08	<0.01	0.12	<0.01	0.02	<0.01	0.02	<0.01	0.03	0.01
<0.01	0.6	1.1	<0.01	<0.01	<0.01	0.11	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.19	0.34	<0.01	0.03	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.06	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.03	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	8.34	10.45		12.72	0.02	4.24		1.5		0.65	0.01	5.88	3.31

U				V (=)	
RoRo/RoPax				RoRo/RoPax	
	2		2		2
	2		2		2
	11.52		11.52		8.64
	0		0		0
	0		0		0

	Hybrid		Hybrid		Hybrid
	Open		Open		Open
	336		315		356
	N/A		N/A		N/A

Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2	Prog. 2
Port seawater inlet	Port scrubber overboard	Stbd seawater inlet	Stbd scrubber overboard	Seawater inlet	Scrubber overboard
336	336	315	315	356	356
	48%		43.50%		92%

	Residual		Residual		Residual
	375cSt @50C		375cSt @50C		345cSt @50C
	2.60		2.60		2.58
	Ship advice (source unknown)		Ship advice (source unknown)		BDN /certificate of quality

U				V (=)	
Port seawater inlet	Port scrubber overboard	Stbd seawater inlet	Stbd scrubber overboard	Seawater inlet	Scrubber overboard
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
<0.01	0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.14	0.01	0.07	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	0.24	0.02	0.12	0.01	0.06
<0.01	0.86	0.12	0.47	<0.01	0.27
<0.02	0.08	<0.02	0.02	0.04	<0.02
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
0.06	5.3	0.09	2.9	<0.01	1.2
0.03	0.46	0.03	0.19	<0.01	0.15
0.06	1.6	0.07	0.72	<0.01	0.17
0.2	1.8	0.24	0.64	<0.01	0.37
1.4	6.1	1.9	1.8	<0.01	1.2
0.11	1.2	0.11	0.29	<0.01	0.02
0.43	1	0.45	0.2	<0.01	0.05
0.75	2.6	0.85	0.45	<0.01	0.08
0.13	0.73	0.12	0.11	<0.01	<0.01
0.02	1.6	0.24	0.21	<0.01	0.03
0.06	0.37	0.06	0.06	<0.01	<0.01
0.02	0.09	0.02	0.02	<0.01	<0.01
0.05	0.55	0.05	0.07	<0.01	<0.01
<0.01	0.08	<0.01	0.01	<0.01	<0.01
0.03	0.36	0.03	0.05	<0.01	<0.01
0.01	0.14	0.01	0.02	<0.01	<0.01
3.36	23.98	4.27	7.74	-	3.27

Ship & engine details									
Ship	W (=Q & B)		X (=V & J)		X2 (=V & J)		X3 (=V & J)		Y
	Multi-Purpose		RoRo/RoPax		RoRo/RoPax		RoRo/RoPax		Vehicle Carrier
Number of engines connected to the scrubber (just engines in operation)		1		2		2		2	2
Number of engines connected to the scrubber (all engines)		1		2		2		2	4
Combined rated power of all engines connected to the scrubber (MW)		8.4		8.64		8.64		8.64	9.72
Number of boilers in operation connected to the scrubber		0		0		0		0	0
Number of boiler connected to the scrubber (all boilers)		0		0		0		0	0
Rated output boiler(s) if connected (kg steam/hr)									

EGCS details									
Type of EGCS (open/closed/hybrid)		Hybrid		Hybrid		Hybrid		Hybrid	Hybrid
Mode of operation (open / closed loop) during sampling		Closed		Open		Open		Open	Closed
Flow rate into the scrubber (m3/hr)		163		356		356		356	639
<i>Note may not be same as flow at sampling point</i>									
Scrubber dilution water flow during sampling (m3/hr) - N/A = samples taken before any dilution		N/A		N/A		N/A		N/A	N/A

Sampling details										
ESSF programme number		EGCSA 2	EGCSA 2	EGCSA 2	EGCSA 2	EGCSA 2	EGCSA 2	EGCSA 2	EGCSA 2	EGCSA 2
Sample description		Seawater	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Scrubber overboard
Flow rate at sampling point (m3/h)		130	~1.5	356	356	356	356	356	356	4.9
Engine load during sampling for each engine connected to the scrubber (%MCR)			81%		92%		92%		92%	57%

Fuel specification										
Fuel type			Residual		Residual		Residual		Residual	Residual
Viscosity			376cSt @50C		345cSt @50C		345cSt @50C		345cSt @50C	340cSt @50C
Sulphur content of the fuel (%m/m)			2.41		2.58		2.58		2.58	1.98
Method for determining Sulphur content (BDN/ Sampling etc).			Ship advice (source unknown)		BDN /certificate of quality		BDN /certificate of quality		BDN /certificate of quality	Ship advice (source unknown)

Washwater analysis										
Ship	W (=Q & B)			X (=V & J)		X2 (=V & J)		X3 (=V & J)		Y
Sample description	Seawater	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard	Seawater inlet	Scrubber overboard
<b>Metals Total</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>	<b>mg/L</b>
Arsenic (As)	0.003	0.024	<0.005	<0.005						<0.05
Cadmium (Cd)	<0.0004	0.00096	<0.0002	<0.0002						<0.002
Chromium (Cr)	0.018	0.160	<0.0015	<0.0015						<0.015
Copper (Cu)	0.007	0.058	0.013	0.006						0.200
Lead (Pb)	<0.005	<0.005	0.001	<0.001						<0.01
Mercury (Hg)										
Nickel (Ni)	0.010	6.600	0.004	0.044						0.220
Vanadium (V)	<0.002	25.000	<0.002	0.200						12.000
Zinc (Zn)	<0.01	0.590	0.023	<0.01						<0.1
<b>PAH</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>
Naphthalene	0.051	1.600	<0.020	5.200	<0.020	5.700	<0.010	5.900	<0.010	0.320
Acenaphthylene	<0.050	<0.050	<0.050	0.120	<0.050	0.470	<0.050	<0.50	<0.050	<0.050
Acenaphthene	<0.010	0.260	<0.010	0.940	<0.010	0.920	<0.010	0.370	<0.010	0.230
Fluorene	<0.010	1.300	<0.010	1.200	<0.010	1.200	<0.010	1.100	<0.010	0.410
Phenanthrene	0.160	4.500	0.011	3.700	<0.010	3.700	<0.010	4.200	<0.010	2.300
Anthracene	0.009	0.110	<0.010	0.082	<0.010	0.065	<0.0050	0.190	<0.010	<0.010
Fluoranthene	0.270	0.340	0.020	0.130	<0.010	0.130	<0.010	0.400	<0.010	0.160
Pyrene	0.150	0.260	0.037	0.190	<0.010	0.190	<0.010	0.170	<0.010	0.240
Benz(a)anthracene	0.061	0.056	<0.010	0.027	<0.010	0.027	<0.010	<0.10	<0.010	0.025
Chrysene	0.048	0.058	<0.010	0.054	<0.010	0.060	<0.010	<0.10	<0.010	0.053
Benzo(b)fluoranthene	0.025	0.024	<0.010	0.012	<0.010	<0.010	<0.010	<0.10	<0.010	0.012
Benzo(k)fluoranthene	0.011	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.10	<0.010	<0.010
Benzo(a)pyrene	0.015	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.10	<0.010	<0.010
Dibenz(a,h)anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.10	<0.010	<0.010
Benzo(g,h,i)perylene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.10	<0.010	0.011
Indeno(1,2,3-c,d)pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.10	<0.010	<0.010
Total detected PAH	0.810	8.500	<0.21	12.000	<0.21	12.000	<0.20	12.000	<0.20	3.500
<b>Additional Organic Compounds</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>	<b>µg/L</b>
BTEX (µg/L)										
Benzene (µg/L)										
Nitrate/Nitrite	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Nitrate (mg/L)										
Nitrite (mg/L)										

Key: test methods  
 Lab 2 - NEN-EN-ISO 17294-2 (ICP-MS)  
 Lab 2 - In house method HPLC  
 Lab 2 - In house method GC-MS

**Laboratory 2 Analyses**

Z		AA		BB	
Cruise		Cruise		Cruise	
	1		1		1
	1		1		1
	11.6		11.6		11.6
	0		0		0
	0		0		0

Hybrid		Hybrid		Hybrid	
Open		Open		Open	
	694		651		565
	N/A		N/A		N/A

EGCSA 2		EGCSA 2		EGCSA 2	
Seawater inlet		Scrubber overboard		Seawater inlet	
	694		651		565
	76%		78%		82%

Residual		Residual		Residual	
323cSt @50C		259cSt @50C		276cSt @50C	
	2.50		3.14		1.23
	Ship advice (source unknown)		Ship advice (source unknown)		Ship advice (source unknown)

Z		AA		BB	
Seawater inlet		Seawater inlet		Seawater inlet	
Scrubber overboard		Scrubber overboard		Scrubber overboard	
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
<0.0015	<0.0015	<0.0015	0.002	<0.0015	<0.0015
0.009	0.059	0.007	0.009	<0.005	0.015
0.003	0.008	<0.001	<0.001	<0.001	<0.001
<0.002	0.120	0.007	0.065	<0.002	0.035
<0.002	0.180	0.019	0.240	<0.002	0.056
<0.01	0.100	<0.01	<0.01	<0.01	0.130
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
0.039	6.900	0.055	1.200	1.100	4.100
<0.050	0.210	<0.050	0.180	<0.050	0.580
<0.010	0.360	0.013	0.420	0.023	0.540
<0.010	0.790	0.057	0.840	<0.010	1.000
<0.010	2.800	0.450	3.400	<0.010	3.700
<0.010	<0.010	<0.010	0.043	<0.010	0.031
<0.010	0.140	0.057	0.370	<0.010	0.370
<0.010	0.290	0.170	1.300	<0.010	1.000
<0.010	0.032	0.027	0.340	<0.010	0.220
<0.010	0.110	0.077	0.550	<0.010	0.370
<0.010	0.027	0.016	0.140	<0.010	0.058
<0.010	<0.010	<0.010	0.016	<0.010	<0.010
<0.010	<0.010	<0.010	0.083	<0.010	0.027
<0.010	<0.010	<0.010	0.011	<0.010	<0.010
<0.010	0.020	<0.010	0.110	<0.010	0.023
<0.010	<0.010	<0.010	0.020	<0.010	<0.010
<0.21	12.000	0.920	9.100	1.100	12.000
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L