**ANNEX 5**

**RESOLUTION MEPC.103(49)**

**Adopted on 18 July 2003**

# GUIDELINES FOR ON-BOARD NOx VERIFICATION PROCEDURE - DIRECT MEASUREMENT AND MONITORING METHOD

THE MARINE ENVIRONMENT PROTECTION COMMITTEE,

RECALLING Article 38(a) of the Convention on the International Maritime Organization concerning the functions of the Marine Environment Protection Committee (the Committee) conferred upon it by international conventions for the prevention and control of marine pollution,

RECALLING ALSO that the Conference of Parties to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78), held in September 1997, adopted the Protocol of 1997 to amend MARPOL 73/78 with a new Annex VI on the Prevention of Air Pollution from Ships,

NOTING that the 1997 Conference by resolution 2 adopted the Technical Code on Control of Emission of Nitrogen Oxides (NOx) from Marine Diesel Engines, which in paragraph 2.4.5 provides the option that on-board NOx verification procedures may be based on a NOx monitoring and recording device, approved by the Administration, based on Guidelines to be developed by the Organization,

BEING AWARE that this requirement cannot be enforced before the entry into force of the Protocol of 1997,

BEING AWARE ALSO of the need to develop relevant Guidelines before the entry into force of the Protocol of 1997 in preparation for the implementation of Annex VI of MARPOL 73/78,

HAVING CONSIDERED the recommendation made by the Sub-Committee on Ship Design and Equipment at its forty-sixth session,

1. ADOPTS the Guidelines for on-board NOx verification procedure - Direct measurement and monitoring method, as set out in the Annex to this resolution;

2. INVITES Governments to apply the Guidelines from the date of entry into force of the Protocol of 1997.

ANNEX

## GUIDELINES FOR ON-BOARD NOx VERIFICATION PROCEDURE - DIRECT MEASUREMENT AND MONITORING METHOD

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# GUIDELINES FOR ON-BOARD NOx VERIFICATION PROCEDURE - DIRECT MEASUREMENT AND MONITORING METHOD

## SAFETY NOTE

Due attention is to be given to the safety implications related to the handling and proximity of exhaust gases, the measurement equipment and the storage and use of cylindered pure and calibration gases. Sampling positions and access staging should be such that this monitoring may be performed safely and will not interfere with the engine.

## PRINCIPLES

These Guidelines are intended as an objective, performance-based document. These Guidelines are recommendatory in nature. However, national administrations are invited to base their implementation on these Guidelines. Because the direct measurement and monitoring method is one of the three permissible on-board NOx verification procedures in the NOx Technical Code (cf. NOx Technical Code, paragraph 2.4.4), its accuracy should be comparable to the other methods. Therefore, these Guidelines for approving on-board NOx monitoring and recording devices appropriately refer to the NOx Technical Code. References to the NOx Technical Code emphasize that relevant requirements are already regulated in a mandatory document, even though they are not grouped in a common chapter (e.g. "Direct measurement and monitoring method"). The values determined by this method may not be directly comparable with the test bed results. Of overriding importance for approval is the suitability of the NOx monitoring and recording devices for on-board use.

As a general principle, an on-board NOx verification procedure should readily facilitate demonstration of compliance with regulation 13 of Annex VI of MARPOL 73/78 (Annex VI). At the same time, it should not be so burdensome as to unduly delay the ship or to require in-depth knowledge of the characteristics of a particular engine or specialist measuring devices not available on board.

## 1 ANALYSING EQUIPMENT

### 1.1 Emission species measurement

1.1.1 On-board NOx monitoring includes, as an absolute minimum, the measurement of gaseous emission concentrations of NOx (as NO + $NO_2$).

1.1.2 If determination of exhaust flow is performed, utilizing the NOx Technical Code, appendix 6 (Method 2, universal, carbon/oxygen-balance), then $O_2$ and/or $CO_2$ should be measured and provisions in appendix 6 that assume complete combustion may be used in all cases. If the provisions in appendix 6 that do not assume complete combustion are preferred, then additionally CO and HC should be measured.

1.1.3 The exhaust gases should be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted. Other systems or analysers may be accepted, subject to the approval of the Administration, provided they yield equivalent results to that of the equipment referenced below:

.1 **Oxides of nitrogen (NOx) analysis**

The oxides of nitrogen analyser should be of the Chemiluminescent Detector (CLD) or Heated Chemiluminescent Detector (HCLD) type. The exhaust gas sampled for NOx measurement should be maintained above its dewpoint temperature until it has passed through an $NO_2$ to NO converter.

**Note:** In the case of raw exhaust gas this temperature should be greater than 333 K (60ºC) if the engine is fueled with ISO 8217 DM-grade type fuel and greater than 413 K (140ºC) if fueled with ISO 8217 RM-grade type fuel.

.2 **Carbon dioxide ($CO_2$) analysis**

When needed, the carbon dioxide analyser should be of the Non-Dispersive Infrared (NDIR) absorption type.

.3 **Oxygen ($O_2$) analysis**

When needed, the oxygen analyser should be of the Paramagnetic Detector (PMD), Zirconium Dioxide (ZRDO) or Electrochemical Sensor (ECS) type.

.4 **Carbon monoxide (CO) analysis**

When needed, the carbon monoxide analyser should be of the Non-Dispersive Infrared (NDIR) absorption type.

.5 **Hydrocarbon (HC) analysis**

When needed, the hydrocarbon analyser should be of the Heated Flame Ionization Detector (HFID) type. The exhaust gas sampled for HC measurement should be maintained at 463 K ± 10 K (190ºC ±10ºC) from the sample point to the detector.

## 1.2 Analyser specifications

1.2.1 The analyser specifications should be consistent with the NOx Technical Code, appendix 3, paragraphs 1.4, 1.5, 1.6, 1.7, 1.8 and 1.9.

1.2.2 The analyser range should be such that the measured emission value is within 15%-100% of the range used.

1.2.3 The analysing equipment should be installed and maintained in accordance with manufacturer's recommendations such that the requirements of the NOx Technical Code, appendix 3, paragraphs 1.5, 1.6, 1.7, 1.8, 1.9 and appendix 4, paragraphs 7 and 8, are met.

## 1.3 Pure and calibration gases

1.3.1 Pure and calibration gases, as required, should comply with the NOx Technical Code, appendix 4, paragraphs 2.1 and 2.2. Declared concentrations should be traceable to national and/or international standards. Calibration gases should be in accordance with the analysing equipment manufacturer's recommendations.

1.3.2 Analyser span gases should be between 80%-100% of the analyser scale being spanned.

**Note:** Under certain conditions, only a span gas for the NOx analyser could be necessary for calibration of the analytical instruments. A NO span gas for a NOx analyser can be applied as a zero gas for an $O_2$ or $CO_2$ analyser if that span gas is balanced only with nitrogen. Ambient air may be applied both as a span gas for an $O_2$ analyser (i.e. 20.9% $O_2$) and as a zero gas for a NOx analyser, provided that the ambient air is uncontaminated by exhaust gas.

### 1.4 Gas sampling and transfer system

1.4.1 The exhaust gas sample should be representative of the average exhaust emission from all the engine's cylinders. The gas sampling system should comply with the NOx Technical Code, paragraph 5.9.3.

1.4.2 The exhaust gas sample should be drawn from a zone anywhere between 10%-90% of the duct diameter.

1.4.3 In order to facilitate the installation of the sampling probe, an example of a sample point connection flange is given in appendix 1.

1.4.4 The exhaust gas sample for NOx measurement should be maintained so as to prevent $NO_2$ loss via water or acid condensation in accordance with analysing equipment manufacturer's recommendations.

1.4.5 The gas sample should not be dried by chemical driers.

1.4.6 The gas sampling system should be capable of being verified to be free of ingress leakage in accordance with analysing equipment manufacturer's recommendations.

1.4.7 An additional sample point adjacent to that used should be provided to facilitate quality control checks on the system.

## 2 ENGINE PERFORMANCE AND AMBIENT CONDITION MEASUREMENT

### 2.1 Engine performance measurements

2.1.1 Table 1 lists the engine performance parameters that should be measured, or calculated, and recorded at each mode point during on-board NOx monitoring.

**Table 1**

| **Symbol** | **Parameter** | **Dimension** |
|---|---|---|
| $n_d$ | Engine speed | $min^{-1}$ |
| $p_{be}$ | Charge air pressure at receiver | kPa |
| P | Brake power (as specified below) | kW |
| $P_{aux}$ | Auxiliary power (if relevant) | kW |
| $T_{sc}$ | Charge air temperature at receiver (if applicable) | K |
| $T_{caclin}$ | Charge air cooler coolant inlet temperature (if applicable) | K |
| $T_{caclout}$ | Charge air cooler coolant outlet temperature (if applicable) | K |
| $T_{Sea}$ | Sea-water temperature (if applicable) | K |
| GFUEL | Fuel flow (as specified below) | kg/h |

2.1.2 Other engine settings necessary to define engine-operating conditions, e.g. wastegate, charge air bypass, turbocharger status, should be determined and recorded.

2.1.3 The settings and operating conditions of NOx control devices should be determined and recorded.

2.1.4 The engine power and speed should be measured to determine whether the engine is operated in a mode according to the specified test cycles (cf. section 3.1 of these Guidelines).

2.1.5 If it is difficult to measure power directly, uncorrected brake power may be estimated by any other means as approved by the Administration (cf. NOx Technical Code, paragraphs 6.3.1.3, 6.3.3.2 and 6.3.7). Possible methods to determine brake power include, but are not limited to:

.1 indirect measurement as per NOx Technical Code, paragraph 6.3.3.1; or by

.2 estimation from nomographs.

2.1.6 The fuel flow (actual consumption rate) should be determined by:

.1 direct measurement; or by

.2 test bed data as per NOx Technical Code, paragraph 6.3.1.4.

**2.2 Ambient condition measurements**

2.2.1 Table 2 lists the ambient condition parameters that should be measured, or calculated, and recorded at each mode point during on-board NOx monitoring.

**Table 2**

| Symbol | Parameter | Dimension |
|---|---|---|
| $H_a$ | absolute humidity (mass of engine intake air water content related to mass of dry air) | g/kg |
| $p_B$ | total barometric pressure (in ISO 3046-1, 1995: $p_x$=$P_x$=site ambient total pressure) | kPa |
| $T_a$ | temperature at air inlet (in ISO 3046-1, 1995: $T_x$=$TT_x$=site ambient thermodynamic air temperature) | K |

### 2.3 Engine performance and ambient condition monitoring equipment

The engine performance and ambient condition monitoring equipment should be installed and maintained in accordance with manufacturers' recommendations such that requirements of the NOx Technical Code, appendix 4, paragraph 1.3.2 and tables 3 and 4, are met in respect of the permissible deviations.

### 2.4 Electrical equipment: materials and design

2.4.1 Electrical equipment should be constructed of durable, flame-retardant, moisture resistant materials, which are not subject to deterioration in the installed environment and at the temperatures to which the equipment is likely to be exposed.

2.4.2 Electrical equipment should be designed such that current carrying parts with potential to earth are protected against accidental contact.

## 3 EXHAUST EMISSION MEASUREMENT

### 3.1 Test cycles

3.1.1 Engine operation on board under a specified test cycle may not always be possible, but the test procedure, as approved by the Administration, should be as close as possible to the procedure defined in the NOx Technical Code, paragraph 3.2.

3.1.2 Regarding the E3 test cycle, if the actual propeller curve differs from the E3 curve, the load point used should be set using the engine speed, or the corresponding mean effective pressure (MEP) or mean indicated pressure (MIP), given for the relevant mode of that cycle.

3.1.3 If the number of measuring points on-board is different from those on the test bed, the number of measurement points and the weighting factors should be approved by the Administration.

3.1.4 Regarding the E2/E3/D2 test cycles, a minimum of load points should be used of which the combined nominal weighing factor, as given in the NOx Technical Code, paragraph 3.2, is greater than 0.50.

3.1.5 Regarding the C1 test cycle, a minimum number of one load point should be used from each of the rated, intermediate and idle speed sections.

3.1.6 If the number of measuring points on board is different from those on the test bed, the nominal weighting factors at each load point should be increased proportionally in order to sum to unity (1.0).

3.1.7 An example of the selection of load points and revised weighting factors are given in appendix 2.

3.1.8 The actual load points used to demonstrate compliance should be within ± 5% of the rated power at the modal point except in the case of 100% load where the range should be +0 to –10%. For example, at the 75% load point the acceptable range should be 70% - 80% of rated power.

3.1.9 At each selected load point, except idle, and after the initial transition period (if applicable), the engine power should be maintained at the load set point within a 5% coefficient of variance (%C.O.V.) over a 10-minute interval. A worked example of the coefficient of variance calculation is given in appendix 3.

3.1.10 Regarding the C1 test cycle, the idle speed tolerance should be declared, subject to the approval of the Administration.

**3.2 Test condition parameter**

The test condition parameter specified in the NOx Technical Code, paragraph 5.2.1, should not apply to on-board NOx monitoring. Data under any prevailing ambient condition should be acceptable.

**3.3 Analyser in-service performance**

3.3.1 Analysing equipment should be operated in accordance with manufacturer's recommendations.

3.3.2 Prior to measurement, zero and span values should be checked and the analyser should be adjusted as necessary.

3.3.3 After measurement, analyser zero and span values should be verified as being within that permitted in the NOx Technical Code, paragraph 5.9.9.

**3.4 Data for emission calculation**

3.4.1 The output of the analysers should be recorded both during the test and during all response checks (zero and span). This data should be recorded on a strip chart recorder or other types of data recording devices.

3.4.2 For the evaluation of the gaseous emissions, a 1-Hertz minimum chart reading of a stable 10-minute sampling interval of each load point should be averaged. The average concentrations (conc) of NOx, $O_2$ and/or $CO_2$, if required, and optionally CO and HC, should be determined from the averaged chart readings and the corresponding calibration data.

3.4.3 As a minimum, emission concentrations, engine performance and ambient condition data should be recorded over the aforementioned 10-minute period.

# 4 DATA EVALUATION

## 4.1 Fuel composition

Fuel composition, to calculate gas mass flow wet (GEXHW), should be provided by one of the following:

.1 fuel composition by analysis (carbon, hydrogen and sulphur); or

.2 default values, see table 3.

**Table 3**

| | **Carbon** | **Hydrogen** | **Sulphur** |
|---|---|---|---|
| | BET | ALF | GAM |
| Diesel oil (i.e. ISO 8217 DM grades) | 86.2% | 13.6% | 0.17% |
| Residual fuel oil (i.e. ISO 8217 RM grades) | 86.1% | 10.9% | 2.7% |

## 4.2 Exhaust gas density

Exhaust gas density, to calculate gas mass flow wet (GEXHW) and NOx Technical Code Table 5, coefficient 'u', should be provided by one of the following:

.1 calculation as per the NOx Technical Code, appendix 6; or

.2 default value of 1.293 kg/m$^3$ ( 273.15 K and 101.3 kPa).

## 4.3 Dry/wet correction

If not already measured on a wet basis, the gaseous emissions concentrations as per paragraph 2 of these Guidelines should be converted to a wet basis according to:

.1 direct measurement of the water component; or

.2 calculated in accordance with the NOx Technical Code, paragraph 5.12.2. (NOx Technical Code, equation 11, CO may be set to zero).

## 4.4 NOx corrections for humidity and temperature

NOx corrections for humidity and temperature should be performed as per NOx Technical Code, paragraph 5.12.3. The reference charge, or scavenge, air temperature ($T_{sc\ ref}$ ) should be stated and approved by the Administration. The $T_{sc\ ref}$ values are to be referenced to 25°C sea water temperature and in the application of the $T_{sc\ ref}$ value due allowance should be made for the actual sea water temperature.

### 4.5 Exhaust gas flow rate

Exhaust gas flow rate should be determined by:

.1 NOx Technical Code, paragraphs 5.5.1 or 5.5.2; or

.2 NOx Technical Code, appendix 6, method 2, with not measured species set to zero and CO2AIR, if applicable, set to 350 ppm.

### 4.6 Calculation of emission flow rates and specific emissions

The calculation of emission flow rates and specific emissions should be performed as per NOx Technical Code, paragraphs 5.12.4 and 5.12.5.

## 5 COMPLIANCE REQUIREMENTS

### 5.1 Limit value and allowances

The emission value obtained by the direct monitoring and measurement method should be compared to the NOx emission limit value as given in regulation 13 of Annex VI, plus allowance values as given in the NOx Technical Code, paragraphs 6.3.11.1, 6.3.11.2 and 6.3.11.3 in order to verify that an engine continues to comply with the requirements of regulation 13 of Annex VI.

### 5.2 Data for demonstrating compliance

Compliance is required to be demonstrated at annual/intermediate, periodic and unscheduled surveys or following a substantial modification as per the NOx Technical Code, paragraph 1.3.2. In accordance with the NOx Technical Code, paragraph 2.3.4, data is required to be current; that is within 30 days. Data is required to be retained on board for at least three months. These time periods should be taken to be when the ship is in operation. Data within that 30-day period either may be collected as a single test sequence across the required load points or may be obtained on two or more separate occasions when the engine load corresponds to that required under section 3.1 of these Guidelines.

### 5.3 Form of approval

The direct measurement and monitoring method should be documented in an on-board monitoring manual based on these Guidelines. The manual should be submitted to the Administration for approval. The approval reference of that manual should be entered under section 3 of the Supplement to the EIAPP Certificate. The Administration may issue a new EIAPP Certificate, with the details in section 3 of the Supplement duly amended, if the method is approved after the issue of the first EIAPP Certificate, i.e. following the pre-certification survey.

### 5.4 Survey of equipment and method

The survey of the direct measurement and monitoring method should take into account, but is not limited to:

.1 the data obtained and developed from the required measurements; and

.2 the means by which that data has been obtained, taking into account the information given in the manual (section 5.3 above).

## APPENDIX 1

## SAMPLE POINT CONNECTION FLANGE

1 The following is an example of a general purpose sample point connection flange which should be sited, as convenient, on the exhaust duct of each engine for which it may be required to demonstrate compliance by means of the direct measurement and monitoring method.

| **Description** | **Dimension** |
|---|---|
| Outer diameter | 160 mm |
| Inner diameter | 35 mm |
| Flange thickness | 9 mm |
| Bolt circle diameter 1 | 130 mm |
| Bolt circle diameter 2 | 65 mm |
| Flange slots | 4 holes, each 12 mm diameter, equidistantly placed on each of the above bolt circle diameters. Holes on the two bolt circle diameters to be aligned on same radii. Flange to be slotted, 12 mm wide, between inner and outer bolt circle diameter holes. |
| Bolts and nuts | 4 sets, diameter and length as required |
| Flange should be of steel and be finished with a flat face. | |

2 The flange should be fitted to a stub pipe of suitable gauge material aligned with the exhaust duct diameter. The stub pipe should be no longer than necessary to project beyond the exhaust duct cladding, sufficient to enable access to the far side of the flange. The stub pipe should be insulated. The stub pipe should terminate at an accessible position free from nearby obstructions which would interfere with the location or mounting of a sample probe and associated fittings.

3 When not in use, the stub pipe should be closed with a steel blank flange and a gasket of suitable heat resisting material. The sampling flange, and closing blank flange, when not in use, should be covered with a readily removable and suitable heat resistant material which protects against accidental contact.

## APPENDIX 2

## SELECTION OF LOAD POINTS AND REVISED WEIGHTING FACTORS

1 As provided for by Section 3.1 of these Guidelines, in the case of the E2/E3/D2 test cycles, the minimum number of load points should be such that the combined nominal weighting factors as given in the NOx Technical Code, paragraph 3.2, are greater than 0.50.

2 Consequently, for the E2/E3 test cycle it would be necessary to use the 75% load point plus one or more other load points. In the case of the D2 test cycle, either the 25% or 50% load point should be used plus either one or more load points such that the combined nominal weighting factor is greater than 0.50.

3 The examples below give some of the possible combinations of load points which may be used together with the respective revised weighting factors:

**E2/E3 test cycles**

| Power | 100% | 75% | 50% | 25% |
|---|---|---|---|---|
| Nominal weighting factor | 0.2 | 0.5 | 0.15 | 0.15 |
| Option A | 0.29 | 0.71 | | |
| Option B | | 0.77 | 0.23 | |
| Option C | 0.24 | 0.59 | | 0.18 |
| Plus other combinations which result in a combined nominal weighting factor greater than 0.50. Hence use of the 100% + 50% + 25% load points would be insufficient. | | | | |

**D2 test cycle**

| Power | 100% | 75% | 50% | 25% | 10% |
|---|---|---|---|---|---|
| Nominal weighting factor | 0.05 | 0.25 | 0.3 | 0.3 | 0.1 |
| Option D | | | 0.5 | 0.5 | |
| Option E | | 0.45 | | 0.55 | |
| Option F | | 0.38 | 0.46 | | 0.15 |
| Option G | 0.06 | 0.28 | 0.33 | 0.33 | |
| Plus other combinations which result in a combined nominal weighting factor greater than 0.50. Hence use of the 100% + 50% + 10% load points would be insufficient. | | | | | |

4 In the case of the C1 test cycle, as a minimum, one load point from each of the rated, intermediate and idle speed sections should be used. The examples below give some of the possible combinations of load points which may be used together with the respective revised weighting factors:

**C1 test cycle**

| Speed | Rated | | | | Intermediate | | | Idle |
|---|---|---|---|---|---|---|---|---|
| Torque | 100% | 75% | 50% | 10% | 100% | 75% | 50% | 0% |
| Nominal weighting factor | 0.15 | 0.15 | 0.15 | 0.1 | 0.1 | 0.1 | 0.1 | 0.15 |
| Option H | | 0.38 | | | 0.25 | | | 0.38 |
| Option I | | | | 0.29 | | 0.29 | | 0.43 |
| Option J | 0.27 | 0.27 | | | | | 0.18 | 0.27 |
| Option K | 0.19 | 0.19 | 0.19 | 0.13 | | 0.13 | | 0.19 |
| Plus other combinations incorporating at least one load point at each of rated, intermediate and idle speeds | | | | | | | | |

5 Examples of calculation of revised weighting factors:

For Option A:

75% load: revised value is calculated as: 0.5 x (1/(0.5 + 0.2)) = 0.71
50% load: revised value is calculated as: 0.2 x (1/(0.5 + 0.2)) = 0.29

For Option F:

75% load: revised value is calculated as: 0.25 x (1/(0.05 + 0.25 + 0.3 + 0.3)) = 0.38

**Note:** The revised weighting factors are shown to 2 decimal places. However, the values to be applied to NOx Technical Code equation 18 should be to the full precision. Hence in the Option F case above the revised weighting factor is shown as 0.38 although the actual calculated value is 0.384615...

Consequently, in these examples of revised weighting factors the summation of the values shown (to 2 decimal places) may not sum to 1.00 due to rounding.

## APPENDIX 3

## DETERMINATION OF POWER SET POINT STABILITY

1 To determine set point stability, the power coefficient of variance should be calculated over a 10-minute interval, and the sampling rate should be at least 1-Hz. The result should be less than or equal to five percent (5%).

2 The formulae for calculating the coefficient of variance are as follows:

$$Ave = \frac{1}{N}\sum_{j=1}^{N} x_j \qquad (1)$$

$$S.D. = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - Ave\right)^2} \qquad (2)$$

$$\%C.O.V. = \frac{S.D.}{Ave} \times 100 \le 5\% \qquad (3)$$

Where,

| | |
|---|---|
| %C.O.V. | power coefficient of variance in % |
| S.D. | standard deviation |
| Ave | Average |
| N | total number of data points sampled |
| $x_i$, $x_j$ | $i^{th}$, $j^{th}$ value of power data point in kW |
| i | index variable in standard deviation formula |
| j | index variable in average formula |

3 As an example, over the 10-minute sampling period, power is sampled at 1-Hz. This results in 600 data points being collected with values of $x_1$, $x_2$, $x_3 \ldots x_{600}$ and N is thus 600. The calculations would then be:

$$Ave = \frac{x_1 + x_2 + x_3 ... + x_{600}}{600}$$

$$S.D. = \sqrt{\frac{\left(x_1 - Ave\right)^2 + \left(x_2 - Ave\right)^2 + \left(x_3 - Ave\right)^2 ... + \left(x_{600} - Ave\right)^2}{600 - 1}}$$

$$\%C.O.V. = \frac{S.D.}{Ave} \times 100 \le 5\%$$

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