Emissions of Nitrogen Oxides from Marine Diesel Engines

Questions and Answers

July 2002
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Introduction

This document has been prepared as a useful source of information for surveyors dealing with the implementation of MARPOL 73/78 Annex VI Regulation 13 and the NOx Technical Code.

The information contained has been assimilated from many sources and is by no means exhaustive.

A simple ‘questions and answers’ format has been adopted although some items have been included in the form of notes with all common areas being grouped into sections.

Each question is clearly differentiated from it’s subsequent answer or note by the style of text. Questions are introduced in larger bold italics text. Where sections of Annex VI or the NOx Technical Code have been quoted a reference is given with the text appearing italicised.

The questions and answers are for internal use only. Their formulation is aimed at providing surveyors with information which will allow them to deal with client enquiries.

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1. General Aspects

1.1 What are oxides of nitrogen (NOx)?

99% of engine intake air is comprised of nitrogen (N₂) and oxygen (O₂). The nitrogen remains largely unreacted in the diesel engine combustion process, however a small percentage is oxidised to form exhaust gases containing various oxides of nitrogen, predominantly nitric oxide (NO) with smaller amounts of nitrogen dioxide (NO₂) and minor concentrations of nitrous oxide (N₂O). The term oxides of nitrogen, or nitrogen oxides (NOx) is used to group both the NO and NO₂ components.

1.2 Are oxides of nitrogen (NOx) harmful?

Nitric oxide (NO) is relatively inert and only moderately toxic but is readily oxidised to form the more harmful gas nitrogen dioxide (NO₂). As an emission species oxides of nitrogen (NOₓ) are of concern for several reasons. They are responsible for acid deposition, respiratory illness in humans and in association with sunlight and organic material, the formation of photochemical oxidants, namely ozone (O₃) and smog.

Ozone in itself has detrimental effects on human health, vegetation and crop yields, and contributes in the degradation of certain materials. Ozone is also a greenhouse gas, controlling the amount of the sun’s UVB radiation from reaching the earth’s surface and so contributes to the problem of global warming.

1.3 How are NOₓ formed?

NOₓ are formed during the combustion process within the burning fuel sprays. At these elevated flame or combustion temperatures nitrogen is no longer inactive and reacts with oxygen to form nitric oxide (NO) and nitrogen dioxide (NO₂). The immediate reaction is the formation of NO. Later in the process, during expansion and in the exhaust system, part of the NO will convert to form NO₂. NOₓ is controlled by local conditions in the spray, with temperature and oxygen concentrations being the dominant influences. The higher the temperature and the longer the residence time at high temperature, the more NOₓ will be created.

1.4 When are NOₓ formed?

The stoichiometric quantity of air is defined as that quantity of air containing the minimum theoretical amount of oxygen required to fully convert all the fuel into completely oxidised products, i.e. for complete combustion. The ratio of the actual fuel/air ratio to the stoichiometric fuel/air ratio is an informative parameter for defining the composition of a fuel mixture. This ratio is termed the fuel/air equivalence ratio, φ, and is thus defined:

\[
\phi = \frac{F/A}{F/A_{\text{stoich}}}
\]

The critical equivalence ratio of the local mixture of fuel and air for NOₓ formation is close to 1, i.e. maximum NOₓ creation occurs when the local air/fuel ratio is close to stoichiometric.

The critical time period for NOₓ creation is when burned gas temperatures are at a maximum i.e. between the start of combustion and shortly after peak pressure. It has been shown that almost all NO formation occurs within 20° of crank rotation following start of combustion.

After the time of peak pressure, burned gas temperatures decrease as the cylinder gases expand.

The decreasing temperature due to expansion and due to mixing of high temperature gases with cooler burned gas freezes the NO chemistry.

NO forms both in the propagated flame front and in the post flame gases. In engines, however, combustion occurs at high pressure so the flame reaction zone is extremely thin (in the order of 0.1mm) and residence time within this zone is short.

Thus, NO formation in the post-flame gases almost always dominates any flame-front produced NO which effectively de-couples the combustion and NO formation processes. However, the reactions which produce NO, take place in an environment created by the combustion reactions, so the two processes are still intimately linked.
2. Control of NOx Emissions

2.1 What engine features control NOx formation rates?

It has already been shown that NOx formation rates are primarily a function of combustion temperature (and pressure) and residence time of the combustion gases at these high temperatures. Hence any features of an engine which may influence these variables will also influence the emission rate. A list of the most influential of these features can be summarised as follows:

- Injection and atomisation equipment
- Injection timing equipment
- Compression ratio
- Combustion chamber geometry
- Turbocharger type and build
- Charge air cooler/pre-heater
- Valve timing
- Rated engine speed
- Fuel composition

Fuel injection equipment design, timing and pressure together with combustion space geometry and fuel properties all influence the fuel atomisation, spray patterns and penetration. These factors are critical to the efficient mixing of the fuel and air charge, significantly influencing combustion efficiency. The quality of mixing of the fuel and air in turn influences the local mixture equivalence ratio, having a critical value close to 1 for high NOx emissions.

Advancing fuel timing and increasing compression ratios tend to increase combustion pressures and temperatures and so increase NOx formation rates.

Ambient conditions, as modified by the charge air system, also influence NOx production. Increased intake air humidity reduces peak combustion temperatures and hence suppresses the formation of NO in the combustion process.

Lower rated engine speeds increase the time over which combustion takes place, increasing residence time of the combustion gases at high temperatures and so tending to increase NOx formation rates.

2.2 What effect does the presence of organic nitrogen (N2) in heavy fuel oil have on NOx emissions?

Nitrogen present in residual fuel is also a factor affecting nitric oxide (NO) formation via a different mechanism. Fuel derived NO proceeds via a series of reactions, a key stage of which is the formation of a NH compound which may either progress to form N2 or NO. The nature of the compounds in which the nitrogen exists in the fuel is considered to be a factor in deciding the outcome of the reaction but under certain conditions could result in a 100% NO yield (amount of fuel nitrogen converted to NO).

The NO yield is also sensitive to the fuel /air equivalence ratio. Relatively high NO yields are obtained for stoichiometric mixtures and are only weakly dependent on temperature, in contrast to the strong temperature dependence of NO formed from atmospheric nitrogen.

In summary, increased nitrogen content in residual fuels will increase NOx emissions.

2.3 What are Primary NOx Emission reduction methods? Why not design extremely low NOx emission engines?

The modified engine design approach can be thought of as a primary method of controlling NOx formation rates. As discussed, lowering the peak combustion temperature is a very effective means of reducing the amount of NOx formed. Unfortunately, the amounts of other pollutants, namely Particulates and Hydrocarbons, will increase instead and there is also a substantial fuel penalty as efficiency drops due to poor combustion. The control of NOx emissions by design is therefore an optimisation process, balancing satisfactory combustion efficiency with acceptable levels of all pollutants.
2.4 What Primary methods can be adopted to reduce NO\textsubscript{x} emissions?

Manufacturers have explored many different methods of reducing NO\textsubscript{x} by primary control methods. Some of the more publicised are listed as follows:

- **Delaying fuel injection.** Retarded fuel injection timing retards the combustion process. Nitric oxide (NO) formation occurs later and with lower concentrations.

- **Reducing the amount of scavenge air, hence reducing the quantity of excess O\textsubscript{2} available for conversion to NO\textsubscript{x}.**

- **Common Rail control -** Common Rail fuel injection has proven to be a very effective way in combating smoke problems as well as a NO\textsubscript{x} reduction technique. There are two main ingredients, one being the freedom to choose injection pressure and timing totally independently of engine load, the other adding an element of computerised control making it possible to consider several engine parameters and then automatically optimise the injection and therefore combustion in each load situation.

- **Injecting water into the combustion chamber (Direct Water Injection, DWI)** Greater heat capacity is utilised to reduce high peak temperatures as the water evaporates immediately upon injection. Rapid evaporation of the injected water also helps to create a homogeneous fuel-air mixture.

- **Emulsified Fuel or Fuel-Water Emulsions (FEW)** is favoured by some manufacturers claiming clear reduction in NO\textsubscript{x} emissions at low cost with no significant design changes and with no adverse effect on the reliability of the engine. Other manufacturers claim that fuel-water emulsions in a conventional injection system causes considerable problems.

- **Injection of very fine water mist after the turbocharger using special nozzles (Combustion Air Saturation System, CASS).** The fine water droplets evaporate fast and further heat is introduced in the air cooler (now acting as an air heater) and humidifies the combustion air.

- **Re-circulating part of the exhaust gas (EGR) -** this is one method of adding dilutants to the intake air, reducing burned gas temperature for any given mass of fuel and oxygen. It has been successfully employed in the automotive industry where good quality fuel is used but marine diesel engine manufacturers claim that even when the fuel has insignificant amounts of sulphur, the practical application of EGR causes unacceptable operational problems.

- **Water Cooled Rest Gas (WaCoReG) -** Developed for slow speed engines, this system utilises the same mechanism as an EGR system, i.e. introducing some 'rest gas' into the combustion space. In an engine with electronically controlled exhaust valve timing it is quite easy to leave some of the exhaust gas in the cylinder. This obviously has a negative impact on engine performance, however this can be dramatically reduced by cooling the rest gas with a water spray, in which case the rest gas accounts for some of the NO\textsubscript{x} reduction and the water spray for the rest.

- **Humid Air Motor (HAM).** Hot compressed air from the turbocharger is led to a humidification tower and exposed to a large surface area and flushed with hot water. The water can be heated by a heat exchanger connected to the jacket cooling system or using an exhaust gas boiler. The principle is the same as that described under Combustion Air Saturation System, CASS previously. One manufacturer claims considerable success in service in reducing NO\textsubscript{x} emissions with the added claim of increasing the indicated power of the engine at certain loads therefore reducing fuel consumption hence proportionally reducing CO\textsubscript{2} emissions.

The actual degree of NO\textsubscript{x} reduction varies from 10% to over 60%, depending on the engine type and which of the above reduction methods are adopted.
2.5 Can the various Primary methods of NOx reduction be combined?
Combinations of primary NOx reduction methods are possible. Reduction of NOx in some medium and high speed engines is achieved by exploiting a combination of high compression ratio with retarded fuel injection.
This calls for the engine to inject fuel late in the cycle and over a short duration without destroying performance.

2.6 What are Secondary NOx reduction methods?
Secondary methods reduce NOx in the exhaust gas by downstream treatment.
Selective Catalytic Reduction (SCR) is such a system and can cut emissions by well over 90% with figures of 98% NOx reduction being recorded.

2.7 How does the Selective Catalytic Reduction (SCR) system work?
In an SCR system the exhaust gas, at a temperature between 250 and 530°C, is mixed with ammonia (commonly in the form of a solution of urea in water). This introduces single atom nitrogen (N) creating a reducing atmosphere before passing through a special catalyst. The NOx is reduced to harmless gaseous stable nitrogen (N2) and water.
The catalyst core is often composed of a heat resistant ceramic honeycomb with a catalytically active material, such as oxides of vanadium, dispersed on its surface. The surface in contact with the exhaust gas needs to be extremely large in order for all the molecules of NOx and N to touch a catalytically active site on the substrate. At the same time the resistance to exhaust gas flow created by placing the catalyst in the exhaust gas path must be minimised to reduce excessive pressure drops.

2.8 If Selective Catalytic Reduction (SCR) has such an extremely high NOx reduction efficiency why is it so rare in marine applications?
There are many reasons contributing to the fact that SCR’s have not been widely taken up for use with marine diesel engines, the major ones are listed:
- Large initial cost
- Large spatial requirements.
- Low efficiency
- High pressure drop
- Fouling tendency
- Resistance to poisoning
- Heat up time
- Recycling of used catalysts
- Safety aspects (handling ammonia)
- Availability

Probably the biggest disadvantage is the massive dimensions of most present commercially available SCR reactors and as such are often impractical to retrofit to an existing marine installation.
As technology progresses SCR systems for the marine environment are being further developed and installed on vessels operating in places such as Sweden where there is a distinct financial gain from having extremely low NOx emission engines.

2.9 How does adding water to the fuel reduce NOx emissions?
Water addition to the fuel is effective in reducing NOx formation during combustion, mainly because the water evaporates immediately upon injection. This improves the intimate mixing of the fuel and air and promotes a homogenous fuel-air mixture. Evaporation of the water also reduces the maximum combustion temperature.
Water emulsified with the fuel prior to injection requires a significant increase in the fuel pump capacity. Special precautions are necessary to keep the water-fuel emulsion stable and prevent corrosion of fuel system components.
Water can also be added to the combustion space through separate nozzles or by the stratified segregated injection of water and fuel from the same nozzle (direct water injection).

Some manufacturers consider direct water injection preferable to the introduction of water as an emulsified fuel. In order to reduce NOx emissions significantly it is claimed that the proportion of water in emulsified fuel must approach 50%.

2.10 Are there any disadvantages in introducing water into the combustion process using fuel emulsification?

It is claimed that addition of water to the combustion process has its drawbacks:

- The emulsion is not always stable and variations in the fuel type may produce different behaviour.
- Severe corrosion could be a problem if the injection system is not flushed with clean fuel before the engine stops.
- The emulsion lowers the energy content per volume of mix and so the injection equipment must be substantially enlarged to produce the same power. This will increase the amount of power absorbed by the injection equipment.

Another way of introducing water into the combustion zone is by humidifying the scavenge air as detailed in 2.4. Warm water is injected and vaporised in the charge air increasing its absolute humidity and reducing NOx emission formation rates. In turbo-charged engines the parameters of charge air humidity and temperature are obviously important downstream of the charge air cooler.

2.11 How does Exhaust Gas Recirculation (EGR) reduce NOx emissions?

Exhaust Gas Re-circulation (EGR) is a method of modifying the inlet air to reduce NOx emissions, an approach widely used in automotive applications. Some of the exhaust gas is cooled and cleaned before re-circulation to the scavenge air side.

Its effect on NOx formation is partly due to a reduction of the oxygen concentration in the combustion zone and partly due to the content of water and carbon dioxide in the exhaust gas. Introduction of these dilutants reduces flame temperatures by increasing the heat capacity of the cylinder charge per unit mass of fuel. Although EGR is an efficient method of reducing NOx emissions (up to 60%) it is considered more practical for engines burning ‘clean’ bunkers such as low sulphur and low ash fuels, alcohol and gas. Engines operating on high sulphur fuels could suffer from corrosion of the turbochargers, intercoolers and scavenging pipes.

Increased fuel consumption is also associated with EGR due to the retarded heat release rate.
2.12 *Can combinations of NOx reduction methods be combined effectively?*

Research by one manufacturer has shown that substantial reductions in NOx (80%+) have been obtained with only minor increases in fuel oil consumption by using the following combination:

- modified fuel valve and fuel nozzle design with
- 50% water addition to the fuel (FEW),
- 20% Exhaust Gas Re-circulation (EGR)
- Reduced firing pressure by retarding timing

The effects of these modifications are shown:

![Diagram showing relative NOx emissions for different combinations of modifications](image)

**Claimed effects of combining NOx reduction techniques**
3. IAPP & EIAPP Certificates, Flag States, MARPOL Annex VI and the NOx Technical Code.

3.1 What is MARPOL 73/78 Annex VI Regulation 13 and the IMO NOx Technical Code?


The Annex and the NOx Technical Code will become mandatory when the required number of Flag States become signatories to the protocol.

For compliance with Regulation 13 of the Annex all diesel engines of 130 kW rated power and above (except those solely for emergency use) installed in ships constructed on or after 1 January 2000 are required to meet certain Oxides of Nitrogen (NOx) emission limits.

The NOx Technical Code establishes the procedures for the testing, survey and certification of diesel engines to ensure compliance with the NOx emission limits (Regulation 13).

3.2 What is an IAPP certificate?

The International Air Pollution Prevention (IAPP) certificate is issued to the vessel by the flag Administration or an organisation authorised to act on its behalf, after the owner demonstrates that the vessel complies with all relevant requirements under MARPOL Annex VI.

The IAPP is valid for five years, and is subject to successful completion of the vessel’s initial and intermediate surveys.

These certificates will not be issued until the Annex enters into force under Article 15 of the MARPOL Convention.

3.3 What is an EIAPP certificate?

The Engine International Air Pollution Prevention (EIAPP) certificate is issued by an authorised organisation for each applicable engine, engine family, or engine group after the engine manufacturer demonstrates that the engine complies with the NOx limits set out in Regulation 13 of Annex VI.

The EIAPP certificate is good for the life of the engine subject to correct maintenance or until it undergoes a major conversion.

These certificates will not be issued until the Annex enters into force under Article 15 of the MARPOL Convention.

3.4 Can EIAPP certificates be issued even though MARPOL Annex VI has yet to be ratified?

At this time it is not possible to issue Engine International Air Pollution Prevention (EIAPP) Certificates. These can only be issued when MARPOL Annex VI and the NOx Technical Code are in force internationally. It is not possible to say when they might come into force as it is dependant on the required number of countries signing Annex VI. Only a statement or certificate of compliance with the NOx Technical Code can be issued at present.

At MEPC 42 the International Maritime Organisation (IMO) adopted a circular which, in effect, says that diesel engines installed on ships constructed on or after 1 January 2000 should have certification for compliance with the NOx Technical Code requirements.

Our information is that statements or certificates issued by Lloyds Register (and it is assumed by other IACS members) will be accepted by National Authorities. These statements /certificates would then be replaced by EIAPP Certificates issued on behalf of the flag administration once Annex VI and the NOx Technical Code come into force.

3.5 What is a Technical File?

The Technical File is a record containing all details of parameters, including components and settings, that influence the NOx emissions of the engine.
According to the NOx Technical Code, the Technical File must contain the following information;

- Identification of those components, settings and operating values of the engine which influence its NOx emissions,
- Identification of the full range of allowable adjustments or alternatives for the NOx sensitive components of the engine in order to maintain compliance within the IMO limits,
- A full record of the relevant engine’s performance, including the engine’s rated speed and rated power;
- A system of on-board NOx verification procedures to verify compliance with the NOx emissions limits during on-board verification surveys in accordance with chapter 6 of the code;
- A copy of the emission test report used to certify the engine
- If applicable, the designation and restrictions for an engine which is a member of an engine group or an engine family;
- Specifications of those spare parts/components which, when used in the engine, according to those specifications, will result in continued compliance of the engine with the NOx emission limits: and
- The EIAPP certificate or Statement of Compliance, as applicable.

### 3.6 What is a ‘Record Book of Engine Parameters’?

The Record Book of Engine Parameters is a document for recording all parameter changes, including components and engine settings, that may influence NOx emissions. This is another essential document for surveys and inspections because it contains a record of adjustments to the engine. At each survey the Record Book is examined to ensure that no changes have been made to the engine that might affect NOx emissions.

Vessel owners must make sure the Record Book is accurately maintained up to date. If the settings on the engine do not match those in the Record Book, an engine survey may include a more time-consuming investigation and, potentially, on board measurement of NOx emissions.

### 3.7 Can LR accept NOx Certificates of Compliance issued by other IACS Classification Society’s for engines that are to be installed in LR classed when requested to do so by the engine builder/shipyard?

It is not the intention to accept unconditionally certification by another IACS member, with regard to NOx at this stage. This situation may change when methods and requirements of the Flag Administrations become clearer after ratification.

### 3.8 Can a body carry out NOx Emission testing of an engine with their own equipment and then certify that engine?

This would not be considered ethical. If the two functions were fully separate then this may be acceptable provided the chain of responsibility was totally separate.

In general, a third party should be employed to witness the testing and verify the accuracy of the equipment.

This gives international credence to the testing especially where the manufacturer may be requesting certification from different flag administrations.

### 3.9 When will MARPOL Annex VI and the NOx Technical Code come into force?

Annex VI of MARPOL 73/78, as adopted by the Protocol of 1997, contains regulations for the prevention of air pollution from ships and includes a resolution which introduces the NOx Technical Code.

Under article 6 of the Protocol of 1997, Annex VI will come into force 12 months after the date on which not less than fifteen States, the combined merchant fleets of which constitute not less than 50 per cent of the world’s merchant shipping, have ratified it. Some countries have already ratified whilst others are in the process of doing so.
Under paragraph 2 of Resolution 2 to Annex VI the NOx Technical Code will enter force, as mandatory requirements, for all Parties to the 1997 Protocol on the same date as Annex VI comes into force.

Therefore in spite of possible delays before Annex VI comes into force, there will be retrospective application of the nitrogen oxide limits to marine diesel engines with a power output of more than 130 kW which are installed in ships, vessels or offshore installations constructed on or after 1st January 2000. The same limits will also apply to marine diesel engines with a power output of more than 130 kW, which undergo a major conversion on or after 1st January 2000.

3.10 What is meant by a “major conversion“ as detailed in Annex VI?

“Major Conversion” means a modification of an engine where:
- the engine is replaced by a new engine built on or after 1st January 2000, or
- any substantial modification is made to the engine, or
- the maximum continuous rating of the engine is increased by more than 10%

3.11 What is meant by “substantial modification”?

1.3.2 “Substantial modification of a marine diesel engine means:
- For engines installed on ships constructed on or after 1st January 2000, substantial modification means any modification to an engine that could potentially cause the engine to exceed the emissions standards set out in regulation 13 of Annex VI. Routine replacement of engine components by parts specified in the Technical File that do not alter emission characteristics shall not be considered a “substantial modification” regardless of whether one part or many parts are replaced.
- For engines installed on ships constructed before 1st January 2000, substantial modification means any modification made to an engine which increases its existing emission characteristics established by the simplified measurement method in excess of the allowances set out in 6.3.11 of the NOx Technical Code. These changes include, but are not limited to, changes in its operations or in its technical parameters (e.g., changing camshafts, fuel injection systems, air systems, combustion chamber configuration, or timing calibration of the engine).

3.12 Will Annex VI Regulation 13 apply to second-hand engines to be fitted on existing vessels?

Regulation 13(1)(a)(i) does not apply to second-hand engines, which may have been overhauled but not modified or the continuous rating is not increased by more than 10 per cent, if they are fitted to ships, vessels or offshore installations constructed before 1st January 2000, as this would not constitute a major conversion under Regulation 13(2)(a)(i). Regulation 13 does apply to any engine with a power output of more than 130kW which is installed on a ship constructed on or after 1 January 2000.

Note: All ships will require to be issued with an IAPP certificate once Annex VI is ratified. However, only ships constructed after January 1st, 2000 will require to demonstrate compliance with Annex VI, Regulation 13, unless the engine undergoes a major conversion.

3.13 What is the procedure for dealing with enquiries on the certification of diesel engines for compliance with MARPOL Annex VI and the NOx Technical Code?

If requested by an owner, builder or engine manufacturer Lloyd’s Register can carry out the required technical file approval, testing and certification for compliance with the NOx Technical Code and regulation 13 of Annex VI.

All enquiries regarding certification of diesel engines for compliance with the NOx Technical Code must be forwarded to MSG, Engineer Services (ES). ES will advise on the procedures for technical file approval and testing requirements. Unless other wise advised by ES, engine emission tests are NOT to be undertaken without being contacted. NOx emission testing can only be witnessed by authorised surveyors.
3.14 Which flag states have authorised Lloyd's Register (LR) to issue NOx certification?

Lloyd's Register (LR) has contacted over 100 administrations seeking authorisation to issue NOx certification on their behalf.

Many Administrations have intimated that a LR certificate will be acceptable to them until such time as MARPOL 73/78 Annex VI and the NOx Technical Code come into force. At that time the LR certificate will then be used to issue an EIAPP certificate either by LR on behalf of the administration or by the administration themselves.

Where an administration has instructed LR to issue certificates on behalf of the administration the Government Title will be referenced on the LR Certificate.

The NOx authorisations have been included in the Flag Administration data on the LR web site; Marine/External Affairs/Library "Country Files". This is regularly up-dated.

In general it is our understanding that during the intervening period leading up to ratification the majority of Flag Administrations will accept tests and certification issued by LR for NOx compliant marine diesel engines.

3.15 Does MARPOL Annex VI apply to offshore installations?

MARPOL 73/78 Annex VI is applicable to all ships of 400 tonnes gross and above and to offshore installations which includes fixed and floating drilling rigs and other platforms.

3.16 Where can the texts of Annex VI and the NOx Technical Code be found?

The IMO have published the texts of MARPOL Annex VI and the NOx Technical Code in a single publication. The IMO sales number is IMO-664E, current price £14.00.

3.17 What are LR’s fees for NOx certification?

LR’s services associated with NOx emissions certification will be charged on the basis of a LR fee for the review of Technical File, assessment of the test reports and issue of a certificate, together with the fees for inspection and witnessing of NOx emission verification tests/survey.

Fee quotations are based on the submitted documentation being complete, and being submitted in the English language, or a language acceptable to LR. Translation costs may be incurred for documentation submitted in other languages. Where translation charges are necessarily incurred for technical documentation, such additional charges will be invoiced at cost.

For initial, periodical and renewal surveys, a quotation will be made upon acceptance of an application.

Should a client withdraw his application for certification, for whatever reason, LR reserves the right to charge fees for costs already incurred.

3.18 What is the period of validity of the pre-certification certificate?

The pre-certification certificate remains valid for all engines validated as manufactured in accordance with the Technical File for the Administration under whose authority it is issued.

Certificates or Statements of Conformity will require to be replaced with an EIAPP Certificate on Annex VI entering into force.

EIAPP Certificates are to be issued by or on behalf of the respective Flag Administration.

3.19 What are the allowable NOx emission limits as stated in Annex VI regulation 13?

- 17.0 g/kWh where n is less than 130 rpm
- 45.0*n(-0.2) g/kWh where n is 130 or more but less than 2000 rpm
- 9.8 g/kWh where n is 2000 rpm or more where n is the rated engine speed (crankshaft revolutions per minute).
The maximum values of 17.0 and 9.8 g/kWh and the simple function of n can be better visualised graphically as shown:

3.20 Which States have already ratified Annex VI? Is there any mechanism to identify the impediments to entry into force?

As of early 2001 only three States have ratified Annex VI, namely Norway, Sweden and Singapore representing nearly 9% of the gross world tonnage.

Conference resolution 1 "INVITES, if the conditions for entry into force of the 1997 Protocol have not been met by 31st December 2002, the Marine Environment Protection Committee (MEPC), at its first meeting thereafter, to initiate, as a matter of urgency, a review to identify the impediments to entry into force of the Protocol and any necessary measures to alleviate those impediments".

3.21 When a ship is classed by LR and the ship owner requests NOx certification for engines installed on board, do certificates have to be issued by LR or are certificates issued by other classification societies acceptable?

There are two types of certificate that may be issued for compliance with MARPOL Annex VI:

- Certification for diesel engines, above 130kW which are not used for emergency purposes, after satisfactory testing for compliance with the NOx Technical Code. This is carried out on the test bed to demonstrate that the NOx emissions generated by the engine are within the limits set out in MARPOL Annex VI, Regulation 13. Marine diesel engines installed on board a new ship after 1st January 2000 must be certified in compliance with Regulation 13 of MARPOL Annex VI and the NOx Technical Code. Until MARPOL Annex VI is ratified, this will be known as a Certificate or Statement of Compliance. After ratification it will be termed an Engine International Air Prevention Pollution (EIAPP) certificate.

- Once MARPOL Annex VI is ratified, then International Air Prevention Pollution (IAPP) certificates will become mandatory. Until then they are not required unless a specific flag administration makes it mandatory for ships registered by them. The IAPP certificate covers the following items as applicable to the type of ship being certified: Ozone Depleting Substances, Nitrogen Oxides (NOx), Oxides of Sulphur (SOx), Volatile Organic Compounds (VOCs), Shipboard Incineration and Fuel Oil Quality.

Certificates are issued for and on behalf of the flag administration with whom the vessel is registered, similar to current statutory certification.

Whether an EIAPP certificate issued by one classification society is acceptable to another is a matter for the flag administration.

This is a subject being discussed within the International Association of Classification Societies (IACS) Working Group on Exhaust Emission Controls forum but at this time there is no clear consensus on the procedure to be adopted.

The on-board surveys and issue of the IAPP certificates would be carried out by the classification society who has responsibility for the issue of the ship’s statutory certificates. Since the Society has been appointed to act for the Administration, they cannot delegate that authority to an other third party.

In general, since LR is acting for and on behalf of the various Flag Administrations LR would prefer to witness the testing to allow them to meet their commitment to the authority. However, where the Parent engine EIAPP certificate has been issued by another body recognised by the Flag Administration, LR could accept this to certify member engines subject to certain conditions being met.
4. On-Board Verification Procedures

4.1 What is an On-Board Verification Survey?

Each diesel engine subject to the requirements of MARPOL 73/78 Annex VI Regulation 13 shall be subject to an initial survey, an intermediate survey and a periodical survey as part of the ships IAPP survey and certification regime. The On-board Verification Survey is detailed in the approved Technical File. It describes the method for confirming the engine remains in compliance with the NOx emission limits and forms part of the ship's IAPP survey.

After a pre-certified engine is installed on-board a ship, an initial installation verification survey is carried out to confirm that the engine remains in compliance with the NOx emission limits. The on-board verification survey is not mandatory until MARPOL Annex VI comes into force when each ship is required to be surveyed for the issue of an IAPP certificate.

4.2 What methods are available for the On Board Verification Survey?

Surveys will be conducted on board using one of the three methods of NOx Verification described in sections 2.4.2 to 2.4.6 of the NOx Technical Code;

2.4.4 On-board NOx verification procedures shall be determined by using one of the following methods:

- Engine parameter check in accordance with section 6.2 of the NOx Technical Code to verify that an engine's component, setting and operating values have not deviated from the specifications in the engine's Technical File;
- Simplified measurement method in accordance with section 6.3 of the NOx Technical Code, or
- Direct measurement and monitoring method in accordance with 2.3.4, 2.3.5, 2.3.7, 2.3.8, 2.3.11 and 5.5 of the NOx Technical Code.

4.3 Who decides which system of On-Board Verification is to be used?

Making reference to Chapter 6 of the NOx Technical Code:

Onboard the vessel it is the owner who decides the system to be followed for the onboard verification.

The engine manufacturer has the responsibility of preparing and documenting an engine survey system to allow the ship owner to use the system he so desires.

The system is to be prepared by the engine manufacturer and submitted to the Administration, or the organisation acting on their behalf, for acceptance.

4.4 What is involved in the Engine Parameter Method?

The engine parameter method of verification documentation must form part of the Technical File.

The survey process detailed here is for guidance as to the typical information to be included in the documentation.

This method is a check to verify that the components, settings and operating values of the engine once installed on the vessel remain the same as those recorded in the Technical File at the time of the pre-certification.

It may be carried out on engines which have a pre-certificate (EIAPP certificate), those which have been certified after installation (IAPP certificate) and after modifications or adjustments since the previous survey.

The surveyor with the assistance of a check sheet will survey the following and confirm they remain within the allowable range specified in the Technical File:

- Review existing certificates and documentation on-board the ship.
- Review the record book of engine parameters noting all recorded changes and confirming their acceptability or otherwise with the Technical File.
• Inspect engine components affecting NOx emission limits and verify they are correct for the engine type.

• Inspect and test the adjustable settings of the engine, as applicable

• Review and test, where applicable, the engine operating values.

• Check NOx emission treatment devices or systems, where appropriate, and their consumption measurement devices,

• Verify electronic engine management systems against original settings, where relevant.

• Complete the check list for the ship and submit with the inspection report to appropriate LR office for review and issue of the appropriate certification.

4.5 Are deviations from test cycles allowable when using the simplified measurement method of on-board verification?

Where maximum or minimum loads cannot be attained or where barred speed ranges preclude operation the test procedure proposal has to be based on the engine manufacturer’s recommendations but be as close as possible to the test cycles defined in chapter 3 of the NOx Technical Code. The proposal would still have to be approved by the administration.

6.3.9.2 Engine operation on board under a test cycle specified in 3.2 may not always be possible, but the test procedure shall, based on the recommendation of the engine manufacturer and approval by the Administration, be as close as possible to the procedure defined in 3.2. Therefore, values measured in this case may not be directly comparable with test bed results because measured values are very much dependent on the test cycles.
5. Engine Specifics

5.1 If an engine is rated above 130 kW but will NOT be fitted on an Annex VI ship does it need to comply?

From an engine perspective Annex VI applies to all diesel engines with a rated power of more than 130 kW which are installed on ships constructed on or after 1 January 2000 and every diesel engine with a rated power of more than 130 kW which undergoes a major conversion on or after 1 January 2000.

From a ship perspective Annex VI applies to all ships, of 400 gross tonnes and above which operates under a Flag Administration that has ratified the Annex.

Note: Administrations who have ratified Annex VI are required to implement the requirements to their own flag ships and to all other flag ships operating in their waters and ports subject to the exemption stated in the Annex.

However, ships under 400 gross tonnes are only subject to the survey requirements at the discretion of the administration. The actual text reads:

“In the case of ships of less than 400 gross tonnage, the Administration may establish appropriate measures in order to ensure that the applicable provisions of this annex are complied with.”

In summary, with specific reference to recreational craft, the requirements of Regulation 13 apply to all vessels, however only vessels over 400 gross tonnage would be subject to the survey requirements of Regulation 5. Vessels below 400 gross tonnage would not be subject to the survey requirements of Regulation 5 unless the local Administration establishes the necessary systems.

Reference should also be made to Regulation 13(1)(c) which allows the Administration to permit a derogation to ships that are only engaged in voyages between ports within the territory of that Administration. This does not only mean that an Administration could have a lower, or even no limit values for exhaust emissions for its own international ships, but could actually make stricter provisions than those of Regulation 13 for its own flag vessels.

5.2 Does MARPOL Annex VI apply to diesel driven cargo pumps having a rated power greater than 130 kW?

Yes. All marine diesel engines with a power rating greater than 130 kW, which are not used specifically for emergency purposes (i.e. emergency generator engines), are required to be certified in compliance with the NOx Technical Code as satisfying the NOx limits as stated in MARPOL Annex VI, Regulation 13. This applies to engines installed on new buildings or existing ships from 1st January 2000.

1.2.1 The NOx Technical Code applies to all diesel engines with a power output of more than 130 kW which are installed, or are designed and intended for installation, on board any ship subject to Annex VI, with the exception of those engines described in paragraph 1(b) of regulation 13.

MARPOL Annex VI regulation 13 (1)(b)(i) states:

“This regulation does not apply to emergency diesel engines, engines installed in lifeboats and any device or equipment intended to be used solely in case of an emergency.

Where engines are not solely for emergency use (i.e. a first start diesel generator which may also be used to supply part of ships electrical load under certain condition), they are to be subject to the requirements of this Regulation.

5.3 What is an ‘installed engine’?

‘Installed’ relates only to permanently installed engines, that is those as given on the ship’s records.

Packaged and other temporarily installed engines should not be included.

5.4 Can an engine having a higher rating and more cylinders be certified based on a parent tested for a lower rating and/or number of cylinders?

The Group and Family engine concepts are available to enable serially manufactured engines to be certified against an approved Parent engine for that Group/Family in order to reduce the amount of emissions testing to a minimum.
The allowable engine types/configurations/rated powers and rated speeds have to be approved by the administration and clearly stated in the Parent Engine Technical File. The chosen Parent Engine for the Group/Family must be shown to be the highest NOx emission engine in that Group/Family. This means that any engine type/configuration/rating of a Group/Family Member Engine must be shown either by prior testing or other means to be a lower NOx emission engine than the Parent.

Justification must be supplied as to why a subsequent engine with a higher rating or increased number of cylinders is a lower NOx emission engine than the Parent Engine.

The main criteria in this justification would be a lower fuel delivery rate per cylinder.

Other criteria that may be supplied to justify an engine as a Group/Family Member may include;
- lower mean effective pressure
- lower maximum cylinder peak pressure
- lower compression pressure ratio
- lower charge air pressure
- lower charge air temperature

5.5 Heavy Fuel Oil (HFO) is used in service in most large marine diesel engines yet the testing requirements detail the use of Marine Diesel Oil (MDO) to be used during the NOx emission test on the test bed. How can the emissions under test bed conditions therefore be related to those under normal in service operation?

The NOx Technical Code states:

5.3.1 Fuel characteristics may influence the engine exhaust gas emission. Therefore, the characteristics of the fuel for the test shall be determined and recorded. Where reference fuels are used, the reference code or specifications and the analysis of the fuel shall be provided.

5.3.2 The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the administration and where a suitable reference fuel is not available, a DM-grade marine fuel specified in ISO 8217, 1996, with properties suitable for the engine type, shall be used.

If an engine is capable of residual fuel operation, it will have been decided early in the planning process whether residual fuel oil or gas oil is to be used. As stated in the NOx Technical Code, in the absence of a suitable reference fuel the requirement is simply that the fuels should conform to, and be tested to ensure compliance with ISO 8217.

Most commercial gas oils conforming to ISO 8217 DMA or DMB grades are adequate reference fuels in that the results from different tests can be comparable. There is therefore a requirement that engines which will subsequently only burn residual fuel oil should be initially tested using gas oil. The use of a residual fuel oil in such engines would give results closer to those which would be encountered in service but the wide quality variations possible would create questionable repeatability of the results. It should be noted that ignition quality and fuel bound nitrogen can have a significant effect on the overall in-service emissions.

5.6 Due to technical reasons a Family engine has to be modified before supply to a vessel. A different turbocharger has been fitted. Can this engine still be certified as a Family member and if so what is the procedure?

The procedure would be as follows:
- Submit details of the turbocharger with reasons why it is an acceptable alternative for the approved NOx compliant diesel engine. Where verifying test results are available these should be submitted as part of the evidence.
- The documentation will be reviewed and approved if found acceptable. This approval will form an addendum to the original Technical File to which it is to be attached certifying it as an alternative turbocharger for that series of engines.
- A copy of the approval and turbocharger information should also be provided for attachment to the engine Technical Files to form part of the on board engine parameter check method information.
5.7 *A main propulsion engine is to be used with a controllable pitch propeller (CPP). This configuration has two different operating modes in normal service. At high speed the engine speed remains constant and the propeller pitch varies. At low speed the propeller pitch is fixed and the engine speed is varied. Which test cycle is applicable?*

It must be understood that the test cycle applied should be in accordance with the normal service condition of the engine. In standard CPP configurations engine speed is constant and the E2 test cycle would be applicable. This configuration would invariably allow the capability to 'fix' the CPP pitch and operate the engine at variable speed as an emergency measure (in the case of a CPP failure). This condition falls outside the definition of normal service and therefore there is no requirement to test the engine in accordance with the E3 cycle.

In cases where both configurations are designed as 'normal service' BOTH test cycles (E2 and E3) must be applied during pre-certification testing. The engine would then be provided with a certificate covering each cycle respectively.

5.8 *Two identical engine types are to be installed on a twin skeg ship. The only difference between them is the direction of rotation ('mirror engines'). Will the engine with different rotation from the Parent Engine be required to undergo further NOx testing?*

There is no requirement by LR to emission test an engine with opposing rotation to that of a previously NOx certified Parent Engine. This is on the condition that the engine is equipped with identical NOx sensitive components to those fitted on the Parent Engine and all settings and adjustments are within the approved ranges as defined in the Parent Engine Technical File.
6. Conformity of Production (COP)

6.1 What is the purpose of the Conformity of Production procedure? What are the roles of the engine manufacturer, ship owner and surveyor?

This relates to engines that are members of either a “family” or a “group” which are serially produced and are intended for compliance with the NOx Technical Code. The manufacturer is required to implement an approved control procedure which will ensure each subsequent engine is assembled using identical parts to those installed in the Parent engine giving a presumption of conformity with MARPOL Annex VI, Regulation 13, NOx Emission limits. This allows the worst case i.e. highest NOx producing engine, termed a “Parent engine”, to be tested to reduce the number of engine tests required.

The production control system must be in place before component manufacturing commences to ensure each is to the same design and marked with a unique identifier.

The attending surveyor monitors the production to confirm the assembly of the final engine and that the control system is being implemented effectively. After final assembly, the surveyor issues a Verification of Conformity report for the engine.

For main and auxiliary engines, this monitoring can be incorporated into the normal classification inspection procedure. However, for the smaller massed produced engines the monitoring can be based on a suitable quality scheme (LR Quality Scheme for Machinery), in view of the volume produced. Reference should be made to the LR guidance document ‘Conformity of Production procedure’ for further information.

The ship owner's role is to purchase a NOx certified engine and to maintain it in compliance with the NOx Emission limits. Thus, during manufacture he must not request modifications which would place the engine outside the limits unless it is to be re-certified.

6.2 What is a Conformity of Production Verification Report?

This is a report prepared by the attending surveyor verifying that the subject ‘series produced’ engines have been manufactured from compliant components as identified in the Parent Technical File in accordance with the manufacturers approved Conformity of Production procedures.

The form is prepared for each engine or series of engines and forwarded to the approval office as part of the approval procedure.

The NOx Verification of Conformity Report provides the approval office with the necessary confirmation of the engine(s) presumption of conformity with the Parent Engine NOx emission limits allowing the submitted Technical Files to be verified and approved.

Typical form of a NOx Verification of Conformity report:
6.3 At what stage should the Conformity of Production procedure be put in place?

The engine builder should be encouraged to have a Conformity of Production procedure in place before testing the Parent engine. Normally this means incorporating the NOx controls into his existing engine production procedures.

This ensures that he can easily demonstrate through this system that the NOx sensitive components in subsequent engines, after the parent, are the same as those components in the parent.

Such a system is designed to reduces any necessity to test subsequent engines.

6.4 Should the Conformity of Production procedure be included in the Technical File?

The Conformity of Production procedure is to be submitted to the Administration for review and approval as part of the certification process. A copy of this document is retained by the Administration together with the Technical File and any other 'additional information' submitted at the review stage. It is not required to form part of the Technical File as supplied with the engine.
7. Pre-Certification Testing

7.1 What is Pre-certification testing?

This is undertaken on the test bed at the engine manufacturer’s works to ensure that the engine as designed and equipped complies with the NOx emission limits contained in regulation 13 of Annex VI. Under certain circumstances this may be conducted on board the ship after installation and prior to entering service and issue of the IAPP certificate.

On completion of the approval process LR will issue either an LR Certificate or Statement of Compliance or an Engine International Air Pollution Prevention (EIAPP) Certificate where authorised by the Administration once Annex VI is ratified.

7.2 How much time should be allocated to a Parent Engine test bed programme? Who should attend?

Sufficient time needs to be allocated in the Parent Engine test bed programme to allow for the inspection of the engine to ensure that it conforms with the proposed Parent Engine design, fit and adjustment. The test bed equipment will need to be assessed for compliance with the NOx Technical Code requirements, this would include a review of calibration certification for the analysers and other measurement equipment.

The actual parent engine test would be expected to take from 3-8 hours under the specified Code requirements. From LR’s viewpoint this attendance will be undertaken only by Surveyors with the necessary experience, training and authorisation.

7.3 On fuel testing.

5.3.2 The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the Administration and when a suitable reference fuel is not available, a DM-grade marine fuel specified in ISO 8217, 1996, with properties suitable for the engine type, shall be used.

Oil fuel used for the test is to be analysed for each of the parameters in the ISO 8217 specification plus carbon, hydrogen and nitrogen. They are not required to be tested for oxygen content since this is taken as zero.

When testing for ISO 8217 grades DMA and DMB the ignition performance parameter is strictly to be determined as Cetane Number not Cetane Index since the latter cannot determine the effect of any cetane improvers.

7.4 On exhaust gas analytical systems.

5.9.2.1 An analytical system for the determination of the gaseous emissions (CO, CO₂, HC, NOₓ, O₂) in the raw exhaust gas shall be based on the use of the following analysers:

- Heated Flame Ionisation Detector (HFID) for the measurement of hydrocarbons;
- Non-Dispersive Infra-Red (NDIR) analyser for the measurement of carbon monoxide and carbon dioxide;
- Heated ChemiLuminescent Detector (HCLD) or equivalent analyser for the measurement of nitrogen oxides; and
- ParaMagnetic Detector (PMD), ElectroChemical Sensor (ECS) or ZiRconium DiOxide (ZRDO) sensor for the measurement of oxygen.

The NOx Technical Code does not provide for alternative analyser principles to be used (unlike ISO 8178). In order to avoid, at least some of, the possible problems with the future reproducibility of test results only the analytical principles as given will be acceptable, i.e. only chemiluminescence analyser is to be used for NOx measurements.

7.5 On non standard air inlet and exhaust systems.

5.9.1.2 The settings of inlet restriction and exhaust back pressure shall be adjusted to the upper limits as specified by the manufacturer in accordance with 5.2.4 and 5.2.5, respectively.

In order to meet the requirements of 5.2.4 the inlet air system should be adjusted, where a non-standard air inlet system is to be used, to give the minimum inlet depression i.e. maximum absolute
pressure post filter or at turbo-blower compressor inlet.

In order to meet the requirements of 5.2.5 the exhaust system should be adjusted, where (as would more normally be the case than for the inlet air system) a non-standard exhaust system is to be used, to give the minimum pressure post turbo-blower turbine exhaust.

### 7.6 On intermediate zero and span checks

5.9.9 After the emission test, the calibration of the analysers shall be re-checked using a zero gas and the same span gas as that used prior to the measurements. The test shall be considered acceptable if the difference between the two calibration results is less than 2%.

Analysers may be subject to intermediate zero and span checks (i.e. between test load points), in which case the drift allowance is to be considered between two consecutive checks. The span and zero may with some instruments be checked without necessarily re-setting the analysers, in other cases such checks will automatically reset the values and hence could mask unacceptable performance.

### 7.7 On alternative test standards for Engine Family Certification

4.3.10.5 If the parent engine of an engine family is to be certified in accordance with an alternative standard or a different test cycle than allowed by the NOx Technical Code, the manufacturer must prove to the Administration that the weighted average NOx emissions for the appropriate test cycles fall within the relevant limit values under regulation 13 of Annex VI and the Code before the Administration may issue an EIAPP certificate.

The use of alternatives to those given in the Code, (i.e. CIMAC, national standards) would not be considered acceptable. Every effort should be made to adhere closely to the requirements as stated in the NOx Technical Code and not to introduce other test methods into the approvals process.

Even in terms of the test cycle, ISO 8178 is specific as to the order of the load points although it should be understood that this is principally related to the effect of load cycle order on hydrocarbon and particulate emissions.

If alternative methods etc. were to be adopted it would remain necessary for the test condition parameter to remain valid and that, as a minimum, the data required by the NOx Technical Code be obtained - under survey conditions.

### 7.8 On the Test Condition Parameter and test validity for engine family approval

5.2.1 Parameter $f_a$ shall be determined according to the following provisions:

For naturally aspirated and mechanically supercharged engines:

$$f_a = \left( \frac{99}{P_s} \right) \left( \frac{T_a}{298} \right)^{0.7}$$

For turbocharged engines with or without cooling of intake air:

$$f_a = \left( \frac{99}{P_s} \right)^{0.7} \left( \frac{T_a}{298} \right)^{1.5}$$

Where $P_s$ is dry atmospheric pressure (kPa) and $T_a$ is the absolute temperature of intake air (K).

For a test to be recognised as valid, parameter $f_a$ shall be such that:

$$0.98 \leq f_a \geq 1.02$$

It is stressed that this requirement applies only to Family Parent Engine emission tests.

The test condition parameter must be retained within the required range across the whole of the engine test period.

Barometric pressure and ambient air temperature readings should be entered as whole numbers only with the result reported to the second decimal place.

At the Marine Environment Protection Committee (MEPC) 44th session it was agreed to approve a proposed amendment to paragraph 5.2.1 of the NOx Technical Code. The MEPC drafting group in their report MEPC 44/WP.5 noted that it may not be possible, due to engine size, to provide test facilities where barometric pressure, temperature and humidity of the intake air can be controlled to
maintain the ‘fa’ factor within the range 0.98 < fa > 1.02. In consequence, the test for engine family approval may only be possible for a limited period during the year. The approved amendment states that the following statement is to be added to the end of paragraph 5.2.1:

“If, for evident technical reasons, it is not possible to comply with this requirement, fa shall be between 0.93 and 1.07.”

This amendment was approved but will not be adopted until Annex VI comes into force.

To allow uniform application of the NOx Technical Code, and to assist Administrations in certifying engines in accordance with it, this amendment is recommended to be used prior to its date of entry into force.

7.9 Who decides which method of NOx calculation is to be used?

The responsibility to produce calculation results lies with the engine manufacturer, or persons nominated by himself to act on his behalf, with regard to testing.

It is the role of the Flag State Administration, or Classification Society acting on their behalf, to witness the testing and validate results and calculations. LR’s validation, to date, has shown no significant divergences from the requirements of the NOx Technical Code.

7.10 Many auxiliary marine diesel engines are coupled to alternators and installed as generating sets. Can this alternator be used on the test bed as the load dynamometer?

The NOx Technical Code is written for testing with a dynamometer since in most instances it is not possible to operate with the driven equipment installed.

Where it is possible to carry out testing in the completed condition, such as with the generator installed, then it is acceptable to test in this condition provided the required test (e.g. D2) may be followed.

The alternator efficiency is normally evaluated at the alternator trials. It is therefore not necessary to evaluate the efficiency during the NOx emission testing. Calculation using the manufacturer’s value is acceptable.

7.11 The NOx Technical Code states testing is to be undertaken with a sea water temperature of 25°C. What does this mean?

This section of the NOx Technical Code describes the procedures for NOx emission measurements on a test bed concerning only engines with charge air cooling:

5.2.2.2 All engines when equipped as intended for installation on board ships must be capable of operating within the allowable NOx emission levels of regulation 13(3) of Annex VI at an ambient seawater temperature of 25°C. 25°C seawater temperature is the reference ambient condition to comply with the NOx limits. An additional temperature increase due to heat exchangers installed on board, e.g., for the low temperature cooling water system, shall be taken into consideration.

The fresh water cooler outlet temperature, and hence the charge air cooling capability, must be based on the inlet temperature of 25°C for the FW cooler coolant.

For the test bed measurements this will require the primary cooling circuit temperature to be suitably adjusted.

7.12 It is sometimes difficult to simulate the required 25°C sea water temperature due to the limitations of the cooling water supply at the factory. Can the test be performed at a higher temperature?

It must be understood that the seawater temperature shall not be lower than 25°C for the pre-certification testing as reduced temperatures result in reduced NOx emission values.

It is acceptable to allow a higher temperature at the test bed as long as it maintains the engine at normal operating temperatures as specified by the manufacturer and also that he is aware that the measured NOx value will be higher.

This temperature should also be recorded in the test report.
7.13 What are the requirements concerning the design of the exhaust gas sampling probe? In the LR Pre-certification checklist it states that the ‘maximum sensor length in exhaust trunk should be 0.75 times the exhaust diameter’. Does this apply to multi-holed sensors?

The NOx Technical Code does not specify the type of sampling probe that should be fitted during the NOx emission pre-certification test. The test procedure as stated in the NOx Technical Code is based on the British Standard EN ISO 8178-1:1996 (Reciprocating internal combustion engines - Exhaust emission measurement; Part 1 Test-bed measurement of gaseous and particulate exhaust emissions). This standard recommends a stainless steel, straight, closed-end, multi-hole probe:

“The inside diameter shall not be greater than the inside diameter of the sampling line. The wall thickness of the probe shall not be greater than 1mm. There shall be a minimum of 3 holes in 3 different radial planes sized to sample approximately the same flow. The probe must extend across at least 80% of the diameter of the exhaust pipe.”

LR will accept an open-ended sampling probe on the condition that it samples a representative gas sample and therefore the open end should be located sufficiently near the exhaust pipe axial centre-line to negate the effects of sampling boundary layers of gas from the internal surface. The maximum figure of 75% penetration of the exhaust pipe diameter stated in the pre-certification checklist would facilitate this requirement and therefore would only apply to open ended sampling probes.

7.14 Why is the location of the sampling probe relative to the engine and exhaust gas system exit so important?

5.9.3.1 The sampling probes for the gaseous emissions shall be fitted at least 0.5m or 3 times the diameter of the exhaust pipe – whichever is the larger – upstream of the exhaust gas exit to avoid possible dilution of the exhaust gas sample by air streams blowing across the atmospheric outlet.

The specified minimum gas temperature of 70°C at the sampling probe is stated to avoid any significant condensation of hydrocarbon (HC) material in the section of the exhaust system prior to the probe. At lower temperatures some of the carbon material present (which would have registered as part of the HC emissions at higher temperatures) would be lost from the system.

Typically the sample will be drawn from a point closer to the turbocharger outlet than exhaust system exit to atmosphere, resulting in gas sample temperatures above 70°C to negate problems with HC condensation.

To prevent the condensation of water vapour, nitrogen dioxide (NO2), and some of the HC species present, both the gas filter and the line used to transfer the sample down to the analysers should be heated, typically being maintained at 190°C.

7.15 How should the exhaust gas sample be taken in ‘Vee’ engine configurations?

5.9.3.2 In multi-cylinder engines having distinct groups of manifolds, such as in a “Vee” engine configuration, it is permissible to acquire a sample from each group individually and calculate an average exhaust emission. Other methods which have been shown to correlate with the above method may be used. For exhaust emission calculation, the total exhaust mass flow must be used.

When an engine is configured with distinct groups of exhaust manifolds the practice of simply connecting the gas sample hoses together using ‘y’ connectors would not necessarily give a representative sample of the engine in that exact balance between each manifold group is assumed.

A sample must be acquired individually from each manifold group and the results mathematically averaged.
8. Parent, Family and Group Engine Concepts

8.1 What are the engine Family and engine Group concepts?

Engines may be individually tested to demonstrate that they satisfy the MARPOL Annex VI Regulation 13 NOx limits.

Alternatively, a manufacturer may nominate a Parent Engine to be tested as representative of an engine family or engine group member to avoid testing every engine which is intended to be serially produced in that range.

The engine family concept may be applied to series produced engines which have similar NOx emission characteristics where no modifications or adjustments which would affect the NOx emissions are required when installed on board a ship. Where adjustable features are provided (e.g. for balancing cylinder peak pressures and individual cylinder exhaust gas temperatures) they are to be such that no setting, or combinations of settings, can adversely affect the engine’s NOx emissions. For engines within a particular family the applicable characteristics detailed in 4.3.8 of the NOx Technical Code should be common to those engines.

The engine group concept may be applied to similar type engines which require minor adjustment or modification during installation or in service on board a ship but whose NOx emission will still remain within the NOx emission limit for the engine. These engines are normally series produced in low numbers such as large powered propulsion engines.

For engines within a particular group, the applicable characteristics as detailed in chapter 4.3.8 of the NOx Technical Code as well as those parameters and specifications indicated in chapter 4.4.5.2 of the NOx Technical Code should be common to those engines.

With regard to the allowable adjustments within an engine group the manufacturer is to provide documentary evidence and/or historical data (e.g. previous test reports) to substantiate that the range of adjustments which are included in the Technical File will permit the engine to operate within the emissions limits as set down in MARPOL Annex VI Regulation 13(3)(a) and chapter 3 of the NOx Technical Code.

Some manufacturers have termed such tests Parameter Sensitivity tests.

It will be up to the attending surveyor, at the time of the Parent Engine emission test to confirm that the allowable adjustments do not result in the total weighted average NOx emission value of that engine exceeding the permissible limits.

In selecting the Parent Engine for a group the most adverse features affecting the NOx emission level should be incorporated. In general the Parent Engine should have the highest NOx emission level of any of the proposed configurations defined by the manufacturer as the engine Group.

8.2 On Parent Engine selection for a Family.

4.3.3 The selection procedure for the parent engine is such that the selected engine incorporates those features which will most adversely affect the NOx emission level. This engine, in general, shall have the highest NOx emission level among all of the engines in the family.

For the engine family concept the Parent Engine must be selected based on criteria contained in chapter 4.3.9.2 of the NOx Technical Code.

The parent engine must have the highest NOx emission value (as a weighted average in terms of g/kWh).

8.3 On the selection of a Parent Engine for an Engine Group.

4.4.7 The selection of the Parent engine shall be in accordance with the criteria in 4.3.9 (Guidelines for Selecting the Parent Engine of an Engine Family), as applicable. It is not always possible to select a parent engine from small volume production engines in the same way as the mass produced engines (engine family). The first engine ordered may be registered as the parent engine. The method used to select the parent engine to represent the engine group shall be agreed to and approved by the Administration.

For the engine group concept the Parent Engine must be tested with the allowable adjustments set to those positions documented in the Technical File which give the worst NOx emission limits.
The engine’s actual NOx emission value is the value obtained at the time of the test bed test of the Parent Engine with the engine adjusted, within the allowable parameters as documented in the Technical File, to give the worst case (highest) NOx emissions. This will ensure that the Parent Engine and all members of the group (or family) always operate at or below this worst case scenario and therefore are always in compliance with the Annex VI Regulation 13 limits.

### 8.4 On the Parent Engine selection for a family.

4.4.5 The Administration shall review for certification approval the selection of the parent engine within the family and shall have the option of selecting a different engine, either for approval or production conformity testing, in order to have confidence that the complete family of engines complies with the NOx emission limits.

Where an Administration selects a different engine from that proposed by the engine builder then the engine builder could elect to test both but could proceed on the basis of testing only the engine as selected by the Administration.

### 8.5 On the Family concept and Conformity of Production.

4.3.7 Before granting an engine family approval, the Administration shall take the necessary measures to verify that adequate arrangements have been made to ensure effective control of the conformity of production.

The extension of the engine family approval to other sites (whether or not part of the parent engine builder company) is dependant on where control lies which ensures conformity of production. Where another site is responsible for its own conformity of production that builder cannot be covered by the original parent engine certification.

What is the definition of the word ‘adequate’ (here and in subsequent references to the conformity of production)? The existence of an ISO 9000 Quality Assurance scheme does not automatically satisfy the Conformity of Production (COP) control procedure requirements (section 6).

### 8.6 Do tests which are used to produce data on which to base the Parent Engine selection have to be carried out under survey conditions?

4.3.4 On the basis of tests and engineering judgement, the manufacturer shall propose which engines belong to an engine family, which engine(s) produce the highest NOx emissions, and which engine(s) should be selected for certification testing.

Tests which are used to produce data on which to base the Parent Engine selection do not need to be carried out under survey conditions. However those tests do need to be carried out in accordance with the NOx Technical Code procedures.

Sufficient data must be submitted in order that the results of such in-house testing can be verified as part of the approval process.