INTERNATIONAL MARITIME ORGANIZATION

E

4 ALBERT EMBANKMENT
LONDON SE1 7SR
Telephone: +44 (0)20 7735 7611 Fax: +44 (0)20 7587 3210

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REVISED DESIGN GUIDELINES AND OPERATIONAL RECOMMENDATIONS FOR VENTILATION SYSTEMS IN RO-RO CARGO SPACES

1 The Maritime Safety Committee, at its sixty-sixth session (28 May to 6 June 1996), approved the *Design guidelines and operational recommendations for ventilation systems in ro-ro cargo spaces* (MSC/Circ.729).

2 The Sub-Committee on Ship Systems and Equipment, at its second session (23 to 27 March 2015), revised the aforementioned guidelines, taking into account advances in technology related to air quality management for ventilation of closed vehicle spaces, closed ro-ro and special category spaces.

3 The Maritime Safety Committee, at its ninety-fifth session (3 to 12 June 2015), after having considered the above proposal by the Sub-Committee on Ship Systems and Equipment, at its second session, approved the *Revised design guidelines and operational recommendations for ventilation systems in ro-ro cargo spaces*, as set out in the annex.

4 Member Governments are invited to bring the Revised design guidelines to the attention of ship designers, shipyards, shipowners and other parties concerned. Member Governments are also invited to apply the revised design guidelines to all ships on a voluntary basis.

5 This circular supersedes MSC/Circ.729.

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ANNEX

REVISED DESIGN GUIDELINES AND OPERATIONAL RECOMMENDATIONS FOR VENTILATION SYSTEMS IN RO-RO CARGO SPACES

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PART 1

DESIGN GUIDELINES FOR VENTILATION SYSTEMS IN RO-RO CARGO SPACES

INTRODUCTION

This document provides general guidelines for the design of suitable ventilation systems for vehicle decks on ro-ro ships, car carriers and car ferries.

Exhaust gas composition

Exhaust gases from motor vehicles contain hazardous substances. Carbon monoxide (CO) from petrol engines, and nitric oxide (NO) and nitrogen dioxide (NO_2) from diesel engines are the substances whose health hazards are discussed in this document. These hazardous substances can affect people in many different ways. Certain substances have a tangible, immediate effect. Others only show injurious effects after a person has been exposed to them for some time. The effect of a substance normally depends on how long a person has been exposed to them and the quantity inhaled.

Carbon monoxide (CO) is a colourless and odourless gas which, to a lesser or greater extent inhibits the ability of the blood to absorb and transport oxygen. Inhalation of the gas can cause headaches, dizziness and nausea and in extreme cases causes weakness, rapid breathing, unconsciousness and death.

Nitric oxide (NO) and nitrogen dioxide (NO_2) are compounds of nitrogen and oxygen, together commonly referred to as oxides of nitrogen or NO_x. NO, a colourless gas is the main oxide of nitrogen formed in the combustion process. NO itself is not of great concern as regards health effects; however, a proportion of the NO formed will combine with oxygen to form NO_2, which is of concern from the point of view of human health. NO_2 is a brown gas which has a stinging, suffocating odour. It exerts a detrimental effect on the human respiratory system. Asthmatics in particular are susceptible to exposure.

Measures

Measures should be considered as follows:

A reduction in exhaust gas emissions;

Provision of an adequate ventilation system;

Limitation of exposure to the gases; and

Prevention of accumulation of hazardous and flammable gases

1 REQUIREMENTS

1.1 Definition of exposure limits and flammability limit

An exposure limit value means the highest acceptable average concentration (time-weighted mean value) of a substance or, in some cases, of a mixture of substances in the air breathed by the occupants. The concentrations are usually given in parts per million (ppm) or mg/m^3. An exposure limit value refers either to a long-term exposure level or a maximum limit value. Short-term exposure level is also used.

Long-term exposure level, means the exposure limit value for exposure during the entire working day (normally 8 hours).

Maximum exposure level means the highest concentration reached.

A short-term exposure level means the time-weighted mean exposure value over a short period of 10 or 15 minutes, dependent on the national occupational exposure standards.

Lower Explosion Limit (LEL) means concentration of flammable gas, vapour or mist in air below which an explosive gas atmosphere will not be formed. Also known as Lower flammability limit.

1.2 Pollutants of interest

The exhaust gases generated by internal combustion engines contain hundreds of chemical substances. The main part of them are nitrogen (N_2), carbon dioxide (CO_2), oxygen (O_2), carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2) aldehydes such as formaldehyde, polyaromatic hydrocarbons such as benzo(a)pyrene and organic and particulate bound lead.

Among the pollutants emitted in the exhaust gases of petrol and diesel engines, CO is generally of the most significant concern for petrol engines and NO_x for diesel engines. Lead, particulate matter (PM) and benzo(a)pyrene are also of a significant concern.

Knowledge of the effects of other pollutants to the health is at present insufficient. However, considerable research is being undertaken.

Monitoring of occupational hygiene should be planned and its results should be assessed by a qualified expert, with special training in this field. The studies should be carried out in cooperation with the monitoring staff, the management of the ship concerned and the relevant Administrations.

1.3 Rate of air change

Regulations II-2/19.3.4 and 20.3 of the 1974 SOLAS Convention, as amended, provides requirements for rate of air changes which are intended to limit maximum concentration of pollutants during loading and unloading and also to prevent a build-up of hazardous and flammable gases in the ro-ro cargo spaces when the ship is at sea with a cargo of motor vehicles. These regulations provide the minimum acceptable standards for ventilation.

2 VENTILATION

2.1 Ventilation on board ships

Ventilation systems for ro-ro cargo spaces on board ship generally operate according to the principle of dilution ventilation, whereby the supply air flow to the area is sufficient for the exhaust gases to mix thoroughly with the air and be removed.

There are two main types of dilution ventilation: exhaust air ventilation and supply air ventilation. Briefly, in exhaust air ventilation, fans remove air from a ro-ro cargo space, and this is then replaced by outdoor air entering through open ramps, doors and other openings. Exhaust air ventilation is employed when sub-atmospheric pressure is required in the ro-ro cargo space. The sub-atmospheric pressure prevents the pollution from spreading to adjacent areas.

Supply air ventilation works in the opposite way. Fans deliver outdoor air into the ro-ro cargo space and the air is then exhausted through ramps and other openings. Supply air ventilation usually creates slight pressurization of the ro-ro cargo space. If supply air ventilation is used exclusively, pollutants may mix with the supply air, be pushed up the internal ramps and contaminate other decks. However, if sufficient mixing with supply air does not occur, contaminants may remain on the deck in question. Particularly, hazardous conditions may occur on lower decks.

Ventilation systems on board ship often combine these two principles. The fans can then be reversible, so that they can either supply air into the ro-ro cargo space or exhaust air from it.

2.2 Air pollutant dispersion

Exhaust gas dispersion will depend upon air flow patterns within the vehicle deck. These will not be uniform but will be dependent upon the capacity, design and mode of operation of the ventilation system; volume and configuration of the cargo space; natural ventilation patterns and the number and location of vehicles on the vehicle deck.

Although the overall rate of air change on vehicle decks may be high, areas with low rates of air change may remain. High velocity air jets are sometimes installed in an attempt to "stir" the air so that the supply air will be evenly distributed throughout the vehicle space.

2.3 Conditions and guidelines for calculating air requirements

The function of a ventilation system in a ro-ro cargo space is to dilute and remove the vehicle exhaust gases and other hazardous gases, to protect persons working in the area from being exposed to a hazardous or disagreeable level of air pollution. The basic particulars necessary for calculating the supply air required are contained in ISO 9785:2002 or national versions of this standard. These may be used as reference in the planning of new installations or in the assessments of the capacity of existing installations.

The formula given in ISO 9785:2002 is similar to that used for calculating the supply air required for ro-ro cargo spaces in ships. However, the formula also takes into account the fact that the outdoor air supplied contains a certain amount of pollutant and also includes a dilution factor. The latter takes into account the degree of estimated or possible dilution of the pollutants in the air (see ISO 9785:2002, paragraph 5).

In addition to the supply air required to dilute and remove the exhaust gases and flammable gases, it is also important to ensure air circulation in the ro-ro cargo space.

2.4 Air flow distributions

Ventilation systems may be operated at decreased capacity when controlled by a detection system that monitors the flammable and harmful gases in the space. Air quality management is based on the measuring and controlling of CO, NO_2 and LEL values. Guidance on how to conduct air quality management is given in appendix 1.

It is not possible to draw up or recommend any universal solutions for the distribution of air flow in different types of ship. Duct runs and the location of supply air and exhaust air openings should be made to suit the design of the individual ship, the estimated vehicle handling and exhaust emissions in areas occupied by the crew and other workers.

The following generally applies:

- The air flow should reach all parts of the ro-ro cargo space. However, ventilation should be concentrated in those areas in which the emissions of exhaust gases are particularly high and which are occupied by the crew or other workers.

- Consideration should be given to the likelihood of unventilated zones being screened behind an object, and also to the fact that exhaust gases readily accumulate in low-lying spaces under the vehicles and in decks beneath the one being unloaded. Furthermore, depending on air flow patterns, it may be possible for contaminants to move into decks above the one actually being off-loaded.

- The air flow on vehicle deck should be suited to the height of the deck.

- The air flow will follow the path of least resistance, and most of the air will thus flow in open spaces, such as above the vehicles, etc.

- Polluted air from ro-ro cargo spaces should be prevented from being dispersed into adjacent spaces, for instance accommodation and engine-rooms.

- Whenever possible, places which are sheltered from the airflow should be indicated on the plan. The actual locations of such spaces on the deck should be painted in a conspicuous manner to indicate that personnel should not stand on that part of the deck, and signs should be hung on the bulkhead to provide a backup warning.

2.5 Determination of air flow requirements

To assess the number of vehicles which may be in operation at the same time in a cargo space without the occupants being exposed to a hazardous or discomforting level of pollution the guidance contained in ISO 9785:2002 for estimating the flow of outdoor air required to dilute and remove the gases exhausted by a vehicle should be followed.

Consideration should be given to the fact that the exhaust gases may not mix completely with the outdoor air supplied, that the exposure limit values should not be reached and that the outdoor air itself will contain a certain level of pollution.

This guidance applies to vehicles with a normal emission of exhaust gases, operating under normal conditions. It should be remembered that the measured or estimated air flow may deviate from the actual air flow and that the concentration of pollutants in the exhaust gases can vary widely.

The guidance specifies the supply air requirement per vehicle, to ensure that the level of pollution is kept below the exposure limit. Nevertheless, subjective (individual) symptoms of discomfort may be felt, particularly from diesel exhaust gases, with supply airflows at or above the recommended levels.

The air flow can be determined by means of direct measurement or by calculation based methodology (such as computational fluid dynamics and/or the use of established empiric formulae) to be accepted by the Administration.

3 TESTING THE VENTILATION SYSTEM

3.1 General

Testing the ventilation system when the ship is delivered is primarily aimed at confirming that the design supply air flow is obtained. The test results apply to empty vehicle deck and the weather prevailing at the time of testing.

The values recorded during testing are neither representative of nor equivalent to those that need to be applied during loading and unloading of the various types of vehicles under varying weather conditions.

To utilize the ventilation system in the ro-ro cargo spaces on a ship most effectively, knowledge should be acquired of its capacity from experience and through simple tests. It is important that guidelines, rules and routines be established for using the ventilation system in typical loading and unloading conditions. It is also important that experience gained will be documented and passed on, to provide guidance for the ship's crew.

The factors that need to be determined are the quantities of air supplied to and exhausted from the ro-ro cargo spaces and the circulation of air within the vehicle deck. Guidelines for suitable testing are contained in appendix 2.

By systematic use of visible smoke, it is possible to assess the air circulation in a ro-ro cargo space, and an anemometer can be used for determining the rate of flow of supply air. If the results are compared with detailed documentation of actual conditions, they can be used to provide a firm foundation for effective measures.

It is important that the conditions prevailing at the time of the test, which are likely to influence the results, are carefully documented since air flow patterns will vary according to loading conditions. The test results are obviously only applicable to the conditions existing at the time of the tests.

3.2 Determining the rate of air change

The rate of air change is governed by the flow of supply air admitted to the ro-ro cargo spaces through the supply air openings. The flow of air can be determined using a direct reading of anemometer or other instrument of equivalent reliability.

Since the velocity profile of the air entering the vehicle deck through supply air openings on ships is generally highly unstable and fluctuates widely, the air flow should be measured by someone experienced in such measurements. However, after some training, responsible members of the crew should also be able to make these measurements.

Even when the measurements are made by competent personnel, allowance should be made for deviations of at least 20% from the actual air flow, when readings are taken by means of anemometers.

A description of air flow measurement procedures is given in appendix 2. Note that a high air change rate does not guarantee low contaminant levels. Poor mixing within the deck could lead to high contaminant levels and potentially high exposures, even though the fans appear to be providing a large amount of air. Once the ventilation system has been fully characterized, spot checks of the system should be made during actual loading or off-loading operations to ensure that the system is operating as expected. Further guidance is provided in part 2 (Operational recommendations for minimizing air pollution in ro-ro cargo spaces).

3.3 Smoke and gas for tracing the air distribution

To improve the quality of the air at the workplace knowledge should be gained of how the pollution from the vehicles is diffused through the air in the ro-ro cargo space.

Visual tests using visible smoke do not provide any direct readings of the rate of air change or air distribution in a ro-ro cargo space, although they often provide sufficient indication of a satisfactory picture to be obtained of the air circulation, the existence of any stagnant or screened zones and the rate at which pollutants are removed by the ventilation system. Recommended methods using visible smoke or tracer gas are given in appendix 2.

The visible smoke method is simple and can readily be carried out by the officer responsible for ro-ro cargo space ventilation.

The use of tracer gas will give a more reliable picture of air changes and the air circulation in the ro-ro cargo space. However, the procedure for using tracer gas is more complicated. As the same measurement points are used, it is expedient to use tracer gas in combination with stationary monitoring of pollutant concentration in a ro-ro cargo space.

3.4 Testing of sensors used for air quality control system

On regular time intervals, such as monthly, for sample detectors and yearly for the complete system, sensors should be calibrated, maintained and tested according to the manufacturer's instructions, taking part 2 of these guidelines into account.

4 DOCUMENTATION

4.1 Operation manual

An operation manual should be supplied and should include a plan of the ventilation system, showing fans, supply air and exhaust air openings and doors, ramps, hatches, etc. The location of the control panel for the ro-ro cargo space ventilation system should also be marked.

The plan should show the various options for operation of the ventilation system. It should include details of the design air flow and of the estimated number of different types of vehicles in the different ro-ro cargo spaces under various loading and unloading conditions.

The plan should be periodically revised and/or supplemented on the basis of the experience gained from the normal vehicle loading and unloading conditions. A number of blank drawings should therefore be kept on board.

On the basis of such experience, it should also be possible to draw up guidelines for the maximum number of vehicles that should be allowed to operate simultaneously.

Whenever possible, places which are sheltered from the air flow should be indicated on the plans.

The operation manual should include guidance for the service and maintenance of the systems.

4.2 Control panels

The control panels on the ship should be installed in a convenient location.

A plan of the ship's ro-ro cargo spaces, showing the location of fans and openings, should be kept at the control panel. Each fan should be given an individual designation.

Indications as to which fans should be used for a given ro-ro cargo space under various loading conditions should also be on display at the control panel.

For safety reasons and to facilitate control of the ventilation system, the control panel should include means of indicating which fans are running.

The individual control and indicator lights should be marked with the same designation as the fans to which they relate.

As far as possible, indicator lights and controls for fans that normally operate simultaneously should be located in groups. This will help to make the function of the controls readily apparent and will therefore facilitate correct use of the controls.

Automatic control of the air quality control system should be indicated at the control panel.

Reference is made to the *Code on Alerts and Indicators, 2009* (A.1021(26)).

PART 2

OPERATIONAL RECOMMENDATIONS FOR MINIMIZING AIR POLLUTION IN RO-RO CARGO SPACES

INTRODUCTION

The operational recommendations contained in this document are primarily directed at those involved with cargo handling in cargo spaces on ro-ro ships or working in similar environments. The main purpose of the recommendations is to suggest ways in which exposure to exhaust gas emissions can be restricted, but the hazards associated with pollution from exhaust gases are also dealt with. A copy of the recommendations should be kept on board the ship.

1 TRAINING AND INFORMATION

Personnel should be properly trained, possess the necessary skills and follow established procedures.

In order to improve/monitor air quality on vehicle decks a process should be established to record and investigate complaints where persistently poor air quality is perceived by shore gang and crew.

Drivers should be given appropriate instructions for embarkation/disembarkation. These should be aimed at minimizing the air pollution generation.

Training and information should be reviewed following a significant change in the operation of the vessel.

2 INSPECTION, MAINTENANCE AND REPAIRS

Inspection, maintenance and repairs should be carried out in a professional manner. Owners should ensure that this is done and that the necessary skills, equipment and spares are available.

Annual testing of the vehicle space ventilation system should be conducted by the ship's safety delegate. Third party testing of the vehicle space ventilation system should be undertaken before entry into service of a new ship and at periodical intervals of five years thereafter.

3 TESTING THE VENTILATION SYSTEM

3.1 Effective use of the ventilation system

When optimizing the ventilation of a ro-ro cargo space, all appropriate options should be considered. Such options include: different fan speeds, fan configurations and the use of natural ventilation through hull openings. Consideration should also be given to the relative safety and environmental conditions.

3.2 Testing of the air quality

When a new ship is put in operation, the air quality should be tested by a competent qualified person with specialist training in occupational exposure. The tests should be carried out in consultation with the ship's safety delegate and any other relevant authorities.

Shipowners and operators should consider testing the air quality in conjunction with tests of the ventilation system to ensure proper maintenance and functioning of the ventilation system. Situations which indicate the necessity to conduct air quality monitoring include worker complaints (e.g. headache, dizziness, stinging of the eyes or respiratory system), indications that the ventilation system itself has deteriorated, and changes in vessel operation which are substantially different from that for which the original ventilation system was verified.

All tests results verifying the adequacy of the ventilation system should be documented and kept with the ship's records. Appendix 3 provides recommendations for conducting air quality monitoring in ro-ro cargo spaces.

4 SHIPS IN OPERATION

4.1 Loading and unloading

Even if the cargo handling on a ship is well planned and the ventilation system is well suited to the planned traffic density, this may still not be enough to ensure that acceptable air quality is maintained under all vehicle handling conditions.

It is extremely important that the ventilation system is operated in the most effective manner under the prevailing operational and weather conditions.

The personnel responsible for loading and unloading of vehicles should consult with the officer responsible for vehicle deck ventilation to familiarize himself with the ventilation system on board (the supply and exhaust air openings and the design air flow) and decide whether the ventilation is adequate in the light of the traffic density, vehicle type and other considerations on a given occasion.

It is important that the supply air has free passage to the ro-ro cargo spaces and ventilation openings should not be unnecessarily obstructed.

If auxiliary air-jet systems have been installed, vehicles should be stowed in such a way that the air jets are allowed to operate at maximum effectiveness for as long as possible.

4.2 Limitation of exhaust emission production

The most effective way of reducing exhaust emissions is to ensure that vehicles spend as little time as possible on board with their engines running. This applies not only to cargo-handling vehicle (trucks, tractors, etc.) but also to vehicles being carried as cargo (cars, coaches, long-distance trucks, etc.). The speed at which the vehicles are driven on board should also be appropriate to the prevailing conditions.

Exhaust emissions are greatly influenced by driving techniques and the temperature at which an engine is running. Smooth and steady driving of a vehicle with a warm engine will generate the lowest exhaust gas emissions. Sudden and heavy acceleration will cause a substantial and often unnecessary rise in the pollution level. This is particularly true when an engine is cold. Since slow speeds and slow acceleration produce significantly lower levels of air pollutants than high speeds and quick accelerations, vehicles should be accelerated very slowly and kept at low speeds.

The essential points to note include the following:

- condition of the engines;

- driving techniques;

- organization of the work (as few engines as possible running at the same time);
- ensuring that drivers do not start their engines sooner than necessary; and
- ensuring that the traffic flows steadily (thereby eliminating heavy acceleration and high speeds). Exhaust emission control equipment for both diesel and petrol engines may influence air quality during embarkation. However, this is likely to have little effect during disembarkation due to cold starting of engines.

4.3 Limitation of exposure

The car decks on ferries are usually equipped with exhaust air ventilation. The supply air is generally admitted through the ramp and the air is removed by exhaust air fans at the other end of the car deck.

A person carrying out heavy manual work uses up twice as much air as a person doing light work. As a result, he will inhale a correspondingly higher proportion of pollutants. Consequently, the work should be organized so that heavy physical work is avoided in areas where the pollution level is high. Nobody should be unnecessarily exposed to hazardous concentrations of exhaust gases.

4.4 Recommendations for specific ship types

4.4.1 Car ferries

During disembarkation at peak times, the highest average concentration of pollution (exhaust gases) in the vehicle deck will occur furthest away from the ramp, in the proximity of the exhaust air fans. Work on the car deck should therefore be organized to eliminate the need for personnel occupying the area of the car deck in which the pollution concentration is highest.

The embarkation and disembarkation should be organized so that no direct queues form inside the ship or in the ramp opening. The embarkation rate should be suited to the capacity of the fans and the flow of outdoor air supplied.

Embarkation should be organized so that ventilation openings, or air jets in an auxiliary system, are not unnecessarily obstructed.

Drivers should be given printed instructions for embarkation/disembarkation. A suitable leaflet could be given to drivers when the tickets are issued or notices posted for examples: Exhaust fumes constitute a health hazard. Do not start your engine before the signal is given and obey instructions.

On enclosed vehicle decks, instructions to start engines should not be given until doors leading to the ramps are open.

4.4.2 Ro-ro ships carrying heavy vehicles

Most of the cargo on ro-ro ships is handled by vehicles. Large trucks and tractors are used for cargo loading and unloading. Trucks of various sizes are used to stow the cargo in the ro-ro cargo spaces. On enclosed vehicle decks, instructions to start engines should not be given until doors leading to the ramps are open.

It is important to eliminate unnecessary exhaust emissions during cargo handling. The vehicles should be kept moving and queues should not be allowed to form. Avoid having vehicles standing with their engines idling. This applies particularly to any waiting during loading and unloading on board and to vehicles on lifts. At these times the ro-ro cargo spaces should be well ventilated.

It is also important to ensure that supply air and exhaust air openings are kept clear and are not obstructed unnecessarily. Failure to observe this can result in the ventilation system not performing effectively.

Attention should be drawn to the fact that exhaust gases can accumulate in poorly ventilated areas and in low-lying areas. A cold engine discharges twice as much pollution as a warm engine.

4.4.3 Car carriers

Owing to the general uniformity of cargo on car carriers, effective organization of embarkation/disembarkation should be possible, thereby avoiding the formation of queues and the resulting unnecessary exhaust emissions.

Drivers should be given printed instructions for driving techniques and should be informed of the importance of not running the engines more than necessary. A vehicle driven slowly and with slower acceleration will emit much less pollutant than a vehicle driven faster and with higher acceleration. Furthermore, a cold engine will often emit twice as much pollutant as a warm engine.

It is therefore recommended that engines be warmed up before the vehicles are driven on board. Vehicles with engines running should not be permitted in the vicinity of the "lashing gang".

5 PERSONAL SAFETY EQUIPMENT

The use of personal safety equipment should always be seen as a last resort, only to be adopted when all else has failed. With regard to exhaust gases, the practical possibilities are limited, since all of the pollutants contained in the emissions are difficult to filter out, which generally rules out the use of masks and the like. Consequently, if the problem is to be solved using personal safety equipment, breathing apparatus should be used. Such apparatus is inconvenient in practice because the oxygen should come either from cylinders carried or worn on the back of the user or through a hose.

APPENDIX 1

VENTILATION OF RO-RO CARGO SPACES – AIR QUALITY CONTROL AND MANAGEMENT SYSTEM

1 General

This appendix gives directions for measuring the quality of air and to regulate the air flow accordingly. This system is called air quality control.

Air quality control may be used as an instrument to regulate the air flow in closed vehicle spaces, closed ro-ro and special category spaces.

Air quality control is based on measurement of CO, NO_2 and LEL values. Based on the measured values the amount of air can be regulated by changing the number of revolutions of the supply and/or discharge ventilators.

2 Requirements

2.1 Monitoring frequency and the resulting response of the ventilation system on air quality in the ro-ro spaces should be sufficient to keep the concentration of flammable and harmful gases below limits.

2.2 Maintenance provisions should be provided by the manufacturer and indicate at least frequency of testing and adjustment of the sensors.

2.3 The system should be capable of automatic operation, with a manual override.

2.4 The power supply, sensors and control equipment should be monitored. An alarm should be generated upon failure, including the manual override.

2.5 Upon any failure in the system including power failure of the control system, the ventilators should switch to the capacity as required in SOLAS regulation II-2/20.3.1.1.

2.6 Maximum section size for sensor equipment should be one hold.

2.7 Periodic onboard test and calibration of sensors should be according to the manufacturer's instructions.

2.8 Alarms as provided in paragraph 2.4 should be sufficient and indicated in the space where the controls for the power ventilation serving the vehicle decks are located on the navigation bridge.[1]

2.9 Gas detection equipment including wiring should be fit for ro-ro cargo hold conditions and meet the relevant standards.

2.10 When CO, or NO_2, or concentration of flammable gasses (LEL) exceeds the threshold concentration, an audible and visual alarm should be given at a continuously manned location.

2.11 The control system should be continuously powered and should have an automatic changeover to a standby power supply in case of loss of normal power supply.

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[1] Refer to the *Code on Alerts and Indicators, 2009* (resolution A.1021(26)).

3 Air quality control systems

3.1 Air quality control is a system to ensure flammable and hazardous gas concentrations are kept below prescribed levels.

3.2 In ro-ro cargo spaces the following gases should be monitored and managed in order to limit the concentration of harmful exhaust gases when vehicles are being loaded and unloaded, and prevent the build-up of flammable gases while the ship is at sea:

.1 for gasoline powered vehicles, carbon monoxide (CO);

.2 for diesel engines nitrogen oxide (NO_2); and

.3 the Lower Explosion Limit (LEL).

3.3 Factors to be taken into consideration when determining what type of system should be specified:

.1 Size of space to be monitored: In areas comprised of dividers, sections, corners and other barriers to free movement of air should be condensed to one sensor per 900 m^2. Lesser number of sensors may be accepted based on calculations or measurements of the response time on air quality in the holds.

.2 Sensor Placement: When installing sensors in a space, care should be taken to keep them away from areas which may have an effect on readings. These include overhead doors (entrances and exits) as well as areas close to the outside air intake or exhaust fans.

4 Minimum quantity of air based on measurements of CO, NO_2 and LEL

4.1 Ventilators should be controlled by the air quality control system in order to provide the appropriate number of air changes to restore the normal values of CO, NO_2 and LEL as soon as those levels are exceeded during 5 minutes. The ventilation regime should be continuously regulated in relation to the increase of gas concentration and to restore normal levels of CO or NO_2 as soon as possible.

4.2 Alarm should be given when the level exceeds 40 mg/m^3 CO or 4 mg/m^3 NO_2 long-term exposure according to the standard ISO 9785:2002 or when a relative concentration of the atmosphere to the LEL is higher than 10%. Other more stringent exposure limits may be used when determined by the Administration, taking national/local occupational regulations into account.

4.3 The minimum amount of ventilation should give sufficient flow for the measurement devices to operate.

5 Detection of CO, NO_2 and LEL

The installation and location of the detectors is dependent on the air flow in the holds. To assess the location and number of detectors, the flow of air in the hold should be taken into consideration. In any case, the detectors should be installed to provide the performance required in paragraph 3 and as indicated below:

.1 suitable height above deck according to the instruction of the manufacturer;

.2 such that each detector covers max 900 m^2. Lesser number of sensors may be accepted but with sufficient response time to keep the concentration of harmful gases below exposure and flammable limits; and

.3 in accordance with paragraph 3 of part 2 of this guideline and with the manufacturer's instructions concerning sensor placement.

6 Approval Test

A test on board to verify the performance of the air quality control systems according to these guidelines should be performed. Real scale tests may be replaced by model tests to the satisfaction of the Administration.

APPENDIX 2

VENTILATION OF RO-RO CARGO SPACES – AIR FLOW TESTING PROCEDURES

1 Scope and field of application

This appendix gives directions for measuring nominal air change and air distribution in connection with testing of ventilation plants in ro-ro ship's cargo spaces where running of vehicles with internal combustion engines occurs.

The nominal air change is measured by calculation of the air flow in supply air and exhaust air terminal devices. The air distribution is normally estimated visually with visible smoke, or by measuring with tracer gas.

2 Nominal air change

In order to verify that the calculated quantity of air is supplied to the ro-ro cargo spaces, the air flow rate should be measured in each supply air and, where appropriate, exhaust air terminal device.

2.1 Instruments for Measurement of Air Flow

Although alternative techniques, such as the pilot traverse method are available, anemometers are generally employed for low velocity air flow measurements. There are two general types of anemometers:

.1 The direct-reading anemometer of the electronic type which registers the air velocity almost instantaneously. This has a distinct non-uniform airflow as any instability or random changes of velocity are immediately seen and the true mean of the velocity at a point can be judged. It is also very quick to use.

.2 The mechanical type of direct reading anemometer with a rotating vane. The movement is a rotary deflection against the action of a spring.

These types of anemometer are small and compact, easy to read and use, give reasonably steady readings and any fault or inconsistency developing is usually quite apparent. Where a correction chart is supplied with an anemometer the correction factors should be applied to the measured velocities before comparing them. With a good quality instrument in proper repair used by an experienced operator, the probable error on the comparative value obtained will range from a maximum of ± 2% when comparing similar velocities to a maximum of ± 5% when comparing widely differing velocities.

2.2 Air Flow Measurement Procedure[2]

For supply or extract grilles the anemometer is used as follows:

The gross grille area is divided into 150-300 mm squares, depending upon the size of grille and variation in the velocity pattern.

[2] Abstracted from the Chartered Institute of Building Services, Commissioning Codes, Series A, Air Distribution, CIBS, London, 1971.

The anemometer is held at the centre of each square with the back of the instrument touching the louvres which should be set without deflection. The instrument will give an immediate reading of the indicated velocity at each square and this reading should be recorded. When the indicated velocities at the centre of all squares have been recorded, the average value of these velocities should be calculated; this average value should be taken as the "indicated velocity" for the whole grille.

This method will normally provide repeatable results. In practice the only inconsistency which is necessary to consider appears where the grille damper is well closed down, causing the air to strike the anemometer vanes in separate jets rather than with uniform velocity. In this case a hood may have to be used with the anemometer.

2.3 Calculations

The air flow rate at each supply-extract grille is calculated as follows:

Air flow rate (m^3/s) = "indicated velocity" (m/s) x area of supply/extract grille (m^2)

The global rate of air change per hour achieved by the vehicle deck system(s) is subsequently calculated as follows:

$$\text{Air changes per hour } = \sum \frac{\text{Air flow rates at extract grilles } (\mathrm{m}^3/\mathrm{s}) \text{ x } 60 \text{ x } 60}{\text{Volume of vehicle deck } (\mathrm{m}^3)}$$

2.4 Report

A report should be drawn up in accordance with paragraph 4 of this appendix.

3 Air distribution

3.1 Visual study with visible smoke

In order to assess air change rate the movement of air and the existence of poorly ventilated areas, visible smoke can be released into the space. With the ventilation system operating, the movement of air and the dissipation of smoke can be studied and the air change rate estimated.

3.2 Measurement with tracer gas

By use of tracer gas it is possible to estimate air change rate and air distribution in chosen points in the ro-ro cargo space.

Measurement with tracer gas involves mixing a gaseous component with the air. The atmosphere in the space is examined to determine how dilution of the tracer gas is tracked at chosen points in the ro-ro cargo space whilst the ventilation system is operational.

This method should be carried out with and without vehicles.

3.2.1 Test procedures

The placing of the measurement probes should be chosen with regard to the purpose of the measurement. The probes are not to be placed near to the supply air terminal devices or at places where a so-called ventilation shadow can be expected, such as behind pillars, webs, etc. As a rule the probes are placed at the head height and in the vicinity of persons working on the deck.

The tracer gas should be spread and mixed in the air as completely as possible. The mixing may be done by the ordinary ventilation plant or with help of external fans. In order to reach an adequate accuracy, the concentration of the tracer gas ought to reach at least 50 times the detection limit of the analytical instrumentation.

When the tracer gas concentration is adequate the ventilation plant as well as the measurement equipment should be started. Tracer gas concentration should be recorded until the detection level is reached.

3.2.2 Calculation

With a dilution ventilation system the logarithm of the concentration of tracer gas will be linear with regard to time (see figure 1 below).

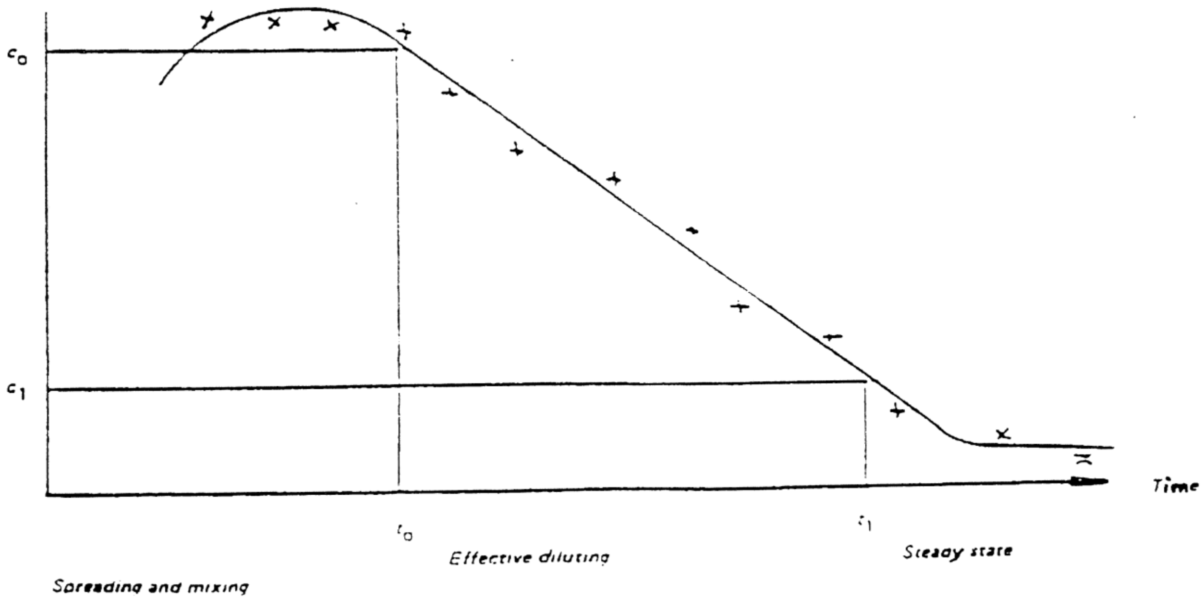

Figure 1 – The logarithm of the concentration of tracer gas

The relation between the concentration of tracer gas and time (the inclination of the graph) is a straight measure of the effect to the ventilation expressed in number of air changes according to the following formula:

$$N = \frac{ln\frac{c_0}{c_1}}{t_1 - t_0}$$

where

N = number of changes
c_0 = the concentration at the beginning of the effective dilution
c_1 = the concentration at the end of the effective dilution
t_0 = the point of time at the beginning of the effective dilution
t_1 = the point of time at the end of the effective dilution

3.3 Alternatives

As an alternative to the tests in paragraphs 3.1 and 3.2, air flow distribution in the ro-ro cargo space may be evaluated by use of an anemometer; or

The air flow can be determined by means of a calculation based methodology (such as Computational Fluid Dynamics and/or the use of established empiric formulae) to be accepted by the Administration.

4 Report

A written report should be provided containing the following information:

Ship's data	including, ship name, register, number, length, breadth, draught, GT, owner, shipyard, name of contractor carrying out the test.
Weather conditions	Wind speed and direction in general and in relation to the longitudinal of the ship during measurements.
Vehicle deck measurements	Deck length, breadth, height, and volume.
Ventilation	A plan of the deck indicating the location of supply and exhaust fans, together with information on grille surface area, design capacity and actual capacity of each unit. The use of additional air mixing equipment (e.g. dirivent) should also be noted. An indication of the status of all other openings to the deck during sampling should also be provided.
Activity	Details of loading and unloading should be included. These should comprise the time taken for each loading/unloading operation, the number of personnel working, the number and type of vehicles present.
Measurements	Time and date of the measurements Instrumentation Calibration Measurement procedure Sample locations Details of sample analysis
Results	Measurement results Calculation of occupational exposure

5 Conclusions/Recommendations

In addition to the statement of results the report should contain a plan of the ro-ro cargo space with supply air and exhaust air ducts shown. Where appropriate, the measurement points, type and number of vehicles, etc. should be indicated. Notes should be made regarding circumstances that affect the ventilation systems and/or air flow patterns on the deck.

When conducting a visual study with visible smoke, a detailed description of discharge and dissipation of the smoke as well as lapse of time should be given.

APPENDIX 3

RECOMMENDATIONS FOR THE EVALUATION OF AIR QUALITY IN RO-RO CARGO SPACES

1 General

Air quality testing should be planned and results evaluated by competent persons with specialist training in air quality evaluation and occupational exposure. Tests should be carried out in consultation with the ship's safety delegate and any other relevant authorities.

The duration of the tests will depend on the operating cycles and working practices on board the vessel. Monitoring should be carried out during several "normal" cycles, i.e. with representative vehicles, activities and ventilation practices.

Both short-term and long-term (over the working day) exposure to air pollutants should be investigated. Either static or personal samplers or ideally a combination of bath techniques should be used in order to provide the most accurate picture of contaminant concentrations and occupational exposure.

2 Air quality measurements

Air quality measurements should be representative of all exposed persons.

Pollutants

The concentrations of the following pollutants should be determined; nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO). In addition concentrations of benzene, toluene, xylene and suspended particulate matter (SPM) should also be determined whenever possible.

There are two general approaches to air quality sampling that can be adopted. Static site monitoring, typically involving continuous monitoring techniques and personal sampling which employs both passive and active methods. Static site monitoring usually includes the more accurate and sensitive techniques, but as the sampling site is fixed the measurements are not entirely representative of exposure. Personal samplers are worn by a representative sub-set of exposed individuals throughout the sampling period. Personal sampling techniques are not usually as sensitive or accurate. Ideally, personal sampling methods should be validated using more sophisticated techniques at regular intervals.

The following exemplary methods are recommended.

Static site monitoring

Pollutant:	Sampling and analysis method:
Nitrogen dioxide	Chemiluminescence, reagent tube, grab sampling/laboratory analysis
Nitric oxide	Chemiluminescence reagent tube, grab sampling/laboratory analysis
Carbon monoxide	Non-dispersive infra-red absorption, reagent tube, grab sampling/laboratory analysis

Benzene	Real time gas chromatography
Toluene	Real time gas chromatography
Xylene	Real time gas chromatography
Suspended particulates*	Dual beam radiation absorption, Tapered Element Oscillating Microbalance, gravimetric

* Suspended particulate matter can be sampled as total suspended particulate matter, PM10 respirable dust (≤ 5 μm).

Personal monitoring

Pollutant:	Sampling and analysis method:
Nitrogen dioxide	Passive (badge) sampler-ion chromatography
Nitric oxide	Electrochemical*
Carbon monoxide	Electrochemical*
Benzene	Passive badge sampler-gas chromatography/FID (Flame Ionization Detection)
Toluene	Passive badge sampler-gas chromatography/FID
Xylene	Passive badge sampler-gas chromatography/FID
Suspended particulates**	Personal sampler, gravimetric

* Electrochemical methods are susceptible to interference; therefore, it is recommended that these methods are regularly validated by intercomparison with other techniques in the test environment.

** Suspended particulate matter can be sampled as total suspended particulate matter or respirable dust (≤ 5 μm).

Supplementary measurements of local air velocity, temperature and relative humidity should also be undertaken.

3 Calculation of occupational exposure to air pollutants

Long-term Reference Period

The occupational exposure over a 24-hour period is determined by treating the cumulative exposure over 24 hours as equivalent to a single uniform exposure. This is generally converted to an 8-hour time-weighted average (TWA) exposure and is represented mathematically by:

$$\frac{C_1T_1 + C_2T_2 + \cdots . + C_nT_n}{8}$$

where C_n is the occupational exposure and T_n is the associated exposure time in hours in any 24-hour period.

Short-Term Reference Period

The short-term reference period generally relates to a period of 10 or 15 minutes, dependent upon the national occupational exposure standards. Exposure is therefore recorded as the average over a 10 or 15-minute reference period. Where the exposure period is less than 10 or 15 minutes, the measurement result is averaged over 10 or 15 minutes. Where the exposure period exceeds the short term reference period, results are averaged for the 10 or 15 minutes period during which maximum exposure occurs.

4 Report

A written report should be provided containing the following information: completed, taking into account paragraph 4 of appendix 2.

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