European Maritime Safety Agency

SAFETY OF AMMONIA FOR USE IN SHIPS

FINAL REPORT - CONCLUSION AND RECOMMENDATIONS

Rev. 1.2

Date: 02/12/2025

EMSA

About this study:

This report was commissioned by the European Maritime Safety Agency (EMSA) under Contract EMSA/OP/6/2023.

Authors:

Vassilis Zouzoulas (ABS), Spyros Hirdaris (ABS), Onur Semiz (ABS), René Sejer Laursen (ABS), Suzy Jiang (ABS), Kai Yu (ABS), Dafni Sofiadi (ABS), Nikolaos P. Ventikos (NTUA), Alexandros Michelis (NTUA), Vassilis Podimatas (NTUA), Panagiotis Tzanos (NTUA), Mar Vicente Lafuente (FVP)

EMSA Review Panel:

Lanfranco Benedetti (EMSA), Mónica Ramalho (EMSA) and Nicolas Charalambous (EMSA)

Acknowledgements:

The development of the various parts of this Study was supported by a group of experts. Special thanks for the contribution to:

- Yara Clean Ammonia (YCA)
- Puerto de Huelva (Port of Huelva)
- Everllence
- Babcock International Group
- Trelleborg
- WINGD
- LEWA
- Nikkiso Clean Energy & Industrial Gases (NIKKISO CEIG)
- Winterthur Gas & Diesel (WinGD)
- MARIC
- TGE Marine
- Cargill
- Færder Tankers
- Oldendorff Carriers
- Knud E Hansen A/S
- Wärtsilä
- DFDS S/A

Recommended citation:

European Maritime Safety Agency (2025), Study Investigating the Safety of Ammonia as Fuel on Ships Part 7 Guidance for Ships Using Ammonia as Marine Fuel EMSA, Lisbon

This report and any associated materials are available online at www.emsa.europa.eu

Document History

Version	Date	Changes	Prepared	Approved
1.0	12/11/2025	N/A	ABS, NTUA, FVP	
1.1	21/11/2025	Addressed comments	ABS, NTUA, FVP	EMSA
1.2	02/12/2025	Removing reference to the report of Part 6 in 1 and 4.1 which will not be published to avoid redundancy. Results are included in this final report.	EMSA	

Executive Summary

With ammonia-fuelled 2-stroke and 4-stroke propulsion engines, as well as genset engines, becoming commercially available, ammonia is gaining traction as a zero-carbon marine fuel with the potential to significantly advance the decarbonisation goals outlined in the 2023 International Maritime Organization (IMO) Green House Gas (GHG) reduction strategy. As a carbon-free substance, ammonia offers near-zero emissions on a tank-to-wake basis and, when produced sustainably, can achieve similar results on a well-to-wake basis. Ammonia can be stored as a liquid at moderate pressures or at -33°C. These conditions are far less demanding than the cryogenic requirements for Liquefied Natural Gas (LNG) or hydrogen. Thus, it could become a viable long-term solution. However, its adoption introduces substantial safety and operational challenges, including toxicity, corrosiveness, and the need for specialised fuel systems and engine designs. Addressing these risks through robust safety protocols, regulatory frameworks, and crew training is essential to ensure the safe and effective integration of ammonia into marine propulsion systems.

Although ammonia is widely produced and utilised across land-based industries as a fertiliser, refrigerant, and chemical feedstock, its application as a marine fuel remains largely uncharted. While ammonia is a chemical product manufactured globally at a large scale, its use for ship propulsion is still in the early phase, with technologies such as ammonia-fuelled internal combustion engines yet to be proven at scale. Nonetheless, the maritime sector has already placed orders[2] for ammonia-fuelled vessels, signaling strong interest in its decarbonisation potential. Importantly, the shipping industry benefits from decades of experience transporting ammonia as cargo aboard liquefied gas carriers, offering a valuable foundation for developing regulatory frameworks and safety protocols for its future use as marine fuel.

Lessons learned from land-based industries offer valuable insights for the maritime sector. A comprehensive review of industrial accidents revealed recurring high-risk patterns that can be applicable to maritime use of ammonia. Valve failures is a frequent cause of incidents, which in some cases may result in toxic dispersion, severe injuries, and environmental harm. Additional root cause include corrosion in pipes and equipment due to chemical exposure and poor maintenance. Design flaws, incorrect technical specifications, and human errors — such as misused alarms, improper procedures, and inadequate training — also contribute to operational hazards, with delayed emergency responses compounding the consequences. The work undertaken throughout this study demonstrates that qualitative and quantitative risk assessment methods may be considered appropriate for identifying system vulnerability and for suggesting appropriate mitigation strategies that safeguard safety in design and operations.

The development of ammonia as a marine fuel necessitates a reliability-based approach to identify and address high-level design and operational issues. Ensuring the safety of bunkering stations should be a high priority. Accordingly, the reliability study investigated: 1) the selection of critical equipment with a higher probability of failure or more severe consequences following failure, 2) the development of a list of top contributors and weak components within the system, and 3) how rational decision can benefit ship owners/operators. As applicable, findings are summarised in the format of a qualitative assessment of Fault Tree Analysis (FTA) diagram with cause-effect failure scenarios and a quantitative assessment of design life estimation by FTA commercial simulation tool that outputs a design-life comparison among systems, top contributors, and a what-if analysis for cost-benefit analysis.

The fuel supply system exhibits the shortest Mean Time To Failure (MTTF) at 9,406 hours, primarily due to its complexity and multiple failure modes, contributing to a higher overall failure rate. To mitigate these risks, efforts should focus on implementing control measures and on addressing design and operation weaknesses identified in the model (e.g. HP ammonia fuel pump leaking, damage of valve sealings/gaskets, no ammonia fuel to engine due to fuel filter blocked or MFV or DBBV position is incorrect, leakage in manual valves, emergency shutdown (ESD) valves, or non-return valves caused by incorrect gasket material selection, etc.). Similarly, the hydraulic and sealing oil systems have a short

[2] To date, according to Clarksons, there are 43 (ammonia) dual fuel vessels in the global orderbook. Most of them are gas carriers, bulk carriers, pure car carriers (PCCs) and tankers.

MTTF of 27,248 hours, driven by operational challenges in maintaining sealing oil pressure above ammonia fuel pressure and potential pump failures. The bunkering system follows with an MTTF of 35,537 hours, where design flaws such as gasket material selection errors can lead to valve leakage and fuel spills during bunkering. The reliquefaction system with an MTTF of 50,000 hours, is mainly limited by compressor design life. Although compressors are reliable for conventional fuels, ammonia fuel expects to use higher-speed compressors for cost benefits to process boil-off gas (BOG), increasing wear and reducing lifespan. To address these vulnerabilities, a What-if analysis was conducted to support design decisions, often serving as input for cost-benefit evaluations in new design processes.

To further assess the risks associated with the utilisation of ammonia as a marine fuel, a Hazard and Operability (HAZOP) operational analysis, accompanied by two Hazard Identification (HAZID) assessments, were conducted on three distinct types of vessels: a generic ship, a Mega Roll-on/Roll-off (Ro-Ro) vessel, and a bulk carrier. Each assessment considered various configurations of dual-fuel internal combustion engines (4-stroke and 2-stroke designs operating on Otto and Diesel cycles) alongside the concept design, layout, and arrangement of the associated ammonia fuel supply systems. The overarching conclusions of the risk assessment studies suggest that ammonia as fuel can be safely integrated in maritime operations; despite the safety challenges it presents being different from those related to LNG, liquefied petroleum gas (LPG), methanol and other conventional fuels.

The risk assessments also revealed that the IMO Interim Guidelines (MSC.1/Circ.1687) lack clear risk acceptance criteria for some key safety functions, such as ventilation system, hazardous area classification, fuel containment and fire & safety measures. This leads to inconsistent hazard control across ship designs. Bunkering operations and reliance on "*equivalent safety*" assessments without standardised risk thresholds introduce additional uncertainty. Interaction and overlaps with existing regulatory frameworks — including the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF), International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC) and International Convention for the Safety of Life at Sea (SOLAS), and existing legislation on occupational exposure limits — are also currently not fully addressed. Overall, the assessments highlighted the need to convert the Guidelines' functional objectives into prescriptive technical and operational standards to ensure consistent and demonstrable safety performance for ammonia-fuelled ships.

Based on the insights gained from these studies, a draft Guidance document was initially developed and circulated for external consultation with industry stakeholders. This Guidance builds upon the existing MSC.1/Circ.1687 and includes several proposed enhancements. Feedback collected through a survey and an online workshop has been integrated into the finalised document presented in Appendix A of this report. This feedback emphasises the necessity of a comprehensive understanding of ammonia's properties to effectively mitigate the safety risks associated with its use as a marine fuel.

Table of Contents

Executive Summary 4

1. Introduction 12

2. Parts 1 and 2 of the Study 13

2.1 Part 1: Properties, Regulations and Accident Review 13

2.2 Part 2: Safety Assessment and Reliability Analysis of Main Equipment, Equipment, Sub-systems, and Systems 15

3. Parts 3, 4 and 5 of the Study 23

3.1 Part 3 - Generic Ship Design 26

3.2 Part 4 - Bulk Carrier Ship Design 28

3.3 Part 5 - Ro-Ro Ship Design 31

4. Part 6 and Main Conclusions and Recommendations 33

4.1 Part 6 – Guidance for Ships Using Ammonia as Marine Fuel 33

4.2 Main Conclusions and Recommendations 35

5. Bibliography 37

Appendix A Updated Guidance 40

Appendix B List of Topics for Future Consideration 135

List of Tables

Table 1. Critical Equipment List Example 17

Table 2. Summary of Findings by Category 21

Table 3. Main Hazardous SIMOPS 29

List of Figures

Figure 1. Ammonia Fuelled Propulsion System Concept Drawing 17

Figure 2. Bunkering System Fault Tree Analysis (Phase I Quantitative Assessment) 18

List of Abbreviations

ABS	American Bureau of Shipping
AEGL	Acute exposure guideline levels
AIChE	American Institute of Chemical Engineers
ANSI	American National Standards Institute
API	American Petroleum Institute
ARMS	Ammonia Release Mitigation System
ASME	American Society of Mechanical Engineers
BOG	Boil Off Gas
CCC	Carriage of Cargoes and Containers Sub-Committee (IMO)
CCTV	Closed-Circuit Television
CFD	Computational Fluid Dynamics
CFR	US Code of Federal Regulations
CIRC	Circular
DBBV	Double Block and Bleed Valves
DF	Dual Fuel
DWT	Deadweight Tonnage
ECA	Engineering Critical Assessment
EEBD	Emergency Escape Breathing Devices
EMSA	European Maritime Safety Agency
ERC	Emergency Release Coupler
ERS	Emergency Release System
ESD	Emergency Shutdown
EU	European Union
FGSS	Fuel Gas Supply System
FL	Filling Limit
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effects and Criticality Analysis
FTA	Fault Tree Analysis
FVT	Fuel Valve Train
FVP	Fundación Valenciaport
GVT	Gas Valve Train
GVU	Gas Valve Unit

GHG	Green House Gas
HAZID	Hazard Identification Studies
HAZOP	Hazard and Operability Study
HFO	Heavy Fuel Oil
HP	High-Pressure
HSE	Health and Safety Executive
IACS	International Association of Classification Societies
ICE	Internal Combustion Engine
IEC	International Electrotechnical Commission
IDLH	Immediately Dangerous to Life or Health
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IMO)
IGF	International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IMO)
IMDG	International Maritime regulation for Dangerous Goods
IMO	International Maritime Organization
ISO	International Organization for Standardization
LEL	Lower Explosive Limit
LFL	Lower Flammability Limit
LL	Loading Limit
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LSA	Life-Saving Appliances
LTEL	Long Term Exposure Limit
MARPOL	International Convention for the Prevention of Pollution from Ships (IMO)
MARVS	Maximum Allowable Relief Valve Settings
MEPC	Marine Environment Protection Committee (IMO)
MFAG	Medical First Aid Guide
MGO	Marine Gas Oil
MSC	Maritime Safety Committee (IMO)
MTTF	Mean Time To Failure
NH3	Ammonia
NO2	Nitrogen Dioxide
NTUA	National Technical University of Athens

NUREG	Nuclear Regulatory Commission
N2	Nitrogen
N2O	Nitrous Oxide
OSHA	Occupational Safety and Health Administration
PCC	Pure Car Carrier
PPE	Personal Protective Equipment
PPM	Parts Per Million
PRV	Pressure Relief Valve
PWHT	Post Weld Heat Treatment
QA/QC	Quality Assurance / Quality Control
Ro-Ro	Roll-on/Roll-off
SCBA	Self-contained breathing apparatus
SCC	Stress Corrosion Cracking
SCR	Selective Catalytic Reduction
SGMF	Society for Gas as a Marine Fuel
SIGTTO	Society of International Tanker and Terminal Operators
SME	Subject Matter Expert
SIMOPS	Simultaneous Operations
SMS	Safety Management System
SOLAS	International Convention for the Safety of Life at Sea (IMO)
SOP	Standard Operating Procedure
SOPEP	Shipboard Oil Pollution Emergency Plan
STEL	Short-Term Exposure Limit
STS	Ship-to Ship
STCW	Standards of Training, Certification and Watchkeeping for seafarers
TCS	Tank Connection Spaces
UEL	Upper Explosive Limit
UI	Unified Interpretation
UN	United Nations
UR	Unified Requirement
VLCC	Very Large Crude Carrier
WRR	Windchill Risk and Reliability

1. Introduction

This report constitutes the final report of the EMSA Study "*Investigating the Safety of Ammonia as Fuel on Ships*" (hereinafter referred to as "*the Study*")

The Study, initiated in 2023, was designed to provide a comprehensive evaluation of the technical, operational, and safety implications of using ammonia as a marine fuel. The study has been carried out by the American Bureau of Shipping (ABS), the National Technical University of Athens (NTUA) and Fundación Valenciaport (FVP) and it has been structured into seven distinct parts, each addressing a critical aspect of the investigation:

- Part 1 - Ammonia Properties, Regulations and Accident Review: This section examined the fundamental physical and chemical properties of ammonia, reviews applicable international and national regulatory frameworks, and analysed historical accident data to identify lessons learned and potential hazards.
- Part 2 - Safety Assessment and Reliability Analysis of Main Components, Equipment, Sub-systems, and Systems: This part focused on evaluating the reliability and failure modes of key components and systems involved in ammonia fuel handling and utilisation, including valves, pumps, compressors, and associated safety devices.
- Part 3 - Risk Assessment of a Generic Ship Design: A baseline risk assessment conducted on a generic vessel configuration to establish reference safety considerations for ammonia fuel integration.
- Part 4 - Risk Assessment of a Bulk Carrier Ship Design: This section applied the risk assessment methodology to a bulk carrier design, identifying specific hazards and mitigation measures relevant to this vessel type.
- Part 5 - Risk Assessment of a Ro-Ro Ship Design: Similar to Part 4, this part evaluated the unique safety challenges and operational risks associated with ammonia fuel systems on Roll-on/Roll-off vessels.
- Part 6 - Guidance for Ships Using Ammonia as Marine Fuel: Based on findings from previous parts, this section provided a practical draft guidance and recommendations for ship designers, operators, and regulators to ensure safe implementation of ammonia as a marine fuel that was enhanced through stakeholder's consultation.
- Part 7 - Final Report, Conclusion and Recommendations: The current report consolidates all findings, presents overarching conclusions, and outlines strategic recommendations for industry stakeholders and regulatory bodies. Additionally, this report provides the updated guidance based on feedback from industry stakeholders.

This report is split in three main sections:

- Section 2 - Key findings and conclusions of Parts 1 and 2
- Section 3 - Key findings and conclusions of Parts 3,4 and 5
- Section 4 - Key findings and conclusions of Parts 6, including the final Guidance and the main conclusions and recommendation of the Study.

2. Parts 1 and 2 of the Study

2.1 Part 1: Properties, Regulations and Accident Review

The first part of the Study was important for understanding the specific hazards inherent to the nature of ammonia, how such hazards affect the ship and persons onboard, where the regulatory framework development stands and what gaps should be covered to contribute to the adoption of ammonia as a marine fuel.

Ammonia (NH_3) is a carbon-free molecule with a worldwide production exceeding 180 million tonnes per year, primarily used for fertilisers and industrial applications. Its use as a marine fuel leverages this existing infrastructure, but its intrinsic hazards present major operational and safety challenges.

From a physical standpoint, ammonia can be stored as a liquid either at low temperatures below –33.4 °C under atmospheric pressure or at ambient temperature (approximately 20–25 °C) under pressurised conditions of about 8–10 barg. Both storage modes carry risks. For example, low temperature storage conditions can increase system complexity and may lead to structural damage if inappropriate materials are selected. Pressurised storage increases the likelihood of high-energy jet releases in case of leaks.

A comprehensive analysis of ammonia's toxicological profile has been conducted, examining its occupational exposure thresholds and flammability characteristics. Together, these factors outline the primary safety challenges associated with its application as a marine fuel. Ammonia is a toxic substance, with acute health effects even at relatively low concentrations. Many regulatory frameworks set strict exposure limits: for example, the Occupational Safety and Health Administration (OSHA) specifies permissible exposure limits (PELs) as either 50 ppm for an 8-hour time-weighted average (TWA), or 35 ppm as a short-term exposure limit (STEL). Similarly, under EU REACH, the time-weighted average is set at 20 ppm (this is defined for an 8-hour period), and the short-term exposure limit at 50 ppm (for a 15-minute period). Furthermore, OSHA refers also that the concentrations of 300 ppm are classified as immediately dangerous to life and health (IDLH), while exposures above 5,000 ppm can rapidly become fatal. Ammonia’s strong odour could even be detected at concentrations as low as 2–5 ppm, which provides early warning of releases, although its reliability as a sole safety barrier is limited. This makes the definition of safe working conditions, adequate ventilation, and reliable monitoring systems critical for maritime applications.

Toxic area requirements are introduced into the International Maritime Organization (IMO) Interim Guidelines (MSC.1/Circ.1687)[3] and classification rules. However, actual toxic areas should be a result of ship specific gas dispersion analysis supported by relevant risk assessment covering several scenarios (e.g., discharges from the pressure relief valves protecting the tank containment system, discharges from secondary barriers around fuel tanks and discharges from secondary enclosures around ammonia leakage sources, etc.). By determining the toxic areas, the below could be verified:

- Ammonia gas does not reach air intakes, outlets and other openings into the accommodation, service and machinery spaces, control stations, the navigation bridge and other non-toxic areas/spaces in the ship.
- Lifesaving appliances (LSA), muster stations and escape routes are not located in toxic areas.[4]
- Decontamination showers and eyewash stations are appropriately positioned and accessible.[5]
- Gas detection requirements and sensors’ locations are adequately defined.
- Bunkering safety zones are properly established.
- Personal Protective Equipment (PPE) selection is made according to working area and exposure to ammonia.

[3] IMO Interim Guidelines were published following the publication of Part 1 of EMSA Study.

[4,5] It needs to be demonstrated that this equipment is not exposed to harmful concentration and thus available for access in a case of release.

Ammonia is flammable in air between 15% and 28% by volume, although its ignition energy is high compared to fuels like Liquefied Natural Gas (LNG) or hydrogen. While this reduces the probability of ignition, the risk cannot be neglected in enclosed or confined spaces where vapour accumulation is possible.

Ammonia's corrosive nature needs to be understood as it plays a critical role in its safety as a marine fuel. When exposed to water, ammonia forms ammonium hydroxide—a highly alkaline and corrosive solution that can cause chemical burns and damage to human tissue through skin contact, inhalation, or ingestion. This reaction also leads to stress corrosion cracking in metals, necessitating careful selection of materials and welding procedures. In humid environments, ammonia becomes significantly more reactive and is generating heat in reaction with water, improving the buoyance's of the ammonia vapour at the tip of the cloud. While water curtains may help to limit the dispersion of ammonia clouds, they may also generate corrosive products that require specialised collection systems to prevent secondary hazards.

Due to these risks, the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) mandates strict safety protocols for ships carrying ammonia. These include the use of corrosion-resistant materials, exclusion of copper, zinc, and their alloys from ammonia-exposed systems, and the installation of indirect gauging instruments. Emergency preparedness is also heightened, requiring gastight protective clothing, self-contained breathing apparatuses for escape, and decontamination showers operable in all conditions. Gas detection systems must be calibrated for ammonia's toxicity, and all safety measures must account for its corrosive behaviour and potential for stress corrosion cracking.

The review of accident databases such as eMARS, US OSHA, EPA, and HSE confirms the potential severity of ammonia releases. These accidents show some recurring patterns. Valve failures is a frequent cause of incidents and in some cases may result in toxic dispersion, severe injuries, and environmental harm. Additionally, corrosion in pipes and equipment due to chemical exposure and poor maintenance is considered frequent root cause. Design flaws, incorrect technical specifications, and human errors — such as misused alarms, improper procedures, and inadequate training — may also contribute to operational hazards, with delayed emergency responses compounding the consequences. Such scenarios could occur during bunkering operations, confined-space maintenance, or accidental system breaches. The risks may extend to human life, onboard systems, and the surrounding port community, underscoring the importance of integrated ship–port emergency coordination.

The review of PPE indicated that for emergency situations, Self-Contained Breathing Apparatus (SCBA) and chemical-resistant suits are mandatory. However, accident reports show that incorrect donning, limited visibility, and physical strains may reduce their effectiveness. Furthermore, medical emergencies linked to ammonia exposure may include acute respiratory distress, chemical burns, and eye injuries. Accordingly, ships and ports should be prepared with dedicated first aid and decontamination equipment. The determination of toxic areas is considered critical in terms of deciding what PPE will be used at different spaces and various types of operations involving ammonia onboard a ship. This is the reason why an approach with PPE layers has been introduced in various publications (e.g. SGMF,2023 and NTU,2022).

A review of the current onshore and offshore regulatory framework was also carried out. It is important to note that since the publication of Part 1 of the present Study, the IMO has made significant progress by issuing the Interim Guidelines on the Safety of Ships using Ammonia as Fuel (MSC.1/Circ.1687). These guidelines supplement the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) which provides a basis for alternative fuels but does not specifically cover ammonia. While other industrial standards, such as those from the International Organization for Standardization (ISO), the American Petroleum Institute (API) and the American Society of Mechanical Engineers (ASME), offer relevant guidance on ammonia handling, storage and compatibility of materials, their adaptation for maritime applications is still in progress. The IMO's Interim Guidelines currently lack clearly defined technical requirements for various ammonia related systems and operational aspects. These gaps may create significant barriers for the safe and efficient implementation of ammonia as marine fuel.

A detailed gap analysis as published in June 2024 can be found in Part 1 of this Study. While there are several industry publications on the safety of ammonia as marine fuel, future development of IMO guidelines should consider:

- **Definition and Specification of Ammonia Fuel.** Develop clear ammonia fuel definitions and specifications. Collaboration with ISO will be essential to establish standardised requirements.
- **Crew Safety Measures.** Establish safe, long-term exposure limits, PPE standards, and emergency response protocols specifically tailored to maritime operations.
- **Safety and Mitigation Measures for Bunkering Operations.** Define prescriptive requirements e.g. for emergency shutdown (ESD) systems, water mist systems, mechanical shielding, leak detection redundancies, and ventilation arrangements, while expanding bunkering safety protocols to include toxicity, spill control and firefighting requirements currently absent.
- **Integration of Ship and Port Interface.** Demonstrate compatibility of physical and operational interfaces between the port and the ship.
- **Ammonia Management When Overboard Discharge Is Prohibited.** Develop solutions for ammonia retention or treatment, including dedicated holding tanks and treatment systems.
- **Storage System Design.** While type C tanks can handle higher temperatures and pressures, storage in temperatures above -30°C is not endorsed by the Interim Guidelines. Approval remains subject to alternative design and arrangements by the relevant Administration.
- **Emergency Ventilation Requirements.** Introduce increased ventilation rates for enclosed toxic spaces in the event of gas detection.
- **Water-Based Safety Systems.** Define requirements for water mist or similar systems used to bind toxic ammonia gas during leaks.
- **Gas Dispersion Analysis and Risk Assessments.** Define quality requirements to the scope and methodology for dispersion modelling and risk assessment.
- **Material Guidelines.** Develop specific guidance for the use of non-metallic materials such as rubber for ammonia application.

2.2 Part 2: Safety Assessment and Reliability Analysis of Main Equipment, Equipment, Sub-systems, and Systems

The reliability of a system (in this case, an ammonia fuelled ship) is defined as the probability that the system will perform its intended functions adequately for a specified period of time under defined environmental condition without failure. The goal of the reliability study is to identify and better understand failures in order to address them and improve reliability. Moreover, the Fault Tree Analysis (FTA) results can serve as an input for cost-benefit analysis.

For the ammonia fuelled ship, knowledge was gathered from established industry best practices of other liquefied gaseous fuels, such as liquefied petroleum gas (LPG). However, ammonia's toxicity necessitates more stringent safety measures and careful engineering to prevent the release of hazardous vapours.

Furthermore, due to the lack of equipment data and testing, it is difficult to obtain an estimated ship life. When developing a new technology, it is necessary to use a logical structure approach to evaluate failure modes and improve reliability. To bridge the gap, FTA is utilised to identify failure modes, determine possible causes and estimate the probability of occurrence for each failure scenario. Through simulations, FTA highlights the weakest components and evaluates equipment redundancy against potential upgrade in ship's lifetime before construction.

The reliability assessment for an ammonia-fuelled vessel was carried out in two phases:

- **Phase I:** A qualitative assessment that identified potential failure scenarios for components critical to the vessel's operation (fault tree failure scenarios); and
- **Phase II:** A quantitative assessment that used simulation tools to evaluate how often each failure scenario occurs and pinpointed the weakest components of the system.

The following steps have been followed:

1. **Experts Workshop.** Industry Subject Matter Experts (SMEs) validated the components chosen for the FTA, organising them in a hierarchical structure. This is commonly referred to as the critical component list.

2. **Fault Tree Analysis.** Eight reliability models (FTA 1 to FTA 8) were developed after interviewing SMEs in ammonia fuel, engine makers, alternative fuel and bunkering equipment vendors, and ship experts. The interviews were constructed using information from LPG applications (Failure Mode and Effect Analysis (FMEA)) which has been adapted and modified as necessary for ammonia fuel applications.

   - FTA 1: Internal Combustion Engines (ICEs) / Ammonia Engine Fuel System
   - FTA 2: ICE / Engine Fuel Oil System
   - FTA 3: ICE / Common Engine Component
   - FTA 4: ICE / Engine Auxiliary Systems
   - FTA 5: ICE / Hydraulic and Sealing Oil Systems
   - FTA 6: Fuel Supply/Recirculation System6
   - FTA 7: Bunkering System
   - FTA 8: Reliquefaction Plant

   In each model, representing each system, a critical component list was used to build the failure scenarios.

3. **Simulation and Analysis**. Upon careful evaluation of the failure scenarios, the FTA models were transferred to the Windchill Risk and Reliability (WRR) simulation tool[7], using as an input the estimated probability of failure or lifetime for each failure scenario. Additionally, information on the equipment failure rates[8] or Mean Time To Failure (MTTF), human error probability[9] and other factors was adjusted for the ammonia fuel application. The tool then calculates the reliability curves and MTTF for the entire system as well as its subsystem.

Phase I Results Summary

In a team interview consisting of SMEs with knowledge on ammonia as fuel, engine makers, alternative fuel and bunkering equipment vendors, and ship experts, the team developed and reviewed a concept drawing (Figure 1) of the system where a critical equipment list example (Table 1) is derived from. Inputs are outlined in Figure 1 and Table 1. Failure scenarios are presented in the cause-and-effect diagram relationships outlined in Figure 2. The concept drawing depicts the ammonia fuel flow (supply and return lines) from ammonia tank, valves, pumps, filters, heaters, double block and bleed valves

[6] Fuel supply system includes ammonia fuel supply, pilot oil fuel supply, inert gas and venting and ventilation systems.
[7] PTC Windchill Enterprise Product Lifecycle Management Software/Quality Management/Risk and Reliability https://www.ptc.com/en
[8] Vendor's data together with iindustry consortium (OREDA) and American Institute of Chemical Engineers (AIChE) data have been used.
[9] Based on Nuclear Regulatory Commission (NUREG), the official designator for a series of reports produced by US Nuclear Commission (NRC).

(DBBV), flowing into engines, then vapour is collected by ammonia release mitigation system (ARMS) and deposited back to the buffer tank. Bunkering operation contains the ammonia fuel flow management consisting of bunkering manifold, ammonia tank, and a reliquefication plant.

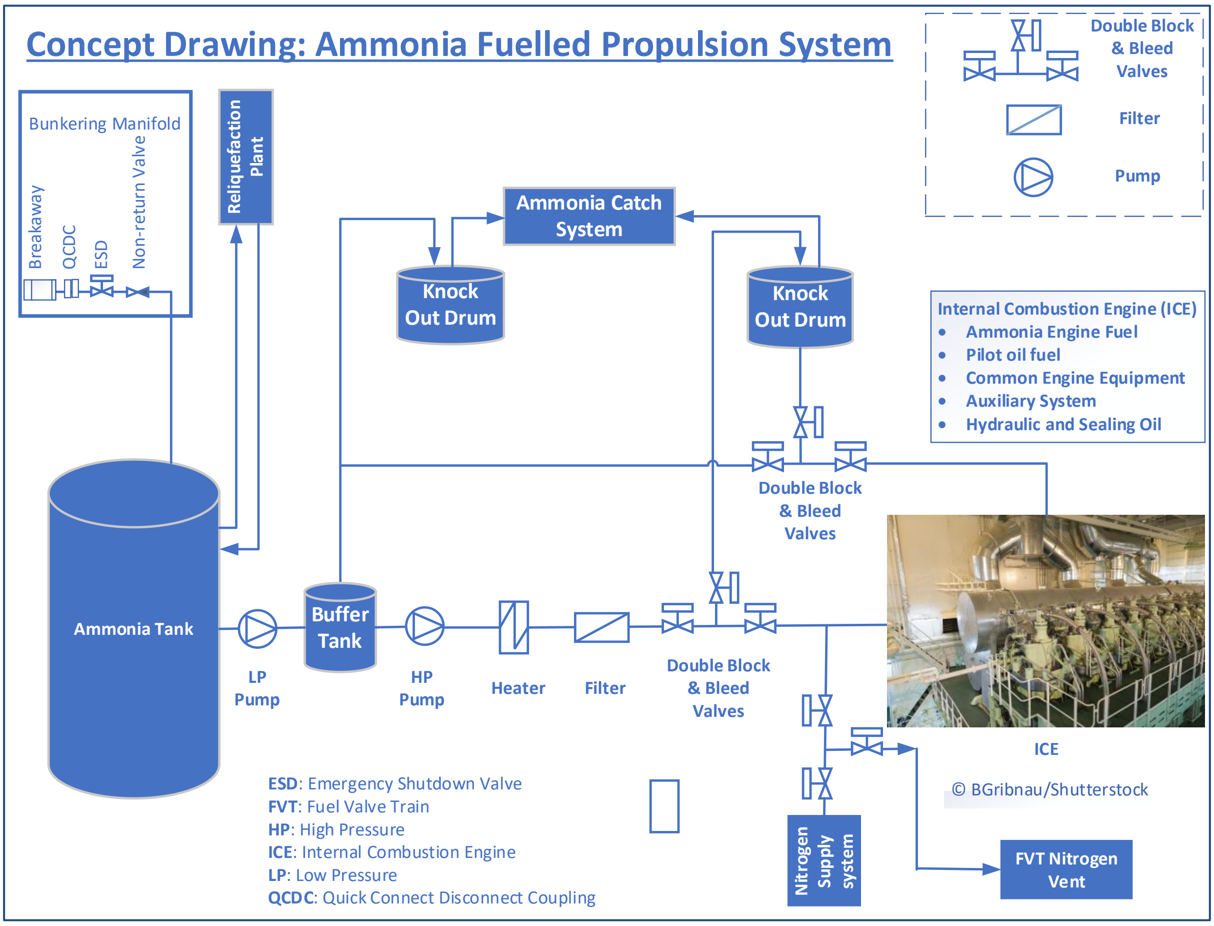

Figure 1. Ammonia Fuelled Propulsion System Concept Drawing

Table 1. Critical Equipment List Example

ICE	Critical Equipment	Example Failure Mode
Ammonia Fuel system on Engine	Ammonia Injector Valve	▪ Corrosion failure ▪ Cyclic fatigue failure
	Exhaust Valve	▪ Valve overheating
	Cylinder Cover	▪ Cylinder cover leaks due to corrosion
	Piston	▪ Piston jam breaks, not installed properly
	Piston Rings	▪ Wrong size installed ▪ New operator insufficient training ▪ Order wrong part
	Turbocharger	▪ Bearing housing overheating ▪ Turbocharger clearance between shaft and bearing out of spec

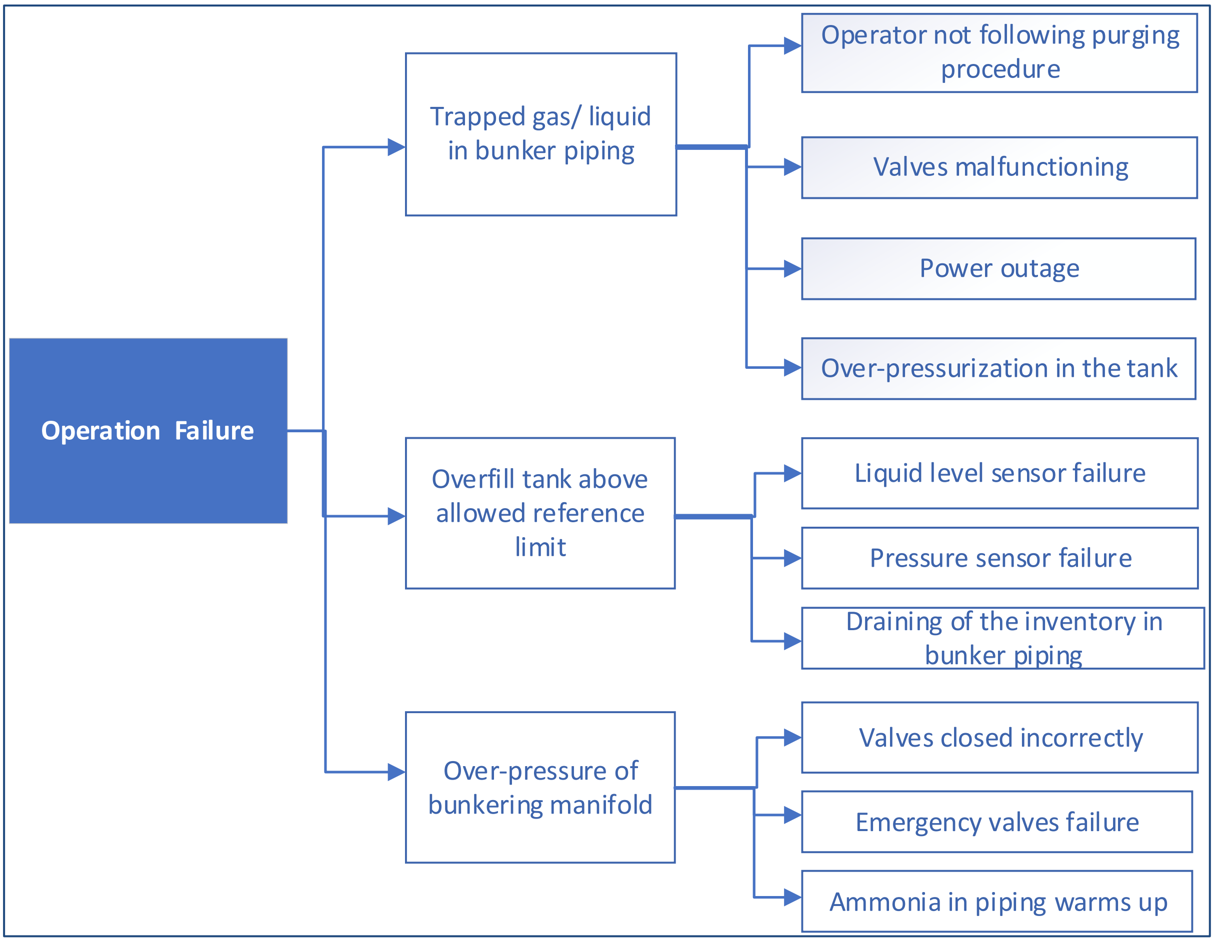

Figure 2. Bunkering System Fault Tree Analysis (Phase I Quantitative Assessment)

Phase II Results Summary

The reliability curve for the total system or subsystem is screened for weak component in the system (top contributors), which in turn can be used for decision-making on where to focus with regards to system reliability improvement. The reliability curve is the probability of a unit being operational when called upon as a function of time. It is an indicator of product reliability, which can also be expressed as MTTF or average design life. It is important to keep in mind that the estimated design life from the FTA is used to weed out the weakest component in the system, and the estimated numeric value does not equate to the actual operational hours.

Baseline Design Life Results

Design life estimations of the systems are summarised below. The ammonia-fuelled ship system design life has been estimated to 4,590 hours and analysed by 8 FTA models based on the hierarchy equipment structure. Out of the 8 subsystems, FTA 6 Fuel supply system has the shortest MTTF (9,406 hours) as it is a more complex system, which has multiple failure modes contributing to a higher failure rate. Effort should be taken to plan for control measures and improving design failures analysed in the model, such as Manual valve/ESD/Non return valve leaking due to incorrect gasket material selection risk. FTA 5, Hydraulic and sealing oil systems, has a shorter MTTF (27,248 hours) compared to other subsystems due to its complex operation to control sealing oil pressure higher than the ammonia fuel or pump failure. For instance, excessive vibration pump or overheated hydraulic oil can lead to pump bearing failure. Sealing oil failure cannot prevent ammonia backflow leading to ammonia contamination in the equipment. Ammonia contamination could be in sealing oil or hydraulic oil. FTA 7, Bunkering system, has a shorter MTTF (35,537 hours) compared to other subsystem due to design failure (such as incorrect material selection for solenoid-operated valves or ESD components). FTA 8, Reliquefaction system, has a shorter MTTF (50,000 hours) due to the high-speed type of compressor design life (particularly high-speed types prone to piston rod deformation and crank gear vibration issues) that requires further root cause analysis.

Top Contributors Results

Top contributors to the weakness of the systems are summarised below:

FTA 1-5: Internal Combustion Engines (ICEs)

- Ammonia injector design
- Valve spring life (jammed spring cannot fully open injector valve)
- Spring failure in booster injector hydraulic
- Fuel injector corrosion risk
- Booster injection valve failure
- Incorrect piston ring material property
- Incomplete combustion process (incorrect autofrettage process)
- Ammonia injector valve fatigue life

FTA 6: Fuel Supply/Recirculation System

- Insufficient vibration design of ammonia components leading to exceeded fatigue load
- Leak of valve components, filters, sealing, gaskets
- Operational failures
- Human related errors - operator not following procedures, PM missed, installation errors, etc.
- Ammonia contamination issues
- Ammonia leaking issues to engine room, ammonia catch system, equipment
- Ammonia entrapped in piping issues
- Insufficient purging length issue
- Clogging of nitrogen filters
- Ventilation flow is too low

FTA 7: Bunkering System

- Overfill tank above allowed reference limit
- Over-pressurisation of bunkering manifold
- Quick release coupling/flange/leak in Emergency Release Coupling (ERC)
- Manual/Emergency Shutdown (ESD) valve/non-return valve leaking
- Bunker hose leaking/pin hole

FTA 8: Reliquefaction Plant

- Liquid separator leaking ammonia
- Ammonia fuel tank overpressure
- Leaking ammonia in the compressor room via sealing/pipe connection
- Excessive vibration level on ammonia reliquefaction compressor crank gear
- Ammonia relique compressor piston seizure
- Low-pressure ammonia pump failure due to suction of contaminated ammonia
- Condenser leaking failure

Sensitivity Analysis Results

The model can be further used to perform sensitivity analyses, also termed as what-if scenarios. If a particular reliability issue (e.g., failure scenarios in component design such as in ammonia pump sealing and membrane) leads to the weakest components, a sensitivity analysis is carried out to investigate how much the system's (e.g., fuel supply system's) MTTF would change if the component's MTTF were to double or triple. Another sensitivity analysis evaluation investigates how much the fuel supply system's MTTF would increase if two or three ammonia pumps are configured in the redundancy.

The following sensitivity analyses for the ammonia-fuelled propulsion system have been conducted to demonstrate the change in MTTF when the operation mode changes, or equipment configuration is modified:

Engine Fuel System (FTA 1 & FTA 2 Model)

Failure in the ammonia fuel system leads to a stop of ammonia operation and to changeover to diesel mode for seamless operations. This is modelled as redundancy in the engine fuel system.

1. Dual Fuel Redundancy Concept Design: MTTF = 4,590 hours for ammonia-fuelled propulsion system.

   If the ammonia fuel engine system fails, the propulsion system can continue its operation and switch over to diesel mode. In this case, the operation is not interrupted, and the mission reliability[5] is met.

2. Ammonia Fuel Engine Design Without Redundancy Design: MTTF = 3,822 hours for ammonia-fuelled propulsion system.

   Either the ammonia fuel engine or diesel fuel engine system fails, it will interrupt the operation. Therefore, MTTF is expected to be shorter than dual fuel redundancy concept design.

FTA 6, FTA 7 and FTA 8 have been selected to further use for sensitivity analyses. Collaboration has been made with ammonia equipment vendors[10] to provide equipment MTTF for the fuel supply system, bunkering system and reliquefaction plant. MTTF came from another ammonia project that is confidential with the original data source published by AIChE[11]. The MTTF information provided has been used to investigate its reliability improvement margin when integrated into the propulsion system. This methodology is intended for the use of ship owners and operators to assist in making a decision based on reliability data even in the early stage of design.

Fuel Supply/Recirculation System (FTA 6 Model)

1. Rotating equipment pumps motor driven pressure centrifugal MTTF = 8,000 hours vs. Redundancy Multiple Pumps.

   Results indicate that redundancy design does not significantly improve fuel supply system reliability. If there is an increasing number of pump failures, a re-design using a root cause analysis may be necessary.

2. Mechanical seals in pumps MTTF = 25,000 hours vs. 50,000 hours.

   Results indicate that the improvement of mechanical seals increased the fuel supply system life from 6,834 to 7,916 hours. If the fuel pump seal failure is trending upwards during operations, this information can be used for seal upgrade evaluation.

3. Protection systems relief valve spring loaded MTTF = 595,238 hours - Not selected

Bunkering System (FTA 7 Model)

1. Solenoid valve not open or close on demand MTTF = 20,000 hours vs. 40,000 hours.

[10] Lewa GmbH, Trelleborg Westbury Limited, Babcock International Limited.
[11] Guidelines for Process Equipment Reliability Data with Data Tables published by American Institute of Chemical Engineers (AIChE).

Results indicate an improvement in bunkering system reliability when a solenoid valve increases its design life. If valve failure is an issue, replacement with an upgraded valve can be considered to improve the bunkering system's reliability.

2. Quick release coupling or ERC (Emergency release coupling) MTTF = 992,000 hours - Not selected
3. Bunker hose MTTF = 1,754,386 hours – Not selected

Reliquefaction Plant (FTA 8 Model)

1. Compressor MTTF = 700 hours (Single vs. Redundancy Multiple Compressors)

Results indicate that the use of a high-speed type of ammonia reliquefaction compressor is a potential risk for the reliquefaction plant system to address. Field development data received in the industry suggests that providing a reliable operation requires handling the ammonia vapour and sending it back to the ammonia tank. Therefore, efforts to improve the compressor's life are necessary. For the case of compressor MTTF = 700 hours, a redundancy design does not provide enough reliability for the reliquefaction operations.

Recommendations and Future Work

Fault Tree Analysis (FTA) is developed based on the four project lifecycles and provides guidance on which control measures are effective in mitigating the potential failure modes. The examples provided should be understood as a general assessment and guidance on how to use the FTA information.

The failure modes have been categorised by the product lifecycle in Table 2, which indicates how these failures can be mitigated in the following paragraphs. For example, mitigating design failures involves design calculation, while installation failure requires procedure development to control human error. The Table shows that more than half of the identified failures occur during the operation phase. However, design failure takes up about a quarter of the failures where its consequence is usually much higher and therefore should not be underestimated. For instance, the ammonia reliquefaction compressor, if not designed properly, may experience piston rod deformation, which could lead to piston seizure and, consequently, compressor shutdown.

Table 2. Summary of Findings by Category

	Number of Findings	Percentage
Design	33	23%
Manufacturing	18	13%
Installation	18	13%
Operations	74	52%

Design Failure

Generally, failure modes in the design phase involve analytical design calculations with safety factors. For instance, ammonia fuel injector design intended to meet the ammonia injection requirements (heat shield spacing, injector geometry) is based on the design for reliability approach. Testing will be conducted to evaluate the ammonia fuel injector design. When test data becomes available, FTA 1 model needs to be updated accordingly. Another example is ammonia reliquefaction compressor, which is designed for high-speed operation exceeding 1000rpm; such a compressor may experience excessive vibration that could lead to loosened screws or joint connections, ultimately causing piston rod deformation due to excessive heat impact. When a root cause analysis is conducted, corrective actions are proposed for the change of design, procedures, or adding marking for proof installation. In a period of time, monitor the effectiveness of the proposed changes. The recommendation is to maintain close collaboration with OEM vendors on the identified design issues to support the update of the FTA assessment.

Manufacturing Defects

Failure modes in the manufacturing phase are mainly related to production defects that may not be the major concern. However, human involvement in manufacturing processes, such as heat treatment, welding, assembly, etc., requires the use of well-defined standard operating procedures to ensure the manufacturing reliability of critical components. Currently, there are no specific manufacturing defects identified for components of the ammonia fuel system. The main manufacturing challenges come from the development of the new equipment, where precise control of the manufacturing process parameters is critical, such as in the case of the HP ammonia fuel pump (in which the PTFE diaphragm is replaced every 12,000 operating hours).

Installation Failure

Failure mode in the installation phase is primarily driven by human error. For every installation, it is important to have the installation procedure in place and the operator properly trained to follow it. The human error probability is relatively high compared to other failure modes, as it involves many human factors, such as psychological, mental, mental, fatigue, procedural adherence, etc. For instance, common installation failures include incorrect installation of gaskets, inner pipe, or outer pipe in the fuel supply system, failure to follow the ammonia fuel injector installation procedure, and damage to the seal between the sealing oil and outer pipe.

Operations Failure

Operations failure rate exhibits a more dynamic pattern where the operating profile requirement changes, resulting in more room for error. Operating hydraulic and sealing oil, fuel supply system, bunkering system, and reliquefaction plant is dynamic due to multiple challenges faced in operating a ship, such as potential improper maintenance and inspection, equipment degradation challenges, operator not following procedure, skipped planned maintenance, overstressing the equipment, ammonia contamination issue in the equipment, valve malfunctioning, ammonia reliquefaction compressor and HP fuel pump reliability issues, ARMS leaking (ammonia release mitigation system, e.g., Knock Out drum, ammonia catching system), etc. Maintenance strategy and sparing analysis are important to minimise the equipment downtime and maintenance cost during the operational phase.

Note - FTA for Other Alternative Fuels

FTA assessment for other alternative fuels should be evaluated case by case. There are similarities and differences for other alternative fuels, such as LPG, LNG or methanol. The ammonia fuel study has taken LPG FMECA study as an input and modified to fit ammonia application. In general, it has similarities due to the common equipment onboard the ship. However, due to material properties and operational profile, it may yield a different component design life among the different fuels. Aside from that one of the main differences is the ammonia catch system that is driven by regulatory requirement and safety concern from ammonia toxicity. Future recommendation is to use the ammonia fuel FTA models and follow the FTA process to revise for other alternative fuels. In addition, as future work concerning design details and operational testing data become available, the FTA model should be updated.

3. Parts 3, 4 and 5 of the Study

Ammonia presents a compelling alternative as a marine fuel, owing to its energy content and potential to reduce greenhouse gas emissions, especially when its production is carbon-free. Current extensive experience gained from various sectors, along with the maritime transportation of ammonia, constitutes a good technical basis for enhancing its practical application in marine fuelling. However, the utilisation of ammonia necessitates a comprehensive risk assessment framework, as it introduces unique safety challenges that differ markedly from those associated with conventional fuels, particularly due to its toxic and corrosive properties.

To effectively address these safety challenges, assessments have concentrated on identifying and analysing the hazards and potential consequences linked to the storage, handling, transportation, and application of ammonia as a marine fuel on board vessels. This includes an acknowledgment of requisite risk mitigation strategies and measures. The risk assessments are based on the rapid implementation of essential technical solutions across several new deep-sea vessels currently on order, the initiation of ammonia internal combustion engines type testing and usage demonstrations, and the development of training programs for qualified crew members across various vessel types. It should be noted that hazards and operability issues arising from the manufacturing, installation, construction, commissioning, or decommissioning phases of the ammonia fuel supply system would be addressed and managed by the safety management system of the shipyard, as well as the procedures set forth by the vendors. Additionally, this analysis did not include hazards and operability challenges associated with typical hull and marine systems, such as ballast water systems and diesel oil systems, as these are not connected to the ammonia fuel supply system. It was further assumed that such hazards would be managed by operators in accordance with relevant regulations, including those of the Flag State, guidelines established by the IMO, and the requirements set forth by classification societies.

The risk assessment workshops that were carried out for the use of ammonia as a marine fuel, provided a comprehensive understanding of the safety challenges and critical considerations associated with its adoption. Through one Hazard and Operability (HAZOP) and two Hazard Identification (HAZID) studies applied respectively to a generic vessel, a bulk carrier, and a Roll-on/Roll-off (Ro-Ro) ship, a wide range of scenarios were systematically identified, analysed, and ranked. These assessments not only quantified the risk landscape of ammonia fuel systems but also highlighted recurring technical, operational, and human-factor issues that demand targeted mitigation.

The conclusions presented below synthesise the findings from all three assessments and intended to provide evidence-based insights for the development of enhanced guidelines that build upon and expand the IMO Interim Guidelines for ammonia as fuel.

Fundamental Safety Challenges of Ammonia

- Flammability, toxicity and corrosivity. While flammability is a bigger concern for LNG and conventional fuels, toxicity and corrosivity can introduce additional hazards for ammonia as marine fuel.
- System integrity and leak prevention are paramount: double barriers, welded connections, minimised piping runs, and robust detection/ventilation are essential.
- Redundancy in monitoring and alarms is critical, especially for leak detection and oxygen monitoring in confined spaces.
- Design and operations must adopt a risk-based philosophy that goes beyond the IMO Interim Guidelines (MSC.1/Circ.1687).

Fuel Storage and Containment

- Continuous temperature control and insulation of tanks are required, with strict filling limits (95%).
- Tank Connection Spaces (TCS) must be designed for safe access, maintenance, and emergency intervention.

- PSV venting and dispersion present significant hazards: vent mast design and toxic zone analysis are essential.
- Welded connections are preferred inside TCS; purging and gas-freeing procedures must be robust.
- Vapour/catch tanks must be adequately sized to avoid toxic exceedances at vent outlets.

Piping, Valves, and Mechanical Systems

- Spray shielding and dropped-object protection must be applied throughout bunkering and piping systems.
- Stress and vibration analyses are required to prevent fatigue-related failures.
- Redundancy and clear valve position indicators are essential to avoid human error.
- Non-return valves and double block & bleed arrangements must be strategically applied, especially in purging and safety-critical lines.

Bunkering Operations

- Bunkering is a high-risk activity, especially in Simultaneous Operations (SIMOPS) contexts.
- Required safeguards include dry disconnect and emergency release couplings, clear standard operating procedures (SOPs), piping diagrams, and valve tagging, continuous monitoring of bunkering zones, and defined SIMOPS protocols.
- Ammonia's lower energy density implies more frequent bunkering. Exposure must be mitigated by larger tanks, optimised schedules, and enhanced safeguards.

Ventilation & Gas Detection

- Tiered gas detection (25 / 110 / 220 ppm) with linked safety actions is required.
- Ventilation design must ensure dilution below toxic thresholds in all spaces, including TCS, engine rooms, and exhaust casings.
- Computational Fluid Dynamics (CFD) and dispersion studies confirm that local concentration peaks can persist; ventilation strategies and detector placement must be validated accordingly.
- Portable or directed ventilation units may be needed during emergencies.

Emergency Preparedness & Crew Protection

- Safe havens, muster stations, and escape routes must be located outside potential toxic zones and validated with dispersion analyses.
- At least one uncontaminated escape route to a safe haven must be maintained under worst-case scenarios.
- Emergency drainage, bilge, and firefighting systems must be designed to handle ammonia contamination and avoid environmental release.
- PPE requirements must reflect ammonia's toxic/asphyxiating risks; portable oxygen detectors to be used.
- Training of crew, port, and terminal personnel on ammonia-specific hazards and first response is critical.

Control, Automation & Cybersecurity

- Control systems must include fail-safe positions, redundancy, and local manual override in case of automation failure.
- Clear control logic for pump redundancy, valve failure, and ESD activation is required.
- Cybersecurity must comply with IMO, IACS, ISO/IEC 27001, IEC 62443 standards.
- Remote support must be controlled, secure, and compliant with operator policies.

Human Factors & Operational Procedures

- Crew exposure to ammonia toxicity is the principal human risk; design and procedures must minimise time spent in hazardous areas.
- SOPs must explicitly address bunkering, purging, venting, maintenance, and SIMOPS activities.

- Material handling, critical spare parts management, and preventive maintenance must be clearly defined.
- Human reliability concerns (misalignment of valves, misinterpretation of alarms, maintenance errors) require systematic safeguards.

Taken together, the outcomes of the HAZOP and HAZID studies underscored both the feasibility and the additional challenges of integrating ammonia as a marine fuel. While the analyses confirmed that effective design and operational measures can reduce risks to acceptable levels, they also demonstrated that ammonia cannot be safely managed by applying LNG-based practices alone. Dedicated ammonia-specific safeguards are essential across design, operations, emergency preparedness, and crew protection. These consolidated conclusions therefore provided a practical foundation for supporting the development of enhanced guidelines that complemented and extended the IMO Interim Guidelines, ensuring that ammonia can be adopted in a safe, reliable, and sustainable manner within the maritime sector.

Gas Dispersion Analysis: Methodologies and Tools

The loss of containment and the resulting rapid dispersion of toxic vapours or gases can create life-threatening situations. Thus, conducting gas dispersion analysis together with risk assessment is essential in assessing the risks associated with the design of ships transporting ammonia fuel for propulsion. The primary outputs of dispersion analyses are typically toxic gas clouds. Consequently, gas dispersion modelling is employed to evaluate whether toxic gases could reach concentrations at exposure durations that might lead to severe exposure or fatality.

To that extent, gas dispersion analysis is needed to quantitatively define the level and scope of ammonia gas risks for different failure modes such as accidental leakage from the bunkering station during ship-to-ship bunkering, ammonia release from the vent mast, and accidental releases of ammonia in the engine room. The results of the gas dispersion analysis are often used as part of a risk assessment to quantify certain risks. Where the consequences are found to be unacceptable, redesign or mitigation measures are needed. Gas dispersion analysis will also help define safety zones for bunkering operations or gas releases from vent masts.

There are various choices for gas dispersion analysis tools, which are based on methodologies of different levels of fidelity. The software packages such as ALOHA, PHAST, and FLACS-CFD reviewed under the present project have increasing levels of fidelity (i.e., from 2D to 3D, from trajectory tracing to domain-based framework). At the same time, the level of geometrical complexity that the software can handle is also increasing. The computational speed, on the other hand, decreases. Fully 3D, Navier-Stokes based CFD has the highest fidelity and highest flexibility in predicting gas plume interactions with complex surrounding structures or even terrains. Those CFD models are built upon first principles, which means they do not need to rely on theoretical models or empirical relations. The high-fidelity CFD also has the potential to add complexities to the existing setup, such as phase change, mixing of substances, handling multiple releases or non-point source releases, and the modelling of mitigation process such as water curtains. Common all-purpose CFD packages can be used for this level of fidelity, such as OpenFOAM, Star-CCM+, and Fluent. For any CFD modelling using all-purpose codes, time step and grid size convergence tests are always recommended. In general, CFD models should be validated against experimental data or other trusted data sources before application.

Although a standard or guideline for dispersion analysis is still lacking and would be highly beneficial, the key lessons learned from this study are as follows:

Engine room

- A ventilation inlet and outlet should be included in the engine room. And the ventilation rate (air change rate) should be provided.
- Turbocharger is using air and buoyance's driven flow generated by the warm engine.
- Gensets and exhaust pipe need to be included in the analysis.
- Leak rate, leak location and shut-off time are critical factors in the event of accidental leakage.

Open air dispersion

- The worst scenario occurs during nighttime with no wind—when temperatures drop and humidity rises, causing ammonia to settle near the ground instead of dispersing upward.
- To assess ammonia concentration levels at designated target areas, such as accommodation spaces, wind direction, vessel heading and the leak location should be provided for the simulations.

3.1 Part 3 - Generic Ship Design

Understanding the properties of ammonia gas is essential for minimizing safety risks associated with its use as a fuel for marine engines. This includes recognizing the requirements for low-temperature conditions, the need for pressurised storage tanks, and the management of flammable gases. Additionally, it's important to consider the corrosive and toxic properties of ammonia, as well as the challenges in effectively handling unburned ammonia. Part 3 seeks to provide additional insights into ammonia safety, focusing on perspectives that enhance those mentioned in Part 2.

The report is divided into three main sections:

- A HAZOP Analysis of an ammonia FGSS.
- An assessment of risks from the perspective of ports, including considerations for SIMOPS.
- Modelling the potential consequences in the event of an ammonia leak.

<u>HAZOP Analysis</u>

In this Study, the HAZOP (Hazard and Operability) analysis focused on identifying potential hazards and operational concerns associated with the standard operational phases of an ammonia fuel supply system developed by NIKKISO CEIG. This system is specifically designed for the WINGD X52DF-A dual-fuel engine, which is intended for installation in a generic Very Large Crude Carrier (VLCC).

The systems analysed include the bunkering stations, the low-pressure system that extends from the bunkering tanks up to, but not including, the high-pressure (HP) system, the transfer of ammonia to the main engine via the HP system, the return of ammonia from the main engine, the handling system for boil-off gas, the glycol water system, and the nitrogen (N2) supply system. The following conclusions have been established:

- Insufficient design may lead to significant risks associated with direct ammonia exposure, necessitating the implementation of rigorous safety measures to effectively manage and control potential releases.
- The safe integration of ammonia fuel technologies on vessels affects ship arrangements and fuel supply system configurations, often necessitating modifications to existing design solutions, which were primarily developed for LNG-powered vessels.
- Establishing a close collaboration among the classification society, engine manufacturer, fuel supply system provider, and shipyard is essential to apply the IMO Alternative Design Approval procedure effectively.
- A wide variety of engine types and power options should be readily available for the relevant segments of the shipping industry.
- It is imperative to validate the compatibility of ammonia engine technologies and their corresponding fuel systems prior to implementation onboard.
- The classification rules and guidelines, along with the IMO Interim Guidelines, offer crucial guidance to designers and shipyards, facilitating the development of new designs of ammonia fuelled ships while substantially minimizing the risks.

Port Risk Assessment Approach

The focus of the port risk assessment was to identify the hazards associated with SIMOPS. That is, situations where two or more operations or activities occur in proximity in terms of time and space. Primarily, the SIMOPS study addressed vessels during their port stay and conducts a risk analysis of port operations that could be impacted using ammonia as a fuel for vessels. To accomplish this, hazardous locations were identified, such as ammonia storage areas, loading/unloading zones, bunkering facilities etc. This facilitated the SIMOPS to be identified, covering ammonia bunkering while boarding of crew, ammonia handling alongside heavy cargo lifting or crane operations, simultaneous maintenance of ammonia tanks and vessel operations, and ammonia bunkering in conjunction with tugboat operations. Once risks are identified, their impact can be assessed, and the probability of their occurrence can be established. Subsequently, a consequence analysis was performed to evaluate the potential outcomes associated with the identified risks. In response, control and mitigation measures are developed and implemented to address any adverse effects.

Consequence Modelling

CFD Modelling

The simulations presented are sample case studies and they are not modelling of the NIKKISO CEIG and WinGD ammonia FGSS but are modelled on a typical set-up. The CFD simulations of ammonia dispersion were conducted for both open-air and enclosed-space release scenarios, using a pure gas modelling approach that incorporated buoyancy effects, species transport, and transient flow resolution. The simulations revealed distinct hazard profiles for different scenarios.

In open-air releases (e.g., ship-to-ship bunkering of Ammonia at a port, Ammonia release from a vent mast), the ammonia plume initially behaved as a cold, dense gas, remaining close to the ground before warming and dispersing downwind. Under low wind speeds and stable atmospheric conditions, elevated concentrations persisted longer and extended farther, with the 25-ppm threshold reached well beyond the immediate release zone[12]. Higher wind speeds reduced persistence but increased the initial footprint.
In enclosed environments, such as the engine room, ammonia accumulated rapidly, with concentrations exceeding 160 ppm (Acute exposure guideline levels AEGL2) and 1,000 ppm (AEGL3) across much of the space within seconds. Clearance times were significantly longer than in open air, with pockets of high concentration persisting despite ventilation.

Overall, the results demonstrate that ammonia dispersion hazards are highly scenario dependent. Open-air releases present acute but transient risks, whereas confined-space releases can sustain hazardous concentrations for extended periods. Ventilation effectiveness is the dominant factor in enclosed-space hazard mitigation. Meteorological variability, such as wind speed, direction, significantly influences open-air dispersion and should be incorporated into safety assessments. The pure gas modelling approach adopted here is conservative, likely overestimating nearfield vapour concentrations by neglecting aerosol rainout, but provides a defensible basis for emergency planning. Detector placement strategies should account for both probable plume paths and potential stagnant zones to ensure timely hazard detection.

[12] Immediate zone means a high ammonia concentration zone near the leak point. Immediate actions are crucial to ensure safety and minimize the impact of the ammonia leak. According to EU standards, an ammonia concentration of 25 ppm is considered the permissible exposure limit (PEL) for human safety. Areas with ammonia levels below this threshold can be designated as safe zones.

3.2 Part 4 - Bulk Carrier Ship Design

MARIC developed a Newcastlemax Bulk Carrier design with a deadweight tonnage (DWT) of 210,000 which incorporates Type C ammonia storage tanks, in addition to tanks designated for heavy fuel oil (HFO) and marine gas oil (MGO). To mitigate boil-off gas (BOG), a reliquefaction system will be installed, and ammonia venting will be strictly limited to emergency scenarios, such as instances of overpressure resulting from fire or malfunctions within the system. Releases occurring during standard operations will be tightly controlled to maintain ammonia concentrations within established safety thresholds. Furthermore, an ammonia catching system will be integrated into the design. A nitrogen-based inerting system will also be implemented to facilitate purging operations and to safely isolate the engine system during periods of shutdown or maintenance.

The engine room will be designed as per the "*gas-safe machinery spaces" principle* as introduced in the IGF Code paragraph 5.4.1.1, allowing for standard maintenance activities. In the event of a significant ammonia leak, the deckhouse will serve as the primary safe area, with the ventilation inlet situated away from any toxic zones. Further details regarding bunkering procedures, crew protection, and simultaneous operations will be discussed and finalised at a later stage of the design process.

The Ammonia FGSS, developed by TGE in alignment with WINGD specifications, will provide a dual-fuel, two-stroke X-DF-A dual-fuel main engine capable of operating on both liquid ammonia and conventional fuel oils. Noteworthy features of this system include electronically controlled ammonia injection, an advanced remote intelligent monitoring system fault detection and safety system with alarms and automated shutdown responses, and full compliance with the IGF and IGC Codes. Redundancy for both propulsion and power generation will be ensured by the capability to utilise fuel oil in the event of an ammonia fuel supply interruption.

This segment of the Study comprised two principal components:

- A HAZID assessment of the Newcastlemax Bulk Carrier design and
- A SIMOPS assessment

<u>HAZID Assessment</u>

In this study, the HAZID focused on identifying potential hazards and operational concerns associated with the design and the configuration of an ammonia fuel supply system. In relation to the ship design under consideration and the associated ammonia FGSS analysis, the following conclusions have been established:

- Operational complexity during the bunkering process presents a significant safety concern, particularly when combined with concurrent activities. Therefore, SIMOPS involving ammonia bunkering alongside cargo operations should be carefully restricted or gradually phased in, particularly during the initial adoption phase of ammonia-fuelled vessels.
- Conservative operational strategies are advisable during this initial deployment phase. For instance, operating ICE generators on MGO while at port or anchorage is recommended, even in the presence of technically available ammonia. This approach reflects a risk-averse strategy that prioritises safety over the flexibility of fuel switching.
- The interactions between ammonia and cargo environments warrant enhanced scrutiny, particularly concerning chemical compatibility and potential dust interference. These factors may compromise bunkering safety, the reliability of gas detection systems, and the overall performance of equipment.
- Adaptations in ship layout and emergency preparedness are essential to address ammonia-specific hazards. A requirement for multiple safe havens may arise, dependent on vessel size and crew distribution. Additionally, muster stations and escape routes must be situated away from ammonia systems.
- A thorough review is necessary to ascertain the requirements (type and use) and availability (quantity and storage onboard) of personal PPE that is lightweight and does not impede physical movement. Furthermore, the PPE should be designed to remain effective irrespective of environmental conditions such as humidity and ambient temperature.

- Design implications represent crucial themes:
- Piping arrangements are essential to accommodate hull deformation (hogging/sagging).
- TCS must facilitate safe maintenance and emergency access.
- Segregation and compartmentalisation of ammonia systems are vital to prevent escalation during leak scenarios and to enhance system maintenance and the availability of subsystems, such as the tank pressure management system.
- Training and human factors are paramount, particularly for port personnel who may possess limited familiarity with ammonia-specific hazards. Tailored training programs should emphasise emergency response, first aid, and safe handling practices.
- The increased frequency of bunkering operations, attributed to ammonia's lower energy density, introduces new logistical and safety challenges. These challenges should be mitigated through appropriate tank sizing, optimised scheduling, and effective bunkering safeguards. Security risks, including the possibility of targeted attacks on vulnerable ammonia-related equipment, warrant formal assessment and mitigation through both physical protection and procedural controls.
- Adopting a risk-based design philosophy is strongly recommended, extending beyond mere compliance with the IGF Code and MSC.1/Circ.1687. This approach must include careful consideration of material selection, corrosion resistance, and long-term reliability in ammonia environments.

SIMOPS

The purpose of the SIMOPS (Simultaneous Operations) assessment was to identify and evaluate potential hazards associated with concurrent operations during ammonia bunkering on a Newcastlemax bulk carrier. This study covered various bunkering scenarios, including operations conducted in port (via barge, truck, or terminal), at anchor, and while underway. It thoroughly analysed the interactions between these scenarios and simultaneous activities such as cargo handling, maintenance, crew transfer, fuel cross-transfer, and concurrent refuelling with multiple fuel types. The assessment aimed to propose practical safeguards and procedural measures to ensure the safe and effective implementation of ammonia bunkering under realistic operational conditions. The principal insights derived from the SIMOPS assessment session are summarised below.

General Observations

- The primary hazard across all SIMOPS scenarios is ammonia release due to loss of containment, potentially caused by equipment failure, operator error, or external damage (e.g., dropped objects).
- Secondary hazards include fire/explosion risks, especially in the presence of flammable cargoes, substances, or fuels (e.g., MGO).
- Human injury is the dominant consequence, with occasional mention of environmental impacts (e.g., ammonia spill at sea).
- Activities assessed span port, terminal, at anchor, and underway bunkering operations.

Main Hazardous SIMOPS

The main hazardous SIMOPS identified are outlined in the table below.

Table 3. Main Hazardous SIMOPS

Operation Category	Typical SIMOPS Risks with Ammonia Bunkering	Notable Recommendations
Cargo Handling	Crane/grab ops, conveyor systems interfering with ammonia infrastructure	Avoid cargo operations during ammonia bunkering, especially coal

Operation Category	Typical SIMOPS Risks with Ammonia Bunkering	Notable Recommendations
Provision Loading	Forklifts/cranes potentially entering hazardous zone	Define safety zones based on wind direction & dispersion modelling
Hazmat Loading	Risk of reaction between ammonia and chemicals (e.g., solvents, oils)	Prohibit simultaneous handling of hazardous materials
MGO Bunkering	Flammability of MGO in proximity to toxic ammonia	Avoid simultaneous ammonia and MGO bunkering
Embarkation/Disembarkation	Exposure of personnel in access ways to ammonia	Restrict access; use stern ladder; schedule outside bunkering
Ship Operations & Drills	Hot work, drills, inspections during bunkering create risk	Conduct these outside bunkering hours; risk assessment required
Man Overboard Response	Conflicting priorities between life-saving operations and bunkering	Immediate halt of bunkering and initiation of SAR procedures

Key mitigating measures

The key mitigating measures proposed are the following:

- Training of port personnel on ammonia-specific risks.
- Clear zoning policies and restricted access during bunkering operations.
- Dedicated procedural planning to schedule high-risk operations at non-overlapping times.
- Emergency response coordination (e.g., with Firefighting tugs, Search & Rescue units).
- Technical upgrades such as leak detection, inerting systems, or anti-spill hoses.
- Infrastructure improvements like increasing ammonia tank size to reduce bunkering frequency.

3.3 Part 5 - Ro-Ro Ship Design

The ship designer Knud E. Hansen (KEH) has been commissioned by Det Forenede Dampskibs-Selskab (DFDS) to develop the design for an ammonia-fuelled Ro-Ro vessel, featuring two electrically driven propulsion lines. The primary generators under consideration are Wärtsilä 31DF engines, complemented by the Wärtsilä AmmoniaPac fuel supply system, which operates on ammonia and MGO, with MGO required as a pilot fuel. Each engine will be equipped with a selective catalytic reduction (SCR) system to ensure compliance with IMO Tier 3 emissions standards.

The design of the ammonia-related systems encompasses bunkering, storage, fuel temperature control, and the ability to supply ammonia at rates commensurate with the maximum output of all main generators. This system design is informed by existing knowledge, technologies, and current applicable standards, guidelines, and codes, and is engineered to manage the vapours, temperatures, and peak pressures in the ammonia tank, following recommendations from the tank manufacturer. Additionally, DFDS plans to transition from MGO to renewable biodiesel as the pilot fuel and to retrofit ammonia fuel cells for low-power demand scenarios, where the engine would typically switch from ammonia to diesel mode. The design also includes batteries for load sharing and peak shaving purposes.

This segment of the Study comprised three principal components:

- A HAZID assessment of the mega Ro-Ro vessel design,
- An evaluation of the potential consequences in the occurrence of an ammonia leak, and
- A probit analysis pertaining to toxic exposure to ammonia, derived from the outcomes of the consequence evaluation.

<u>HAZID Assessment</u>

The assessment was conducted utilizing the arrangement drawings, pertinent documents, and philosophies available during the workshop. It is strongly recommended that any significant future modifications to the design, which may influence hazard assessments, be subject to a comprehensive reassessment. With respect to the specific ship design and the ammonia FGSS presently under review, the following conclusions have been established:

- Ammonia's toxicity, corrosivity, and flammability require safety measures, with its toxicity and corrosivity posing challenges beyond those associated with conventional or LNG fuels.
- System integrity and leak prevention are critical. Design should prioritise double barriers, short piping runs, and welded connections to minimise leak potential.
- Detection and ventilation systems must be robust and redundant.
- Early leak detection, oxygen monitoring, and carefully designed ventilation and dispersion control are essential to protect personnel and equipment.
- Emergency response planning must be comprehensive.
- The vessel must include safe havens, mustering zones, and clearly defined escape routes, especially considering toxic gas release scenarios.
- Bunkering operations demand special focus. The use of dry disconnects, emergency release systems, drainage provisions, and updated procedures, such as an emergency plan for ammonia-fuelled vessels analogous to the Shipboard Oil Pollution Emergency Plan (SOPEP), Ship-to Ship (STS) plans, is vital for safe ammonia bunkering.
- Fuel storage and PSV venting require toxic zone management. Toxic dispersion analysis, safe integration of PSVs, and appropriate vent mast design are necessary to manage accidental releases.
- SOPs and operational limitations must be clearly defined. SOP's should address both routine operations and emergencies, particularly for purging, closed entry, and power loss scenarios.
- Crew protection and lifesaving systems need careful positioning. Lifesaving appliances, firefighting equipment, and escape paths must be located outside potential toxic gas areas.

- The implementation of dedicated safety protocols for passenger vessels is essential to ensure that the incorporation of ammonia does not compromise passenger health and safety.
- Key initiatives encompass the implementation of comprehensive passenger awareness programs and the establishment of clearly defined muster and evacuation procedures.
- Personnel responsible for passenger safety should provide briefings on ammonia hazards, alarm signals, and safe zones through presentations and signage in multiple languages.
- The Safety Management System must mandate regular drills that involve passenger participation.
- Best practices should prioritize coordination and communication between the crew and passengers to enhance overall preparedness.
- In the event of an emergency, passengers should be guided to sealed indoor areas or ammonia-free muster stations, which should be equipped with emergency breathing devices.
- Cyber security and automation safety must be included. Digital systems controlling safety functions should meet relevant cyber protection standards, such as ISO/IEC 27001 and IEC 62443.
- Lessons from ammonia cargo and related industries are valuable. Existing accident records, standards, and operational practices from cargo ships and industry can guide safer designs and procedures.

Consequence Modelling

CFD Modelling

The gas dispersion modelling was conducted using CFD to predict the air quality and to identify the impact of ammonia dispersion for a ferry design. The release of the ammonia was assumed to be in a gaseous state however, two-phase flows including both liquid and gaseous ammonia is typically involved. The assumption of the purely gaseous state was applicable since the implemented CFD modelled provided a more conservative assessment of the release due to the slow evaporation nature of liquid ammonia. This gives the crew time to respond and take measures. This study evaluated the scenario during possible incidental events. The ammonia tank’s relief valve activates and ammonia vapour is routed to the rear vent at the stern of the vessel. Two wind conditions were investigated in this study, i.e. one wind is blowing from the starboard side to the port side and the other wind is blowing from the starboard-aft direction. The study showed that the rear vent release has no impact on the vessel and personnel.

ALOHA Modelling

As part of this Study, a series of ammonia dispersion simulations were carried out using ALOHA software. These simulations assess potential risk areas in the event of a leak during bunkering operations, supporting the definition of exclusion zones, emergency planning, and the validation of key recommendations in the SIMOPS analysis.

Probit Analysis

A probit analysis was carried out to estimate the probability of fatality resulting from exposure to toxic ammonia vapours under two representative leak scenarios: an indicative short-duration (1 minute) release, during bunkering operations and a large-scale rupture of a refrigerated fuel tank with sustained release (60 minutes). The results, based on standard ammonia toxicity parameters, indicate that for the brief 1-minute ammonia leak fatality probability drops effectively to zero at distances greater than 500–1000 m, depending on wind and atmospheric conditions, whereas the tank rupture scenario yields significantly higher risk levels, with probabilities exceeding 70% at distances below 250 metres. The analysis also confirmed that exposure duration is a critical factor and that negative probit values, observed in low-concentration zones, correspond to negligible risk. These findings provide a robust quantitative basis for defining toxic hazard zones and support the design of appropriate safety measures and emergency response strategies.

4. Part 6 and Main Conclusions and Recommendations

4.1 Part 6 – Guidance for Ships Using Ammonia as Marine Fuel

To support the safe adoption of ammonia as a marine fuel, the IMO issued *via* their Maritime Safety Committee (MSC.1/Circ.1687) interim guidelines. The Guidelines begin by defining essential terminology, such as “*ammonia*”, “*fuel consumer*”, “*toxic space*”. If designers propose alternative designs and arrangements they must demonstrate safety equivalency, subject to approval by the relevant maritime Flag Administration. At the core of the Guidelines lies a detailed set of functional requirements. These are introduced to ensure that safety, reliability, and dependability are on par with conventional oil-fuelled systems. Critical design considerations include minimising ammonia leaks and toxic gas accumulations, protecting components from external damage, robust detection and alarm systems, and safe storage, supply, and bunkering operations. Notably, the Guidelines stress that no single system failure should result in an unsafe or unreliable condition.

Part 6 resulted from the experience gathered throughout this work and incorporates comments and suggestions on MSC.1/Circ.1687 guidance document. The overarching goal has been to ensure that ammonia-fuelled systems achieve safety, reliability, and dependability equivalent to conventional oil-fuelled systems. Rather than prescribing detailed technical standards, the guidance emphasizes broad design intentions, leaving technical specifications to evolve through industry standards and classification society rules as the technology matures. As applicable, parts of the IGF and the IGC Codes are included in a section-by-section format which is the result of a thorough review amongst consortium parties, consultation with key industry stakeholders via the EU survey tool and a virtual workshop hosted with EMSA in October 2025.

A central principle of the guidance is that no single system failure should result in unsafe or unreliable conditions. Accordingly, the recommendations drew on insights from Parts 1 to 5 of the Study and incorporated targeted feedback from regulators, industry stakeholders, and end users. Stakeholder consultations conducted in August–October 2025 highlighted the following priority areas:

- **Operational Risks:** The use of ammonia as a marine fuel introduces significant operational hazards due to its toxicity, volatile nature, and corrosiveness. Key risks include accidental releases during bunkering, system leaks, and inadequate emergency response protocols. Water spray systems can be effective in mitigating the gas dispersion in case of ammonia leaks. However, spraying on ammonia leak sources can exacerbate vapourisation if misapplied, underscoring the need for precise engineering and validation. ESD systems must be tailored to ammonia’s unique properties to minimise leak inventory during incidents. Fire safety strategies are also complicated by ammonia’s marginal flammability, shifting the focus from combustion suppression to toxic exposure management, an area still lacking type-approved solutions. While continuous ventilation in toxic spaces can be considered an effective measure to dilute ammonia vapour and reduce toxic vapour concentration in the space, attention must still be given to the potential impact on the surrounding environment, such as cargo terminals located within residential areas, and to the health and safety of working personnel who may be exposed during operations.
- **Storage Challenges:** MSC.1/Circ.1687 mandates fully refrigerated, near-atmospheric storage tanks, as this provides the highest level of safety as the evaporation rate of cold ammonia is very low. This is a strategy that effectively minimises toxic vapour release by excluding pressurised and semi-refrigerated options. This restriction limits design flexibility and forces a shift toward Type A tanks, which are less familiar to operators than the widely used Type C tanks for ammonia transport. Storage constraints complicate bunkering logistics, particularly for truck-based supply chains, primarily because of their reliance on reliquefication systems. Additionally, leakage collection systems lack standardised routing protocols, and Safe Haven ventilation systems must be carefully engineered to ensure isolation during toxic gas events.

- **Regulatory Gaps:** Current international regulations do not address the management of ammonia effluent from ships using ammonia as fuel, which leaves critical gaps on the standardised procedures for onboard retention, shore disposal, and documentation. Ventilation and fire safety standards borrowed from LNG protocols may be insufficient for ammonia's distinct hazard profile. While the IMO's Pollution Prevention and Response Committee is developing new Guidelines, the lack of immediate, detailed regulation creates uncertainty for ship operators and port authorities alike.
- **Human Factors:** Crew safety is heavily dependent on training, appropriate personal protective equipment (PPE), and clear protocols. The absence of standardised training requirements tailored to ammonia, currently complicates integration into Safety Management Systems. Protective equipment must be chosen to address specific operational hazards while also considering staff operational needs. Safe haven(s) design must ensure accessibility and occupant protection, while emergency ventilation systems in toxic spaces should prevent exacerbating off-site exposure. These human-centric considerations are critical for safe operations and must be integrated into vessel design and regulatory frameworks.

The version of the guidance, included in Appendix A, considered the above-mentioned items as much as practically possible and provides a foundation for future regulatory developments. Appendix B lists pending items that could be considered in the process of future regulatory developments.

4.2 Main Conclusions and Recommendations

Ammonia is emerging as a leading candidate in the transition to low- and zero-carbon marine fuels, offering a viable pathway to significantly reduce greenhouse gas emissions in the shipping sector. Its carbon-free combustion profile, alignment with existing transportation infrastructure, and prospective compatibility with advanced propulsion technologies are currently considered for integration into the next-generation vessel designs. For the maritime stakeholders, this underscores the importance of regulatory clarity and investment in safety standards, while technology providers are focused on optimizing fuel handling, engine development / integration, and emissions control systems to enable scalable deployment.

Risk and reliability methods can advance the safe use of alternative emerging fuel technologies. This is because they help identify top risk contributors and establish mitigation measures to support technology adoption. Notwithstanding this, as assumptions made during the technology's development evolve with field data, a reliability repository for alternative fuels should be considered essential. Such a repository should include equipment lists, failure modes, probability models, and data governance procedures while providing a shared platform for evergreen reliability data across industries.

A thorough understanding of the properties of ammonia is essential for minimizing safety risks related to its use as a fuel in marine engines. The chemical, physical, and toxicological characteristics of ammonia (toxicity, corrosiveness, flammability, and cryogenic/pressurised behaviour) have been primarily documented within the context of LPG operations. Although ammonia is not highly flammable, even small concentrations in the air can be hazardous to human health and the marine environment during prolonged exposures, presenting a significant danger. Advanced CFD tools are available to simulate potential leak scenarios, via dispersion analyses. These tools support the assessment of ammonia vapour behaviour in critical areas such as engine rooms, as well as during venting and bunkering operations.

Effectively managing ammonia onboard ships requires the development of specific skills and safety protocols. Material standards that mitigate corrosion have been established and applied for decades. Similarly, the maritime sector has long employed appropriate PPE, supported by comprehensive safety protocols and medical response procedures. These measures should be enhanced further to account for the use of ammonia as fuel onboard vessels. A revised safety framework is necessary for the successful integration of ammonia as an alternative fuel, and the specific requirements associated with ammonia may demand adjustments to existing ship configurations or even the creation of entirely new inherently safe designs that will minimise the inventory that can be released.

A review of industrial accident data highlights the potential severity of unintended ammonia releases. Comparative analysis of national and international exposure limits and odour thresholds underscores the urgent need for harmonised safety mitigation standards and approaches. In parallel, an examination of regulatory frameworks, technical standards, and prevailing industry practices reveals that while ammonia presents a compelling zero-carbon fuel alternative, its safe and effective adoption hinges on the conclusive development of harmonised technical standards and regulations. Consequently, the uniform implementation of robust safety protocols across the maritime value chain will ensure safe and sustainable ship / port operations.

Throughout this study, a review of port-level risks, dispersion modeling, and SIMOPS assessments underscored that shipboard safety alone is insufficient; it must be reinforced by comprehensive port-side preparedness and coordinated emergency response planning. The interface between ammonia bunkering and concurrent port activities demands careful management, particularly in the areas of: (a) zoning and designation of exclusion zones; (b) real-time communication protocols between ship and shore; (c) operational coordination to prevent risk escalation during simultaneous activities. Looking ahead, the active involvement of port authorities in the development of regulatory frameworks and safety standards will be essential.

Overall, the Study outlined preliminary goals and functional requirements, serving as a first step toward the formation of a harmonised framework for the safe bunkering and the use of ammonia onboard ships.

The results formed a critical groundwork for the development of practical guidance to support safe implementation. The guidance presented in Appendix A of this report, provides the foundation for future regulatory developments. It includes about 50 clarification comments, adds approximately 100 new requirements across multiple sections of the MSC.1/Circ.1687 to strengthen safety provisions, and includes 60 best practice recommendations aligned with current industry standards. Key contributions include:

- Outlining the scope for risk assessment studies to ensure comprehensive hazard identification.
- Introducing quality criteria for gas dispersion simulations to improve predictive accuracy.
- Enhancing ship design and safety requirements for ammonia-related systems, covering bilge arrangements, bunkering stations, fuel supply systems, and Emergency ShutDown (ESD) provisions.
- Specifying requirements for ventilation system arrangements in toxic spaces.
- Introducing new standards for the control and monitoring of toxic spaces.
- Providing actionable recommendations for periodic testing and surveys of ammonia systems.
- Establishing high-level requirements for crew training and emergency response preparedness.

By setting functional safety requirements and identifying critical gaps, this Study aims to inform technology developers, regulators, and policymakers about the safe and effective introduction of ammonia as a viable marine fuel.. Finally, Appendix B lists pending items that could be considered in the process of future regulatory developments.

5. Bibliography

ABS. (2020). *Sustainability Whitepaper: Ammonia as Marine Fuel.*

ABS. (2023a). *Requirements for Ammonia Fueled Vessels*

ABS. (2023b). *Rules for Building and Classing Marine Vessel, Part 5C Specific Vessel Types (Chapters 8, 13).*

ABS. (2023c). *Beyond the Horizon: View of the Emerging Energy Value Chains.*

ABS. (2024). *Ammonia Bunkering Advisory- Technical and Operational Advisory.*

ABS. (2025a). *Materials for Liquid Hydrogen, Liquid Ammonia and Liquid Carbon Dioxide Containment Systems Advisory.*

ABS. (2025b). *Requirements for Ammonia Fueled Vessels*

ALOHA (Areal Locations Of Hazardous Atmospheres). (n.d.). Retrieved from https://www.epa.gov/cameo/aloha-software

American Institute for Chemical Engineers (1989), *Guidelines for Process Equipment Reliability Data, with Data Tables*

Bouet, R. (2005). *AMMONIA Large-scale atmospheric dispersion tests.* INERIS.

Cramer, S., Davies, M., & Covino, B. (2006). Volume 13C Corrosion: Environments and Industries. In M. Davies, *Corrosion by Ammonia.* ASM.

Dawson, D., Ware, D., & Vest, L. (2022). *Ammonia at sea: Studying the potential impact of ammonia as a shipping fuel on marine ecosystems.* Environmental Defense Fund (EDF), Ricardo PLC, Lloyd's Register (LR).

Duong, P., Ryu, B., Song, M., Nguyen, H., Nam, D., & Kang, H. (2023). *Safety Assessment of the Ammonia Bunkering Process in the Maritime Sector: A Review.* Energies.

EMSA. (2023). *Potential of Ammonia as Fuel in Shipping.*

EMSA. (2023). *Study Investigating the Safety of Ammonia as Fuel on ships. Part 1 - Ammonia: properties, regulations and accidents review.*

EMSA. (2024). *Study Investigating the Safety of Ammonia as Fuel on ships. Part 2 - Safety assessment and reliability analysis of main components, equipment, sub-systems and systems.*

EMSA. (2025). *Study Investigating the Safety of Ammonia as Fuel on ships. Part 3 - Risk Assessment of a Generic Ship Design.*

EMSA. (2025). *Study Investigating the Safety of Ammonia as Fuel on ships. Part 4 - Risk Assessment of a Carrier Ship Design.*

EMSA. (2025). *Study Investigating the Safety of Ammonia as Fuel on ships. Part 5 - Risk Assessment of a RoRo Ship Design.*

EMSA. (2025). *Study Investigating the Safety of Ammonia as Fuel on ships. Part 6 - Guidance for Ships Using Ammonia as Marine Fuel*

EMSA. Energy Solutions. (2023, October). *MAN B&W two-stroke engine operating on ammonia. Retrieved November 2023, from https://www.man-es.com/docs/default-source/marine/tools/man-b-w-two-stroke-engine-operating-on-ammonia.pdf*

Energy Solutions. (2024). *A new chapter – ammonia two-stroke engines. Retrieved from https://www.man-es.com/marine/products/two-stroke-engines/ammonia-engine*

EUROMOT. (2025). *EUROMOT Position: Ammonia Safety.*

Fecke, M., Garner, S., & Cox, B. (2016). *Review of Global Regulations for Anhydrous Ammonia Production, Use,.* IChemE.

FLACS-CFD. (n.d.). Retrieved from https://www.gexcon.com/software/flacs-cfd/

GCMD . (2023). *Safety and Operational Guidelines for Piloting Ammonia Bunkering in Singapore.* Global Centre for Maritime Decarbonisation (GCMD).

HSE. (1986). *Storage of Anhydrous Ammonia Under Pressure in the United Kingdom: Spherical and Cylindrical Vessels.* Health and Safety Executive.

Hua, M., Yue, T.-t., Pi, X.-y., Pan, X.-h., & Jiang, J.-c. (2017). *Experimental Research on Water Curain Scavenging Ammonia Dispersion in Confined Space.* Nanjing, Jiangsu, China: 8th International Conference on Fire Science and Fire Protection Engineering.

IEC. (2020). *IEC 60079-10-1: Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres.*

IMO. (2015). *IGF Code: International code of safety for ships using gases or other low-flashpoint fuels.* IMO.

IMO. (2016). *IGC Code: International code for construction and equipment for ships carrying liquified gases in bulk.* IMO.

IMO. (2018). *IBC Code: International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk.* IMO.

IMO. (2018). *ISM Code: International Safety Management Code.*

IMO. (2020). *International Convention for the Safety of Life at Sea (SOLAS).*

Intergovernmental Panel on Climate Change. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.*

International Labor Organization (ILO). (n.d.). *Ammonia (Anhydrous)*. Retrieved from https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0414&p_version=2

IRENA. (2022). *Innovation Outlook: Renewable Ammonia.*

Jamaludin, Z., Rollings-Scattergood, S., Lutes, K., & Vaneeckhaute, C. (2018). Evaluation of sustainable scrubbing agents for ammonia recovery from anaerobic digestate. *Bioresource Technology*.

Jang, H., Mujeeb-Ahmed, M., Wang, H., Park, C., Hwang, I., Jeong, B. Mickeviciene, R. (2023). Regulatory gap analysis for risk assessment of ammonia-fuelled ships.

Kay Leng Ng, C., Liu, M., Siu Lee Lam, J., & Yang, M. (2023). Accidental release of ammonia during ammonia bunkering: Dispersion behaviour under the influence of operational and weather conditions in Singapore. *Journal of Hazardous Materials (452)*.

Lauf, J., Wsewolod, R., & Zimmermann, R. (2021). Nitrogen based propellants as substitute for carbon containing fuels. *NATO Energy Security Centre of Excellence*.

Li, J., Lai, S., Chen, D., Wu, R., Kobayashi, N., Deng, L., & Huang, H. (2021). A Review on Combustion Characteristics of Ammonia as a Carbon-Free Fuel. *Frontiers Energy Research 9:760356*.

Linde. (n.d.). *Ammonia Datasheet*. Retrieved from https://www.linde-gas.com/en/images/linde-datasheet-01-ammonia-June-2017_tcm17-417364.pdf

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS). (2023). *Managing Emissions from Ammonia-Fueled Vessels.*

Mærsk Mc-Kinney Møller for Zero Carbon Shipping. (2023). *Recommendations for Design and Operation of Ammonia-Fuelled Vessels Based on Multi-disciplinary Risk Analysis.*

MAN Energy Solutions. (2023, October). *MAN B&W two-stroke engine operating on ammonia.* Retrieved November 2023, from https://www.man-es.com/docs/default-source/marine/tools/man-b-w-two-stroke-engine-operating-on-ammonia.pdf

New Jersey Department of Health. (n.d.). *Right to Know: Hazardous Substance Fact Sheet - Ammonia*. Retrieved from https://nj.gov/health/eoh/rtkweb/documents/fs/0084.pdf

NIOSH (National Institute for Occupational Safety and Health). (2007). *NIOSH Pocket Guide to Chemical Hazards.* Centers for Disease Control and Prevention (CDC).

NTU. (2022). *Ammonia as a marine fuel – Bunkering, Safety and Release Simulations.* Singapore.

PGS. (2020a). *PGS 12 – Ammonia - Storage and Offloading.* Publicatiereeks Gevaarlijke Stoffen (PGS).

PGS. (2020b). *PGS 13 – Ammonia as a refrigerant in cooling systems and heat pumps.* Publicatiereeks Gevaarlijke Stoffen (PGS).

PHAST (Process Hazard Analysis Tool). (n.d.). Retrieved from https://www.dnv.com/software/services/plant/consequence-analysis-phast.html

SGMF. (2023). *Ammonia as a Marine Fuel.*

SGMF. (2024). *An Introduction to Ammonia Accidental Release Preparedness and Response.*

SIGTTO. (1988). *Information Paper no. 2 - Avoidance of Stress Corrosion Cracking (SCC) in Cargo Tanks, Reliquefaction Condensers And Condensate Return Pipework With Liquefied Ammonia Cargoes.*

SIGTTO. (2016). *Liquefied Gas Handling Principles on Ships and in Terminals (LGHP4), Fourth Edition.* Witherby Publishing Group Ltd.

SIGTTO. (2021). *Recommendations for Emergency Shutdown and Related Safety Systems (Second Edition).* Witherby Publishing.

SIGTTO. (2022). *Detection and Reporting of Fugitive Methane Emissions from LNG Carriers.* Witherby Seamanship.

SIGTTO. (2022). *Annual Report and Accounts.*

Skarsvåg, H., Bucelli, M., Aasen, A., & Spillum Grønli, M. (2023). *MaritimeNH3 - Webinar #3: Release of refrigerated ammonia: modelling and safety analysis*. Retrieved from SINTEF: https://www.sintef.no/en/events/archive/2023/maritimenh3-webinar-3-release-of-refrigerated-ammonia-modelling-and-safety-analysis/

Sousa Cardoso, J., Silva, V., C. Rocha, R., J. Hall, M., Costa, M., & Eusébio, D. (2021). Ammonia as an energy vector: Current and future prospects for low carbon fuel applications in internal combustion engines. *Journal of Cleaner Production 296*.

The Engineering ToolBox. (n.d.). *Ammonia - Properties at Gas-Liquid Equilibrium Conditions*. Retrieved from https://www.engineeringtoolbox.com/ammonia-gas-liquid-equilibrium-condition-properties-temperature-pressure-boiling-curve-d_2013.html

The Engineering ToolBox. (n.d.). *Ammonia Gas - Density vs. Temperature and Pressure*. Retrieved from https://www.engineeringtoolbox.com/ammonia-density-temperature-pressure-d_2006.html

The Royal Society. (2020). *Ammonia: zero-carbon fertiliser, fuel and energy store.* The Royal Society.

U.S. Code of Federal Regulations. (n.d.). Retrieved from https://www.ecfr.gov/

U.S. EPA. (2013). *Aquatic Life Ambient Water Quality Criteria for Ammonia - Freshwater 2013.* U.S. Environmental Protection Agency.

Wyer, K., Kelleghan, D., Blanes-Vidal, V., Schlauberger, G., & Curran, T. (2023). Ammonia emissions from agriculture and their contribution to fine particulate matter: A review of implications for human health. *Journal of Environmental Management*.

WinGD. (2024). *X-DF-A Ammonia Engine Documentation. Retrieved from https://www.wingd.com/en/engines/engine-types/x-df-dual-fuel-ammonia/documentation/*

The New Weibull Handbook, 5th ed., by Dr. Robert B. Abernethy

NUREG/CR-1278 (1985). A.D. Swain, H.E. Guttmann. Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report.

Yadav, A., & Jeong, B. (2022). Safety evaluation of using ammonia as marine fuel by analysing gas dispersion in a ship engine room using CFD. *Journal of International Maritime Safety, Environmental Affairs, and Shipping*, 6, 99 – 116.

YCA. (2023). *Ammonia Emergency Workshop.* Yara Clean Ammonia.

IMO MSC Circulars

- MSC.1/Circ.1687 Interim Guidelines for the Safety of Ships Using Ammonia as Fuel
- MSC.1/Circ.1212/Rev.1 Revised Guidelines on Alternative Design and Arrangements for SOLAS Chapters II-1 and III
- MSC.1/Circ.1394/Rev.2 Generic Guidelines for Developing IMO Goal-Based Standards
- MSC.1/Circ.1455 Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments
- MSC.1/Circ.1599/Rev.2 Revised Guidelines on the Application of High Manganese Austenitic Steel for Cryogenic Service
- MSC.1/Circ.1599/Rev.3 Draft Revised Guidelines on the Application of High Manganese Austenitic Steel for Cryogenic Service
- MSC.1/Circ.1621 Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel
- MSC.1/Circ.1622/Rev.1 Guidelines for the Acceptance of Alternative Metallic Materials for Cryogenic Service in Ships Carrying Liquefied Gases in Bulk and Ships Using Gases or other Low-flashpoint Fuels

Appendix A Updated Guidance

Text directly copied form MSC.1/Circ.1687, IGF Code, IGC Code, International Convention for the Prevention of Pollution from Ships (MARPOL) and International Convention for the Safety of Life at Sea (SOLAS) or other instruments have been included in Italics. Suggested additions and comments/recommendations are presented in blue.

Note: The numbering of the Sections below follows MSC.1/Circ.1687 numbering, including Sections 4 to 20.

Section 4 - General Provisions

HAZARDS
N/A
GOAL
Ensure that the necessary assessments of the risks involved are carried out in order to eliminate or mitigate any adverse effect on the persons on board, the environment or the ship.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
N/A
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **Risk assessment** *4.2.1: A holistic risk assessment should be conducted to ensure that risks arising from the use of ammonia as fuel affecting persons on board, the environment, the structural strength, or the integrity of the ship and its sub-systems are addressed. Consideration should be given to the hazards associated with physical layout, operation, and maintenance following any reasonably foreseeable failure.* **Comment on MSC.1/Circ.1687, 4.2.1:** The risks should be analysed using acceptable and recognised risk assessment techniques. Details of risks, and the means by which they are mitigated should be documented in a report. Reference may be made to International Association of Classification Societies (IACS) Recommendation No. 146 on Risk Assessment and the Maritime Technologies Forum (MTF) publication on Guidelines for Conducting Qualitative Risk Assessments for Alternative-Fuelled Ships: HAZID and HAZOP. **Recommendation:** The risk assessment should specifically consider, but not limited to the following items: • Required number of compressed air safety equipment and personal protective equipment (PPE); in line with the section 20. • Duration of the Emergency Escape Breathing Devices (EEBDs); in line with the section 20. • Number of, persons and location of, machinery space emergency escape equipment; in line with the section 20. • The toxic areas identified in Section 12bis including arrangements and access for Life-Saving Appliances (LSA), muster stations and escape routes. For those vessels not equipped with enclosed lifeboats equipped with self-contained air support systems (as required by SOLAS Chapter III Regulation 31.1.6), the risk assessment should consider the need for enclosed lifeboats to be equipped with self-contained air support in accordance with Chapter IV, 4.8 of the Life-Saving Appliances Code. • Arrangements of fuel preparation rooms and tank connection spaces spaces/enclosures; in line with the section 5.

- Arrangement of bilge system, drain tank(s) and capacity of drip trays; in line with the section5.
- Arrangement and capacity of the Ammonia Release Mitigation System (ARMS) ; in line with the section 9.
- Arrangements of airlocks and airlock access to the spaces containing potential source of ammonia release/leakage; in line with the section 5.
- Arrangement of the fuel containment system; in line with the section 6.
- Arrangements of enclosed or semi-enclosed bunker stations; in line with the section 8.
- Evaluation of ventilation systems serving the spaces with source of ammonia release/leakage; in line with the section 13.
- Gas detection and closing arrangements of the air intakes and other openings into the accommodation spaces, service spaces and control stations; in line with the section 13.
- The need for additional quantitative analysis, such as gas dispersion study, to support the design approval and the items identified by the requirements under section 12bis.4.3 and the Table 1 in section 15.

Note: Preliminary assessments of gas dispersion effects may be conducted using basic gas dilution theory. These initial evaluations can help determine at an early stage whether more detailed and accurate simulations may be necessary. For further guidance, reference may be made to the EUROMOT Position Paper published in May 2025.

4.2.2: The risk assessment should specifically consider the ammonia system integrity with a focus on its ability to prevent and isolate leakages and evaluate potential toxicity hazards, ignition mechanisms and the consequences of ignition. Special consideration should be given, but may not be limited, to the following specific ammonia-related hazards and topics:

.1 loss of function;
.2 component damage;
.3 fire;
.4 explosion;
.5 toxicity; and
.6 electric shock.

Comment on to MSC.1/Circ.1687, 4.2.2: While this clause emphasizes prevention and isolation of ammonia leaks, it does not explicitly reference early detection measures. Detection is a critical layer of protection that enables timely intervention before escalation. It is recommended to include explicit consideration of detection systems, such as continuous gas monitoring, alarm integration, and sensor placement, as part of the risk assessment, to ensure comprehensive coverage of ammonia-related hazards.

4.2.3: Risks, which cannot be eliminated, should be mitigated as necessary. Details of risks, and the means by which they are mitigated, should be documented to the satisfaction of the Administration.

Suggested additional requirement: The Risk Assessment Plan should be submitted to the relevant Administration or recognised organisation acting on its behalf, for review prior to implementation. The plan should include, at minimum:

.1 Description of proposed function;
.2 Quantitative or Qualitative Risk assessment method(s) to be used and their description if using a nonstandard method;
.3 Scope and objectives of the assessment
.4 Subject matter experts/participants/risk analysts, including their background and area of expertise;
.5 Proposed risk acceptance criteria or risk matrix; and
.6 Risk control and management measures.

Note: Both qualitative and quantitative risk assessment methods may be applied, depending on the nature and complexity of the hazards identified. In practice, qualitative techniques should be generally used during the initial stages to identify and prioritize risks. Where significant or high-

consequence hazards are identified, quantitative methods may subsequently be employed to provide a more detailed evaluation and support informed decision-making. It is noted that risk acceptance criteria may be subject to the requirements of national jurisdiction, as determined by the Flag Administration. - **Limitation of explosion consequences** *4.3.1 An explosion in any space containing any potential sources of release and potential ignition sources should not:* *.1 Cause damage to or disrupt the proper functioning of equipment/systems located in any space other than that in which the incident occurs;* *.2 Damage the ship in such a way that flooding of water below the main deck or any progressive flooding occurs;* *.3 Damage work areas or accommodation in such a way that persons who stay in such areas under normal operating conditions are injured;* *.4 Damage ship personnel normally present in work or accommodation spaces under normal operating conditions;* *.5 Disrupt the proper functioning of control stations and switchboard rooms necessary for power distribution;* *.6 damage life-saving equipment or associated launching arrangements;* *.7 Disrupt the proper functioning of fire-fighting equipment located outside the explosion-damaged space;* *.8 Affect other areas of the ship in such a way that chain reactions involving, inter alia, cargo, ammonia and bunker oil may arise; or* *.9 Prevent persons' access to life-saving appliances or impede escape routes.*
Further Recommendations
N/A

Section 5 - Ship Design and Arrangement

HAZARDS
Systems concerned: Fuel storage tanks, Ventilation openings, Machinery space, Fuel preparation room, Fuel piping, Tank Connection spaces, Bunkering stations, Bilge systems, Entrance to enclosed spaces, Drip trays • Vessel collision or grounding leading to fuel tank damage and ammonia leakage; • Damage of ammonia-related equipment or piping due to external impacts (e.g. cargo operations); • Exposure of individuals to flammable, toxic or asphyxiating gases; • Cross-boundary contamination between toxic and non-toxic zones; • Loss of propulsion power, power for essential services, or manoeuvring capabilities; • Exposure of the ship's structural components to critically low temperatures that may compromise material integrity or operational safety; • Hazardous chemical reactions due to gas or materials incompatibility (ref. added requirement about secondary heating circuits).
GOAL
Provide for safe location, space arrangements and mechanical protection of power generation equipment, fuel storage systems, fuel supply equipment and refuelling systems.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
5.2.1.1: The fuel tank(s) should be positioned in such a way that the probability for the tank(s) to be damaged following a collision or grounding is reduced to a minimum, when taking into account the safe operation of the ship and other hazards that may be relevant to the ship; *5.2.1.2: Fuel containment systems, fuel piping, and other fuel sources of release should be so located and arranged that released ammonia is led to a recovery system, treatment system, or a safe location in the open air;* *5.2.1.3: The access or other openings to spaces containing fuel sources of release should be so arranged that flammable, asphyxiating or toxic gas cannot escape to spaces that are not designed for the presence of such gases considering the specific gravity and dispersion characteristics of ammonia gas;* *5.2.1.4: Fuel piping and fuel supply system should be protected against mechanical damage;* *5.2.1.5: The propulsion and fuel supply system should be so designed that safety actions after any ammonia leakage do not lead to an unacceptable loss of power;* *5.2.1.6: The probability of an explosion in a machinery space with ammonia-fuelled machinery should be minimized; and* *5.2.1.7: The space where machinery and equipment fuel are installed should be designed to minimize the risk of exposure of persons on board to leaked ammonia.*
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **General**

5.3.1 Fuel storage tanks should be protected against mechanical damage.
5.3.2 Fuel storage tanks and/or equipment located on an open deck should be located to ensure sufficient natural ventilation to prevent accumulation of ammonia.
5.3.3 Mustering stations and life-saving equipment, and access to such stations and equipment, should not be located in toxic areas as specified in 12bis.4.
5.3.4 Air intakes, outlets and other openings into the accommodation, service and machinery spaces, control stations and other non-toxic spaces in the ship should not be located in toxic areas as specified in 12bis.4.

Suggested additional requirement: The windows and side scuttles of accommodation spaces, service spaces, and control stations, which are normally manned, and facing ammonia fuel tanks located on deck and/or the vent mast or riser location should be of the fixed (non-opening) type.

- **Fuel tank protection against collision and grounding**

5.4 Unless expressly provided otherwise, the requirements of 5.3.3, 5.3.4 and 5.3.5 of the IGF Code part A-1 should apply to ships using ammonia as fuel. [Refer to the original IGF Code for full requirement details.]

- **Machinery space arrangement**

5.5.1 Machinery spaces containing ammonia fuel systems and/or ammonia-fuelled machinery should be arranged such that the spaces may be considered gas safe under all conditions, normal as well as abnormal conditions, i.e. inherently gas safe.
5.5.2 In a gas-safe machinery space, a single failure cannot lead to the release of fuel gas into the machinery space.
5.5.3 A gas-safe machinery space may be arranged as a conventional machinery space.
5.5.4 A single failure within the fuel system should not lead to a fuel release into the machinery space.
5.5.5 All fuel piping within machinery space boundaries should be enclosed in a gastight enclosure, taking into account paragraph 9.6 of the IGF Code part A-1.

Comment on MSC.1/Circ.1687, 5.5.5: To avoid repetition, it is recommended that the specific paragraph be removed, as the relevant provisions are also discussed in Section 9.

5.5.6 Access to machinery spaces should not be arranged from toxic areas or toxic spaces.

- **Fuel piping**

5.6.1 Fuel pipes and fuel supply systems should not be located less than 800 mm from the ship's side.

Comment on MSC.1/Circ.1687, 5.6.1: In line also with 5.3.1, mechanical protection may be required based on the local hazards and the findings of risk assessment.

5.6.2 Fuel piping should not be led directly through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention, even though the piping is protected by secondary enclosures.
5.6.3 Fuel pipes led through ro-ro spaces, special category spaces and on open decks should be protected against mechanical damage.

Comment on MSC.1/Circ.1687, 5.6.1 to 5.6.3: It should be made clear that the above provisions apply to ammonia fuel piping as well as any other piping that may contain ammonia (e.g., fuel bleed or purge lines, relief pipes, and vent pipes except for open ended pipes led to open air).

- **Fuel preparation room**

5.7.1.1 Fuel process equipment should be arranged in a fuel preparation room arranged in accordance with provisions in these Interim Guidelines. As an exemption to this provision, vaporizers, heat exchangers, and motors for pumps submerged in tanks may also be located in tank connection spaces
5.7.1.2 When fuel preparation rooms cannot be located on open deck, or accessed from open deck, access should be provided through an airlock in compliance with 5.11.

Comment on MSC.1/Circ.1687, 5.7.1.2: To ensure clarity, it is suggested to be rephrased.
Suggested rewording: "When fuel preparation rooms cannot be located on or accessed from the open deck, access should be provided through an airlock in compliance with 5.11."

5.7.1.3 Fuel preparation rooms should be designed to safely contain fuel leakages. The fuel preparation room boundaries should be gastight towards other spaces in the ship.
5.7.1.4 The probable maximum leakage into the fuel preparation room should be determined based on detail design, detection and shutdown systems.
5.7.1.5 The material of the boundaries of the fuel preparation room should have a design temperature corresponding with the lowest temperature it can be subjected to in a probable maximum leakage scenario, unless the boundaries of the space, i.e. bulkheads and decks, are provided with suitable thermal protection.
5.7.1.6 The fuel preparation room should be fitted with ventilation arrangements ensuring that the space can withstand any pressure build-up caused by vaporization of the liquefied fuel.
5.7.1.7 The fuel preparation room entrance should be arranged with a sill height exceeding the liquid level resulting from a calculated maximum leakage, but should in no case be lower than 300 mm.
5.7.1.8 Fuel preparation room entrances should be arranged with water screens having constantly available water supply. The water screen should be possible to activate from a safe location outside the fuel preparation room toxic zone if an ammonia leak occurs. The water screens should be arranged on the outside of the fuel preparation room. The arrangement should include the means to safely manage any ammonia effluent produced in their operation.

Suggested addition to MSC.1/Circ.1687, 5.7.1.8: Water screen systems should be designed to maintain continuous operation for at least 30 minutes.
Comment on the suggested addition: The intention of specifying a 30-minute continuous operation period is not to impose a limitation on system performance, but rather to establish a minimum design requirement to ensure adequate fire suppression capability under emergency conditions. Reference may be also made to IMO MSC/Circ.1165, Guidelines for the Approval of Equivalent Water-Based Fire-Extinguishing Systems for Machinery Spaces and Cargo Pump-Rooms.

5.7.1.9 A leakage in the fuel preparation room should not render necessary safety functions out of order due to low temperatures caused by the evaporation of leaking fuel.
5.7.1.10 Fuel preparation rooms should be designed to manage any ammonia release for personnel to enter safely.

Comment on MSC.1/Circ.1687, 5.7.1.10: Managing *any* possible ammonia release may be infeasible. The emergency shutdown arrangements, as specified in 9.4.4, should be designed to minimize the quantity of ammonia released to the greatest extent practicable. Fuel preparation rooms should be designed to manage the maximum credible ammonia release in case of a single component failure, based on the findings of risk assessment.

Suggested additional requirements:

- When located on deck, fuel preparation rooms should be protected against mechanical damage where vessel cargo handling operations increase the risk of mechanical impact damage.
- The fuel preparation room should be designed to provide adequate space to enable crew members to perform operational tasks and maintenance activities safely ensuring unobstructed access to all equipment.

Recommendations:

- Relevant warning notices for safe entry should be posted adjacent to the entrance of fuel preparation rooms accompanied by appropriate visual alert systems such as flashing beacons, or warning lights in the event of ammonia detection. All warning signs and notices should be in accordance with the principles outlined in IMO A.1116(30) – Escape Route Signs and Equipment Location Markings.
- Fuel preparation rooms should be equipped with closed-circuit television (CCTV) systems for monitoring ammonia fuel critical equipment, thereby reducing the need for personnel to enter the area for routine entries.

- **Tank connection spaces**

5.7.2.1 Fuel tank connections, flanges and tank valves should be located in a tank connection space arranged in accordance with the provisions in these Interim Guidelines. Apart from fuel process equipment allowed in tank connection spaces as defined in 5.7.1.1, Tank connection spaces and fuel preparation rooms should not be combined.

Comment on MSC.1/Circ.1687, 5.7.2.1: Tank connection space is required for tanks with connections in enclosed spaces. Tank connection space may also be required for tanks on open decks where the restriction of toxic areas is safety critical. A tank connection space may also be necessary to protect essential fuel system safety equipment such as tank valves, safety valves, and instrumentation from adverse environmental conditions and mechanical damage.

5.7.2.2 Tank connection spaces should be designed to safely contain fuel leakages. The tank connection space boundaries should be gastight towards other spaces in the ship.
5.7.2.3 The material of the bulkheads of the tank connection space should have a design temperature corresponding with the lowest temperature it can be subject to in a probable maximum leakage scenario.
5.7.2.4 The probable maximum leakage into the tank connection space should be determined based on detail design, detection and shutdown systems.
5.7.2.5 Tank connection spaces should be fitted with ventilation arrangements ensuring that the spaces can withstand any pressure build-up caused by vaporization of the liquefied fuel.
5.7.2.6 Tank connection space entrances should be arranged with a sill height exceeding the liquid level resulting from a calculated maximum leakage, but should in no case be lower than 300 mm.
5.7.2.7 Tank connection space entrances should be arranged with water screens having constantly available water supply. The water screen should be possible to activate from a safe location outside the tank connection space toxic zone if an ammonia leak occurs. The water screens should be arranged on the outside of the tank connection spaces. The arrangement should include the means to safely manage any ammonia effluent produced in their operation.

Suggested addition to MSC.1/Circ.1687, 5.7.2.7: Water screen systems or water deluge systems, as applicable, should be designed to maintain continuous operation for a period of 30 minutes or more.
Comment on the suggested addition: The intention of specifying a 30-minute continuous operation period is not to impose a limitation on system performance, but rather to establish a minimum design requirement to ensure adequate fire suppression capability under emergency conditions. Reference may be also made to IMO MSC/Circ.1165, Guidelines for the Approval of Equivalent Water-Based Fire-Extinguishing Systems for Machinery Spaces and Cargo Pump-Rooms.

5.7.2.8 Unless the access to the tank connection space is independent and direct from the open deck, it should be provided through a bolted hatch. The bolted hatch should be located in a protective entry space of gastight construction with a self-closing gastight door. The access should be arranged to facilitate the evacuation of an injured person from the tank connection space by personnel wearing breathing apparatus and PPE.
5.7.2.9 A leakage in the tank connection space should not render necessary safety functions out of order due to low temperatures caused by the evaporation of leaking fuel.

Suggested additional requirements:
- Access to tank connection spaces should be provided with proper locking arrangements. Relevant warning notices for safe entry should be posted adjacent to the entrances.
- Tank connection spaces shall be designed to facilitate safe access to the extent practicable while wearing the required PPE, enabling maintenance personnel to reach all equipment and valves.(ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 - Risk Assessment of a Generic Ship Design).
- The piping in tank connection spaces should be of full penetration welding construction with flange joints kept to a minimum (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 - Risk Assessment of a Generic Ship Design).

- **Bunkering stations**

5.7.3.1 The location and arrangement of the bunkering station, including whether open, enclosed, or semi-enclosed, should be subject to special consideration within the risk assessment. Depending on the arrangement this may include, but is not limited to:
.1 segregation from other areas of the ship;
.2 hazardous and toxic area plans for the ship;
.3 requirements for forced ventilation;
.4 requirements for leakage detection;
.5 safety actions related to leakage detection;
.6 access to bunkering station from non-hazardous areas through airlocks; and
.7 monitoring of bunkering station by direct line of sight or closed-circuit television (CCTV).
5.7.3.2 Mechanical spray shielding should be arranged around potential leakage sources from the ammonia system in the bunkering station.
5.7.3.3 The bunker station should be located in an area where sufficient space for efficient work and access is ensured for the personnel involved in bunkering and their equipment while wearing SCBA and PPE, and to ensure that, in an emergency, they have a clear escape route.

- **Bilge systems**

5.8.1 Bilge systems installed in areas where fuel covered by these Interim Guidelines can be present should be segregated from the bilge system of spaces where fuel cannot be present.

5.8.2 Where fuel is carried in a fuel containment system requiring a secondary barrier, suitable drainage arrangements for dealing with any leakage into the hold or insulation spaces through the adjacent ship structure should be provided. The bilge system should not lead to pumps in spaces having no risks of ammonia. Means of detecting such leakage should be provided.
5.8.3 The hold or interbarrier spaces of type A independent tanks for liquid gas should be provided with a drainage system suitable for handling liquid fuel in the event of fuel tank leakage or rupture.

Suggested additional requirements :

- The deck plating of toxic spaces should be arranged to facilitate easy cleaning and drying and there should be no separate plating provided above the deck plating.
- The draining and pumping arrangements are to be such as to prevent the build-up on free surfaces. The drainage system should be sized to remove not less than 125% of the capacity of either the water screen, deluge, or water spray system, whichever has the greater capacity. This can apply to any space containing a potential source of ammonia release/leakage and any adjacent compartment where the contaminated water may accumulate.
- Bilge water originating from toxic areas, such as fuel preparation room, tank connection space, tank hold or interbarrier space, etc., should be collected into bilge holding tank(s) before disposal ashore. Alternatively, it may be arranged for further processing and treatment before discharge at sea in compliance with applicable international or national regulations.
- Discharging ammonia-contaminated bilge water at sea should require approval from the Administration and/or local Authorities. Where allowed, bilge discharge should be directed to a safe location where there is no risk of human exposure to ammonia.
- Bilge holding tank(s) serving the toxic areas and spaces, should be located outside non-hazardous and non-toxic spaces including machinery spaces and their air vent pipe is also to be directed to areas on open deck where there is no risk of human exposure to ammonia gas at or near the vent outlet. The location, arrangement and capacity of the tank(s) should be further evaluated during the risk assessment.
- Bilge piping system and tanks serving the toxic areas and spaces should be made of a suitable material and/or properly coated/protected, in accordance with the provisions of Section 7.
- Bilge valves serving the toxic areas and spaces, are to be provided with means for remote operation located in a safe place outside the compartment to provide safe control and isolation of the bilge system when needed (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - Part 3 - Risk Assessment of a Generic Ship Design).

Comment on the discharge of ammonia effluents: The current provisions of the IMO's IBC Code may permit the discharge of small quantities of aqueous ammonia into the sea, subject to approval by the relevant authorities. However, for ammonia used as fuel, a unified regulatory approach is necessary. The IMO is expected to issue a dedicated guideline by the end of 2027. In the meantime, the recommended practice should be the collection of any ammonia effluents onboard, and their safe disposal to shore-based facilities.

- **Drip trays**

5.9.1 Drip trays should be fitted where leakage may occur which can cause damage to the ship structure or where limitation of the area which is affected from a spill is necessary.
5.9.2 Drip trays should be made of suitable material.
5.9.3 The drip tray should be thermally insulated from the ship's structure so that the surrounding hull or deck structures are not exposed to unacceptable cooling, in case of leakage of liquid fuel.
5.9.4 Each tray should be fitted with a drain valve to enable water to be drained over the ship's side where the tray is installed in a location where water may be retained.
5.9.5 Each tray should have a sufficient capacity to ensure that the assumed maximum amount of spill according to the risk assessment can be handled.

5.9.6 Drip trays should be provided with means to safely drain or transfer spills that contain ammonia to be contained or treated.

- **Arrangement of entrances and other openings in enclosed spaces**

5.10.1 Direct access should not be permitted from a non-hazardous area to a hazardous area. Where such openings are necessary for operational reasons, an airlock which complies with 5.11 should be provided.
5.10.2 Direct access should not be permitted from a non-toxic space to a toxic area or space. Where such openings are necessary for operational reasons, an airlock which complies with 5.11 should be provided.
Comment on MSC.1/Circ.1687, 5.10.1 & 5.10.2: These requirements could be merged as done, for example, in MSC.1/Circ.1687, 5.11.6.

5.10.3 For inerted spaces, access arrangements should be such that unintended entry by personnel should be prevented. If access to such spaces is not from an open deck, sealing arrangements should ensure that leakages of inert gas to adjacent spaces are prevented.
5.10.4 Arrangements for fuel storage hold spaces, void space, fuel tanks and other spaces classified as hazardous/toxic areas or spaces should be such as to allow entry and inspection of any such space by ship personnel wearing PPE and breathing apparatus, as well as to allow for the evacuation of injured or unconscious ship personnel. Such arrangements should comply with the following:
.1 access should be provided as follows:
.1 access to all fuel tanks. Access should be directly from open decks as far as practicable;
.2 access through horizontal openings, hatches or manholes. The size should be sufficient to allow a person wearing a breathing apparatus to ascend or descend any ladder without obstruction, and also to provide a clear opening to facilitate the hoisting of an injured person from the bottom of the space. The minimum clear opening is to be not less than 600 mm X 600 mm;
.3 access through vertical openings or manholes providing passage through the length and breadth of the space. The minimum clear opening should be not less than 600 mm × 800 mm at a height not more than 600 mm from the bottom plating, unless gratings or other footholds are provided; and
.4 circular access openings to type C tanks are to have a diameter of not less than 600 mm.
.2 the sizes referred to in 5.10.4.1.2 and 5.10.4.1.3 may be decreased, if 5.10.4 can be met to the satisfaction of the Administration.
.3 where fuel is carried in containment systems requiring secondary barriers, 5.10.4.1.2 and 5.10.4.1.3 do not apply to spaces separated from hold spaces by a single gastight steel boundary. Such spaces are to be provided only with direct or indirect access from open decks, excluding any enclosed non-hazardous areas.

Suggested additional requirement: Unless access to the fuel storage hold and/or interbarrier spaces is independent and direct from the open deck, it should be arranged as a bolted hatch and located at the top of the space.

- **Airlocks**

5.11.1 An airlock is a space enclosed by gastight bulkheads with two substantially gastight doors spaced at least 1.5 m and not more than 2.5 m apart. Unless subject to the requirements of the International Convention on Load Lines, the door sill should not be less than 300 mm in height. The doors should be self-closing without any holding back arrangements.

5.11.2 Airlocks should be mechanically ventilated at an overpressure relative to the adjacent hazardous/toxic area or space. *5.11.3 The airlock should be designed in a way that no gas can be released to safe spaces in case of the most critical event in the gas-dangerous space separated by the airlock. The events should be evaluated in the risk analysis according to 4.2.* *5.11.4 Airlocks should have a simple geometrical form. They should provide free and easy passage and should have a deck area of not less than 1.5 m2. Airlocks should not be used for other purposes, for instance as storerooms.* *5.11.5 An audible and visual alarm system to give a warning on both sides of the airlock should be provided to indicate if more than one door is moved from the closed position.* *5.11.6 For non-hazardous/non-toxic spaces with access from hazardous/toxic spaces below deck where the access is protected by an airlock, upon loss of underpressure in the hazardous/toxic space, access to the space is to be restricted until the ventilation has been reinstated. Audible and visual alarms should be given at a manned location to indicate both loss of pressure and opening of the airlock doors when pressure is lost.*
Further Recommendations
N/A

Section 6 - Fuel Containment System

HAZARDS
Systems concerned: Fuel tanks, pressure relief valves, Boil-off gas management system, Reliquefication systems, Thermal oxidation systems (Gas Combustion Unit), Interbarrier spaces. Fuel containment systems must ensure that leaks do not pose danger to the vessel or the crew, and ammonia should generally be stored in a refrigerated state at atmospheric pressure. The design must also consider pressure relief and tank venting systems, which are subject to stringent requirements, including minimum vent heights and safe discharge arrangements. Hazards to be considered include: • Loss of containment due to storage tank structural failure; • Release of toxic gases into the environment due to increased internal or external pressure beyond design capabilities; • Explosion caused by the ignition of flammable fuels; • Exposure of individuals to flammable, toxic, or asphyxiating gases; • Exposure of the ship's structural components to critically low temperatures that may compromise material integrity or operational safety; • Hazardous chemical reactions due to gas or material incompatibility.
GOAL
Ammonia storage is adequate to minimize the risk to personnel, the ship and the environment to a level that is equivalent to a conventional oil-fuelled ship.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
6.2.1: A fuel containment system should be so designed that a leak from the tank or its connections does not endanger the ship, persons on board or the environment. Potential dangers to be avoided include: exposure of ship materials to temperatures below acceptable limits, flammable fuels spreading to locations with ignition sources, toxicity potential and risk of oxygen deficiency due to fuels and inert gases, restriction of access to muster stations, escape routes and life-saving appliances (LSA), reduction in availability of LSA. *6.2.2: The pressure and temperature in the fuel tank should be kept within the design limits of the containment system and possible carriage requirements of the fuel.* *6.2.3: The fuel containment arrangement should be so designed that safety actions after any ammonia leakage do not lead to an unacceptable loss of power.*
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **General** *6.3.1 The ammonia fuel should be stored in a refrigerated state at atmospheric pressure.*

Comment 1 on MSC.1/Circ.1687, 6.3.1: To ensure clarity, it is suggested to be reworded.
Suggested rewording: "The ammonia fuel should be stored in a refrigerated state at atmospheric pressure under normal operating conditions."
Note: Reference should be made to SOLAS Chapter II-1 Regulation 3/5 for the definition of "*normal operating conditions*". In the context of using ammonia as fuel, this term can refer to the normal fuel supply to fuel consumers and bunkering operations, excluding activities related to maintenance, inerting or purging during which the ammonia supply system may not be fully operational.

Comment 2 on MSC.1/Circ.1687, 6.3.1: The storage of ammonia in liquid form above -30°C when using type-C tanks is technically feasible. However, it is not endorsed by the Interim Guidelines. It remains uncertain whether such design decisions can be accommodated by the alternative design and arrangements guidelines. Approval decisions are therefore subject to the agreement and evaluation of the relevant Administration on a case-by-case basis following risk assessment.

6.3.2 Tank connection spaces and fuel storage hold spaces other than for tank type C should be gastight towards adjacent spaces. These spaces should not be adjacent to accommodation spaces, service spaces, electrical equipment rooms and control stations by a single bulkhead or deck. "Adjacent" means linear contact and point contact.
6.3.3 Pipe connections to the fuel storage tank should be mounted above the highest liquid level in the tanks, except for type C fuel storage tanks. Connections below the highest liquid level may however, also be accepted for other tank types after special consideration by the Administration.
6.3.4 Piping between the tank and the first valve which release liquid in case of pipe failure should have safety equivalent to a type C tank, with dynamic stress not exceeding the values given in 6.4.15.3.1.2 of the IGF Code part A-1 [Refer to the original IGF Code for full requirement details].
6.3.5 If piping is connected below the liquid level of the tank, it has to be protected by a secondary barrier up to the first valve.
6.3.6 Means should be provided whereby liquefied gas in the storage tanks can be safely emptied.
6.3.7 It should be possible to empty, purge and vent fuel storage tanks with fuel piping systems. Instructions for carrying out these procedures must be available on board. Inerting should be performed with an inert gas prior to venting with dry air to avoid an explosion hazardous atmosphere in tanks and fuel pipes. For further information, the provisions of the IGF Code, part A-1, paragraph 6.10, should be taken into account:

> *IGF: 6.10.1 A piping system shall be arranged to enable each fuel tank to be safely gas-freed, and to be safely filled with fuel from a gas-free condition. The system shall be arranged to minimize the possibility of pockets of gas or air remaining after changing the atmosphere.*
> *IGF: 6.10.2 The system shall be designed to eliminate the possibility of a flammable mixture existing in the fuel tank during any part of the atmosphere change operation by utilizing an inerting medium as an intermediate step.*
> *IGF: 6.10.3 Gas sampling points shall be provided for each fuel tank to monitor the progress of atmosphere change.*
> *IGF: 6.10.4 Inert gas utilized for gas freeing of fuel tanks may be provided externally to the ship.*

- **Ammonia fuel containment**

6.4.1 Unless expressly provided otherwise, the requirements of the IGF Code, part A-1, chapter 6.4, should apply to ships using ammonia as fuel.

> *IGF: 6.4.1.1 The risk assessment required in 4.2 shall include evaluation of the ship's liquefied gas fuel containment system, and may lead to additional safety measures for integration into the overall vessel design.*
> *IGF: 6.4.1.2 The design life of fixed liquefied gas fuel containment system shall not be less than the design life of the ship or 20 years, whichever is greater.*

6.4.1.4 Liquefied gas fuel containment systems shall be designed in accordance with North Atlantic environmental conditions and relevant long-term sea state scatter diagrams for unrestricted navigation. Less demanding environmental conditions, consistent with the expected usage, may be accepted by the Administration for liquefied gas fuel containment systems used exclusively for restricted navigation. More demanding environmental conditions may be required for liquefied gas fuel containment systems operated in conditions more severe than the North Atlantic environment.

IGF: 6.4.1.5 Liquefied gas fuel containment systems shall be designed with suitable safety margins:

.1 to withstand, in the intact condition, the environmental conditions anticipated for the liquefied gas fuel containment system's design life and the loading conditions appropriate for them, which shall include full homogeneous and partial load conditions and partial filling to any intermediate levels; and

.2 being appropriate for uncertainties in loads, structural modelling, fatigue, corrosion, thermal effects, material variability, ageing and construction tolerances.

IGF: 6.4.1.6 The liquefied gas fuel containment system structural strength shall be assessed against failure modes, including but not limited to plastic deformation, buckling and fatigue. The specific design conditions that shall be considered for the design of each liquefied gas fuel containment system are given in 6.4.15. There are three main categories of design conditions:

.1 Ultimate Design Conditions…[Refer to the original IGF Code for full requirement details].

.2 Accidental Design Conditions…[Refer to the original IGF Code for full requirement details].

.3 Fatigue Design Conditions…[Refer to the original IGF Code for full requirement details].

IGF: 6.4.1.7 Measures shall be applied to ensure that scantlings required meet the structural strength provisions and are maintained throughout the design life. Measures may include, but are not limited to, material selection, coatings, corrosion additions, cathodic protection and inerting.

IGF: 6.4.1.8 An inspection/survey plan for the liquefied gas fuel containment system shall be developed and approved by the Administration. The inspection/survey plan shall identify aspects to be examined and/or validated during surveys throughout the liquefied gas fuel containment system's life and, in particular, any necessary in-service survey, maintenance and testing that was assumed when selecting liquefied gas fuel containment system design parameters. The inspection/survey plan may include specific critical locations as per 6.4.12.2.8 or 6.4.12.2.9.

IGF: 6.4.1.9 Liquefied gas fuel containment systems shall be designed, constructed and equipped to provide adequate means of access to areas that need inspection as specified in the inspection/survey plan. Liquefied gas fuel containment systems, including all associated internal equipment shall be designed and built to ensure safety during operations, inspection and maintenance.

IGF: 6.4.2.1 The containment systems shall be provided with a complete secondary liquid-tight barrier capable of safely containing all potential leakages through the primary barrier and, in conjunction with the thermal insulation system, of preventing lowering of the temperature of the ship structure to an unsafe level.

IGF: 6.4.2.2 The size and configuration or arrangement of the secondary barrier may be reduced or omitted where an equivalent level of safety can be demonstrated in accordance with 6.4.2.3 to 6.4.2.5 as applicable.

IGF: 6.4.2.3 Liquefied gas fuel containment systems for which the probability for structural failures to develop into a critical state has been determined to be extremely low but where the possibility of leakages through the primary barrier cannot be excluded, shall be equipped with a partial secondary barrier and small leak protection system capable of safely handling and disposing of the leakages (a critical state means that the crack develops into unstable condition). The arrangements shall comply with the following:

.1 failure developments that can be reliably detected before reaching a critical state (e.g. by gas detection or inspection) shall have a sufficiently long development time for remedial actions to be taken; and

.2 failure developments that cannot be safely detected before reaching a critical state shall have a predicted development time that is much longer than the expected lifetime of the tank.

IGF: 6.4.2.4 No secondary barrier is required for liquefied gas fuel containment systems, e.g. type C independent tanks, where the probability for structural failures and leakages through the primary barrier is extremely low and can be neglected.

IGF: 6.4.2.5 For independent tanks requiring full or partial secondary barrier, means for safely disposing of leakages from the tank shall be arranged.

IGF: 6.4.3 Secondary barriers in relation to tank types…[Refer to the original IGF Code for full requirement details].

IGF: 6.4.4 Design of secondary barriers…[Refer to the original IGF Code].

IGF: 6.4.5 Partial secondary barriers and primary barrier small leak protection system…[Refer to the original IGF Code].

IGF: 6.4.6 Supporting arrangements…[Refer to the original IGF Code].

IGF: 6.4.7 Associated structure and equipment…[Refer to the original IGF Code].

IGF: 6.4.8.1 Thermal insulation shall be provided as required to protect the hull from temperatures below those allowable (see 6.4.13.1.1) and limit the heat flux into the tank to the levels that can be maintained by the pressure and temperature control system applied in 6.9.

IGF: 6.4.9 Design loads…[Refer to the original IGF Code].

IGF: 6.4.10 Structural integrity…[Refer to the original IGF Code].

IGF: 6.4.11 Structural analysis…[Refer to the original IGF Code].

IGF: 6.4.12 Design conditions…[Refer to the original IGF Code].

IGF: 6.4.13 Materials and construction…[Refer to the original IGF Code].

IGF: 6.4.14 Construction processes…[Refer to the original IGF Code].

IGF: 6.4.15 Tank types…[Refer to the original IGF Code].

IGF: 6.4.16 Limit state design for novel concepts…[Refer to the original IGF Code].

6.4.2 The provision of 6.4.1.3 of the IGF Code part A-1 related to portable tanks should not apply to ships using ammonia as fuel.

- **Pressure relief system**

6.7.1.1 All fuel storage tanks should be provided with a pressure relief system appropriate to the design of the fuel containment system and the fuel being carried. Fuel storage hold spaces, interbarrier spaces and tank connection spaces, which may be subject to pressures beyond their design capabilities, should also be provided with a suitable pressure relief system. Pressure control systems specified in Section 6.9 should be independent of the pressure relief systems.

6.7.1.2 Fuel storage tanks which may be subject to external pressures above their design pressure should be fitted with vacuum protection systems.

6.7.2.1 Liquefied ammonia fuel tanks should be fitted with a minimum of two pressure relief valves (PRVs) allowing for disconnection of one PRV in case of malfunction or leakage.

6.7.2.2 Interbarrier spaces should be provided with pressure relief devices. For membrane systems, the designer should demonstrate adequate sizing of interbarrier space PRVs.

Comment on MSC.1/Circ.1687, 6.7.2.2: Refer to IACS Unified Interpretation *GC28 – "Guidance for sizing pressure relief systems for interbarrier spaces".*

6.7.2.3 The opening pressure of the pressure relief valves (PRVs) should not be higher than the vapour pressure that has been used in the design of the tank. Valves comprising not more than 50% of the total relieving capacity may be set at a pressure up to 5% above MARVS to allow sequential lifting, minimizing unnecessary release of vapour.

6.7.2.4 The following temperature provisions apply to PRVs fitted to pressure relief systems:

.1 PRVs on fuel tanks with a design temperature below 0°C should be designed and arranged to prevent their becoming inoperative due to ice formation;

.2 the effects of ice formation due to ambient temperatures should be considered in the construction and arrangement of PRVs;

.3 PRVs should be constructed of materials with a melting point above 925°C. Lower melting point materials for internal parts and seals may be accepted provided that fail-safe operation of the PRV is not compromised; and

.4 sensing and exhaust lines on pilot-operated relief valves should be of suitably robust construction to prevent damage.

6.7.2.5 In the event of a failure of a fuel tank PRV, a safe means of emergency isolation should be available, as follows:

.1 procedures should be provided and included in the operation manual (refer to Section 18);

.2 the procedures should allow only one of the installed PRVs for the liquefied gas fuel tanks to be isolated, physical interlocks should be included to this effect; and

.3 isolation of the PRV should be carried out under the supervision of the master. This action should be recorded in the ship's log, and at the PRV.

6.7.2.6 Each pressure relief valve installed on a liquefied ammonia fuel tank should be connected to a venting system, which should be:

.1 so constructed that the discharge will be unimpeded and normally be directed vertically upwards at the exit;

.2 arranged to minimize the possibility of water or snow entering the vent system; and

.3 arranged such that the height of vent exits should not be less than B/3 or 6 m, whichever is the greater, above the weather deck and 6 m above working areas and walkways. However, vent mast height could be limited to a lower value according to special consideration by the Administration.

6.7.2.7 The outlet from the pressure relief valves should normally be located at least B (greatest moulded breadth) or 25 m, whichever is less, from the nearest:

.1 air intake, air outlet or opening to accommodation, service and control spaces, or other non-hazardous area; and

.2 exhaust outlet from machinery installations.

6.7.2.8 All other fuel gas vent outlets should also be arranged in accordance with 6.7.2.6 and 6.7.2.7. Means should be provided to prevent liquid overflow from gas vent outlets, due to hydrostatic pressure from spaces to which they are connected.

6.7.2.9 In the vent piping system, means for draining liquid from places where it may accumulate should be provided. The PRVs and piping should be arranged so that liquid cannot, under any circumstances, accumulate in or near the PRVs.

6.7.2.10 Suitable protection screens of not more than 13 mm square mesh should be fitted on vent outlets to prevent the ingress of foreign objects without adversely affecting the flow.

6.7.2.11 All vent piping should be designed and arranged not to be damaged by the temperature variations to which it may be exposed, forces due to flow or the ship's motions.

6.7.2.12 PRVs should be connected to the highest part of the fuel tank. PRVs should be positioned on the fuel tank so that they will remain in the vapour phase at the filling limit (FL) as given in 6.8, under conditions of 15° list and 0.015L trim, where L is defined in 2.2.25 of the IGF Code.

- **Sizing of pressure relieving system**

[Refer to the original document of MSC.1/Circ.1687, 6.7.3 for full requirement details.]

Comment on MSC.1/Circ.1687, 6.7.3: The IGC's Code requirements may be used as a basis for the verification of safety valves:

IGC: 8.2.5.1 PRVs shall be type-tested. Type tests shall include:

.1 verification of relieving capacity;

.2 cryogenic testing when operating at design temperatures colder than -55°C;

.3 seat tightness testing; and

.4 pressure containing parts are pressure tested to at least 1.5 times the design pressure.

Note: PRVs shall be tested in accordance with recognized standards:

ISO 21013-1:2008 – Cryogenic vessels – Pressure-relief accessories for cryogenic service – part 1: Recloseable pressure-relief valves;

ISO 4126-1; 2004 Safety devices for protection against excessive pressure – part 1 and part 4: Safety valves

IGC: 8.2.5.2 Each PRV shall be tested to ensure that:

.1 it opens at the prescribed pressure setting, with an allowance not exceeding ± 10% for 0 to 0.15 MPaG, ± 6% for 0.15 to 0.3 MPaG, ± 3% for 0.3 MPaG and above;

.2 seat tightness is acceptable; and

.3 pressure containing parts will withstand at least 1.5 times the design pressure.

IGC: 8.2.6 PRVs shall be set and sealed by the Administration or recognized organization acting on its behalf, and a record of this action, including the valves' set pressure, shall be retained on board the ship.

- **Loading limit for fuel tanks**

6.8.1 Storage tanks for liquefied ammonia should not be filled to more than a volume equivalent to 98% full at the reference temperature as defined in 2.2.36 of the IGF Code.

LL = FL ρR/ρL

where:

LL = loading limit as defined in 2.2.27 of the IGF Code, expressed in per cent;

FL = filling limit as defined in 2.2.16 of the IGF Code expressed in per cent, here 98%;

ρR = relative density of fuel at the reference temperature; and

ρL = relative density of fuel at the loading temperature.

IGF: 2.2.36 Reference temperature means the temperature corresponding to the vapour pressure of the fuel in a fuel tank at the set pressure of the pressure relief valves (PRVs).

IGF: 2.2.16 Filling limit (FL) means the maximum liquid volume in a fuel tank relative to the total tank volume when the liquid fuel has reached the reference temperature.

IGF: 2.2.27 Loading limit (LL) means the maximum allowable liquid volume relative to the tank volume to which the tank may be loaded.

6.8.2 In cases where the tank insulation and tank location make the probability very small for the tank contents to be heated up due to an external fire, special considerations may be made to allow a higher loading limit than calculated using the reference temperature, but never above 95%.

Comment on MSC.1/Circ.1687, 6.8.2: The alternative loading limit option given under Section 6.8.2 is understood to be an alternative to the one given by Section 6.8.1. It should only be applicable when the calculated loading limit using the formulae given in Section 6.8.1 yields a lower value than 95%.

- **Maintaining fuel storage condition – Boil-off gas management**

6.9.1.1 The temperature of the liquefied ammonia in 6. should be maintained at a temperature of no more than -30°C at all times by means acceptable to the Administration. Systems and arrangements to be used for this purpose may include one, or a combination of, the following methods:

.1 reliquefaction of vapours;

.2 thermal oxidation of vapours; or

.3 liquefied ammonia fuel cooling.

The method chosen should be capable of maintaining the fuel temperature assuming no consumption for propulsion or power generation.

Comment on MSC.1/Circ.1687, 6.9.1.1:

- In case of maintenance activities, it may not always be feasible to maintain the temperature of liquefied ammonia in the fuel storage tanks below -30°C. In such cases, provided that the tank design pressure is sufficient, the pressure accumulation method should be considered appropriate to contain the resulting ammonia vapour without the need for venting. (see also comments on MSC.1/Circ.1687, 6.3.1**)**

6.9.1.2 Venting of fuel vapor for control of the tank pressure is not acceptable, except in emergency situations.

Comment on MSC.1/Circ.1687, 6.9.1.1 & 6.9.1.2: Clear criteria for the emergency situations where the direct release of ammonia may be acceptable need to be developed. The following phrasing from MARPOL VI/Reg. 3.1 could be used:

"This requirement shall not apply to any emission necessary for the purpose of securing the safety of a ship or saving life at sea; or any emission resulting from damage to a ship or its equipment, provided that all reasonable precautions have been taken after the occurrence of the damage or discovery of the emission for the purpose of preventing or minimizing the emission; and except if the owner or the master acted either with intent to cause damage, or recklessly and with knowledge that damage would probably result."

Reference is also made to IACS Unified Interpretation GF8, which clarifies that *"the activation of the safety system alone is not considered an emergency situation."*

6.9.2.1 For worldwide service, the upper ambient design temperature should be sea 32°C and air 45°C. For service in particularly hot or cold zones, these design temperatures should be increased or decreased, to the satisfaction of the Administration.

6.9.2.2 The overall capacity of the system should be such that it can control the temperature and pressure within the design conditions without venting to atmosphere.

- **Reliquefaction systems**

6.9.3.1 The reliquefaction system should be arranged in one of the following ways:

.1 a direct system where evaporated fuel is compressed, condensed, and returned to the fuel tanks;

.2 an indirect system where fuel or evaporated fuel is cooled or condensed by refrigerant without being compressed;

.3 a combined system where evaporated fuel is compressed and condensed in a fuel/refrigerant heat exchanger and returned to the fuel tanks; or

.4 if the reliquefaction system produces a waste stream containing ammonia during pressure control operations within the design conditions, these waste gases should be disposed of without venting to the atmosphere.

- **Thermal oxidation systems**

6.9.4 Thermal oxidation can be done by either consumption of the vapours according to the provisions for fuel consumers described in these Interim Guidelines or in a dedicated gas combustion unit. It should be demonstrated that the capacity of the oxidation system is sufficient to consume the required quantity of vapours.

- **Compatibility**

6.9.5 Refrigerants or auxiliary agents used for refrigeration or cooling of fuel should be compatible with the fuel they may come in contact with (not causing any hazardous reaction or excessively corrosive products). In addition, when several refrigerants or agents are used, these should be compatible with each other.

- **Availability of Systems**

6.9.6.1 The availability of the system and its supporting auxiliary services should be such that in case of a single failure (of a mechanical non-static component or a component of the control systems) the fuel tank pressure and temperature can be maintained by another service/system.
6.9.6.2 Heat exchangers that are solely necessary for maintaining the pressure and temperature of the fuel tanks within their design ranges should have a standby heat exchanger unless they have a capacity in excess of 25% of the largest required capacity for pressure control and they can be repaired on board without external sources.

6.10 The IGF Code chapter 6 should be taken into account, where applicable, in order to fulfil the functional requirements.

Applicable references from the IGF Code:

Atmospheric control within the fuel containment system

IGF: 6.10.1 A piping system shall be arranged to enable each fuel tank to be safely gas-freed, and to be safely filled with fuel from a gas-free condition. The system shall be arranged to minimize the possibility of pockets of gas or air remaining after changing the atmosphere.
IGF: 6.10.2 The system shall be designed to eliminate the possibility of a flammable mixture existing in the fuel tank during any part of the atmosphere change operation by utilizing an inerting medium as an intermediate step.
IGF: 6.10.3 Gas sampling points shall be provided for each fuel tank to monitor the progress of atmosphere change.
IGF: 6.10.4 Inert gas utilized for gas freeing of fuel tanks may be provided externally to the ship.

Inert gas production and storage on board

IGF: 6.13.1 Arrangements to prevent back-flow of fuel vapour into the inert gas system shall be provided as specified below.
IGF: 6.13.2 To prevent the return of flammable gas to any non-hazardous spaces, the inert gas supply line shall be fitted with two shutoff valves in series with a venting valve in between (double block and bleed valves). In addition, a closable non-return valve shall be installed between the double

block and bleed arrangement and the fuel system. These valves shall be located outside non-hazardous spaces.
IGF: 6.13.3 Where the connections to the fuel piping systems are non-permanent, two non-return valves may be substituted for the valves required in 6.13.2.
IGF: 6.13.4 The arrangements shall be such that each space being inerted can be isolated and the necessary controls and relief valves, etc. shall be provided for controlling pressure in these spaces.
IGF: 6.13.5 Where insulation spaces are continually supplied with an inert gas as part of a leak detection system, means shall be provided to monitor the quantity of gas being supplied to individual spaces.
IGF: 6.14.1 The equipment shall be capable of producing inert gas with oxygen content at no time greater than 5% by volume. A continuous-reading oxygen content meter shall be fitted to the inert gas supply from the equipment and shall be fitted with an alarm set at a maximum of 5% oxygen content by volume.
IGF: 6.14.2 An inert gas system shall have pressure controls and monitoring arrangements appropriate to the fuel containment system.
IGF: 6.14.3 Where a nitrogen generator or nitrogen storage facilities are installed in a separate compartment outside of the engine-room, the separate compartment shall be fitted with an independent mechanical extraction ventilation system, providing a minimum of 6 air changes per hour. A low oxygen alarm shall be fitted.
IGF: 6.14.4 Nitrogen pipes shall only be led through well-ventilated spaces. Nitrogen pipes in enclosed spaces shall:

- be fully welded;
- have only a minimum of flange connections as needed for fitting of valves; and
- be as short as possible.

Suggested additional requirements:

- The composition of the inert gas used to purge ammonia from the tank should be compatible with ammonia.
- Interbarrier and fuel storage hold spaces requiring only a partial secondary barrier can be filled with dry air provided that the ship maintains a stored charge of inert gas, or is fitted with an inert gas generation system sufficient to inert the largest of these spaces, and provided that the configuration of the spaces and the relevant vapor detection systems, together with the capability of the inerting arrangements, ensures that any leakage from the liquefied gas fuel tanks will be rapidly detected and inerting effected before a dangerous condition can develop. Equipment for the provision of sufficient dry air of suitable quality to satisfy the expected demand should be provided.

Further Recommendations

N/A

Section 7 - Material and General Pipe Design

HAZARDS
Systems concerned: Fuel piping systems, expansion joints, fuel tanks, pressure vessels and other pressure-bearing equipment. Compatibility with ammonia, which is known to cause stress corrosion cracking in certain metals. Piping must be robust and thermally insulated where necessary and designed to avoid the accumulation or phase change of fuel. Hazards to be considered include: • Ammonia-induced corrosion and Stress Corrosion Cracking (SCC). • Structural failure resulting from material defects or improper material selection with respect to mechanical properties. • Fatigue failure caused by repeated thermal expansion and contraction cycles, or vibration. • Piping failure due to excessive mechanical stresses (overpressure, thermal stresses, trapped fluid.
GOAL
Ensure the safe handling of fuel, under all operating conditions, to minimize the risk to the ship, personnel and to the environment, having regard to the nature of the products involved.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
7.2.1.1: Fuel piping should be capable of absorbing thermal expansion or contraction caused by temperatures of the fuel without developing substantial stresses. *7.2.1.2: Provision should be made to protect the piping, piping system and components and fuel tanks from excessive stresses due to thermal movement and from movements of the fuel tank and hull structure.* *7.2.1.3: If the fuel gas contains heavier constituents that may condense in the system, means for safely removing the liquid should be fitted.* *7.2.1.4: Low-temperature piping should be thermally isolated from the adjacent hull structure, where necessary, to prevent the temperature of the hull from falling below the design temperature of the hull material.* *7.2.1.5: Materials should be selected considering the relevant properties of ammonia. Consideration should be given to the corrosiveness of the fuel according to the relevant environment conditions, including stress corrosion cracking. System components other than piping that are likely to come into contact with and be degraded by ammonia in a leakage scenario should be compatible with ammonia.* *7.2.1.6: Fuel piping should be designed to prevent fuel from unintended accumulation in piping in consideration of the characteristics of ammonia. In addition, fuel piping should be arranged for emptying, inerting and gas freeing.*
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)

- **General**

7.3.1 Fuel piping systems for liquid ammonia should as a minimum have a design pressure of 18 bar, corresponding to the vapor pressure of ammonia at 45°C, to prevent venting of ammonia in idle conditions. Fuel piping systems for gaseous ammonia should as a minimum have a design pressure of 10 bar. For fuel piping systems for liquid ammonia fitted with closed loop pressure relief arrangements routed back to the fuel storage tank, the minimum design pressure should as a minimum have a design pressure of 10 bar.
7.3.2 Expansion joints and bellows should not be used in ammonia fuel piping systems. Engine-mounted expansion bellows could be accepted based on evaluation, as reflected in the safety concept of the engine.

Comments on MSC.1/Circ.1687, 7.3.2:

- This content appears to be more appropriately categorised under Section 10, ' Power generation including propulsion and other fuel consumers '.
- It should be clarified that engine mounted expansion bellows should be of double-wall type and type-approved by Classification Society.
- A definition for the "*safety concept of the engine*" is additionally needed. It is suggested to adopt the one provided by the IACS Unified Requirement M78: *"Safety Concept is a document describing the safety philosophy with regard to gas as fuel".* Reference should be made also to the Section 1.5 "Safety concept" of the same UR, for the scope and required content of subject document.

7.3.3 Anhydrous ammonia may cause stress corrosion cracking in containment and process systems made of carbon-manganese steel or nickel steel. To minimize the risk of this occurring, measures detailed in 17.12.2 to 17.12.7 of the IGC Code should be taken, as appropriate.

- **Reference to the IGF Code**

7.4 The IGF Code chapter 7 should be taken into account, where applicable, in order to fulfil the functional requirements.

<u>Other applicable references from the IGC</u>:

IGC: 17.12.2 Where carbon-manganese steel is used, cargo tanks, process pressure vessels and cargo piping shall be made of fine-grained steel with a specified minimum yield strength not exceeding 355 N/mm2, and with an actual yield strength not exceeding 440 N/mm2. One of the following constructional or operational measures shall also be taken:

.1 lower strength material with a specified minimum tensile strength not exceeding 410 N/mm2 shall be used; or
.2 cargo tanks, etc., shall be post-weld stress relief heat treated; or
.3 carriage temperature shall be maintained, preferably at a temperature close to the product's boiling point of -33°C, but in no case at a temperature above -20°C; or
.4 the ammonia shall contain not less than 0.1% w/w water, and the master shall be provided with documentation confirming this.

IGC: 17.12.3 If carbon-manganese steels with higher yield properties are used other than those specified in 17.12.2, the completed cargo tanks, piping, etc., shall be given a post-weld stress relief heat treatment.

Comment on IGC Code, 17.12.3: For Type C tanks constructed from carbon and carbon-manganese steels, the IGC Code mandates that Post Weld Heat Treatment (PWHT) is required when the design temperature is below -10°C. However, according to the IACS Unified Requirement W1-1975, an exemption to the standard post-weld stress relief heat treatment may be granted, provided that an alternative approach, such as Engineering Critical Assessment (ECA), is approved by the Classification Society or follows recognised standards.

IGC: 17.12.4 Process pressure vessels and piping of the condensate part of the refrigeration system shall be given a post-weld stress relief heat treatment when made of materials mentioned in 17.12.2.
IGC: 17.12.5 The tensile and yield properties of the welding consumables shall exceed those of the tank or piping material by the smallest practical amount.
IGC: 17.12.6 Nickel steel containing more than 5% nickel and carbon-manganese steel, not complying with the requirements of 17.12.2 and 17.12.3, are particularly susceptible to ammonia stress corrosion cracking and shall not be used in containment and piping systems for the carriage of this product.
IGC: 17.12.7 Nickel steel containing not more than 5% nickel may be used, provided the carriage temperature complies with the requirements specified in 17.12.2.3.

Other applicable references from the IGF Code:

IGF: 7.3.1.1 Fuel pipes and all the other piping needed for a safe and reliable operation and maintenance shall be colour marked in accordance with a standard at least equivalent to the EN ISO 14726:2008 Ships and marine technology – Identification colours for the content of piping systems.
IGF: 7.3.1.2 Where tanks or piping are separated from the ship's structure by thermal isolation, provision shall be made for electrically bonding to the ship's structure both the piping and the tanks. All gasketed pipe joints and hose connections shall be electrically bonded.
IGF: 7.3.1.3 All pipelines or components which may be isolated in a liquid full condition shall be provided with relief valves.
IGF: 7.3.1.4 Pipework, which may contain low temperature fuel, shall be thermally insulated to an extent which will minimize condensation of moisture.
IGF: 7.3.1.5 Piping other than fuel supply piping and cabling may be arranged in the double wall piping or duct provided that they do not create a source of ignition or compromise the integrity of the double pipe or duct. The double wall piping or duct shall only contain piping or cabling necessary for operational purposes.
IGF: 7.3.2.1 The minimum wall thickness shall be calculated as follows…[Refer to the original IGF Code for full requirement details]
IGF: 7.3.2.2 The absolute minimum wall thickness shall be in accordance with a standard acceptable to the Administration.
IGF: 7.3.3.1 The greater of the following design conditions shall be used for piping, piping system and components …[Refer to the original IGF Code for full requirement details.]
IGF: 7.3.3 Design condition…[Refer to the original IGF Code for full requirement details]
IGF: 7.3.4 Allowable stress…[Refer to the original IGF Code for full requirement details]
IGF: 7.3.5 Flexibility of piping…[Refer to the original IGF Code for full requirement details]
IGF: 7.3.6 Piping fabrication and joining details…[Refer to the original IGF Code for full requirement details]
IGF: 7.4.1.1 Materials for fuel containment and piping systems shall comply with the minimum regulations given in the tables 7.1 to 7.5…[Refer to the original IGF Code for full requirement details.]
IGF: 7.4.1.2 Materials having a melting point below 925°C shall not be used for piping outside the fuel tanks.

IGF: 7.4.1.4 Where required the outer pipe or duct containing high pressure gas in the inner pipe shall as a minimum fulfil the material regulations for pipe materials with design temperature down to minus 55°C in table 7.4.
Further Recommendations
Suggested additional requirement: Materials that may be directly exposed to ammonia during normal operations should be resistant to the corrosive actions and environmentally assisted cracking associated with ammonia service. .1 Materials of construction such as aluminium and austenitic stainless steel may be applied in ammonia service; .2 The following materials are not to be used: Mercury, cadmium, copper, zinc or alloys of these materials; .3 Components of rubber or plastic materials that are likely to deteriorate if exposed to ammonia are not to be used. The use of alternative metallic materials for ammonia service may be accepted subject to the IMO Guidelines MSC.1/Circ.1622, as amended by MSC.1/Circ.1648. **Note:** Materials that encounter or may potentially be exposed to ammonia (e.g., in the event of a leak) should be evaluated: .1 to ensure they meet design criteria .2 are suitable for operation at the service temperatures .3 have established aging properties appropriate for the design life .4 and have sufficient damage susceptibility

Section 8 - Bunkering

HAZARDS
Systems concerned: Bunkering station, Bunkering hoses, Bunkering manifold, Emergency Shutdown (ESD), Drip trays, Water spray system. Bunkering procedures are addressed in detail to prevent fuel leaks or accidental discharges during refuelling. This includes requirements for hose design, manifold configuration, purging systems, and emergency release systems to ensure safe operations even under adverse conditions. Hazards to be considered include: • Ammonia loss of containment (leakage) due to material degradation, pipe connection failure, operator errors, hose/loading arm failure, hose quick-release arrangement, mooring line failure, communication failure, personnel injuries, fire, blackout, ship collision, fender burst, vessel excessive movements, extreme weather conditions, passing vessel/marine traffic, uncontrolled venting.
GOAL
Provide suitable bunkering systems on board the ship and to ensure that bunkering can be conducted without causing danger to persons, the environment, or the ship. Systems should ensure the safe handling of fuel at all times and under all operating conditions
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
3.2.12: Safe and suitable fuel supply, storage and bunkering arrangements should be made, capable of receiving and containing the fuel in the required state without leakage. Other than when necessary for safety reasons, fuel supply, storage and bunkering arrangements should be designed to prevent venting under all normal operating conditions, including idle periods. *8.2.1.1: The piping system for transfer of fuel to the storage tanks should be designed such that any leakage from the piping system cannot cause danger to persons, the environment or the ship.*
Further Recommendations
N/
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **General** **Comment on MSC.1/Circ.1687, 8.3.1.1 to 8.5.9**: The application of the requirements of Sections 8.3 to 8.5 that may be affected by specific bunkering vessel arrangements and relate to the bunkering procedures and operations are to be evaluated on a case-by-case basis as part of the risk assessment required in Section 4. *8.3.1.1 Enclosed or semi-enclosed bunkering stations should be gastight towards adjacent spaces. The term "adjacent" includes linear contact and point contact.*

8.3.1.2 Air intakes and openings in accommodation spaces, service spaces, engine rooms and control stations should not be located in hazardous and toxic areas associated with bunkering stations.

Comment on MSC.1/Circ.1687, 8.3.1.2: As per the 12.bis.4.1.1, 10 m is the minimum distance a bunker station can be from air intakes and openings in accommodation spaces, service spaces, engine rooms, and control stations. During bunkering operations, such openings should remain closed.

8.3.1.3 Connections and piping should be so positioned and arranged that any damage to the bunkering piping does not cause damage to the ship's fuel containment system resulting in an uncontrolled fuel discharge.
8.3.1.4 Bunkering piping should not be led through accommodation spaces, service spaces, electrical equipment rooms or control stations. Where bunkering piping is arranged in other enclosed spaces, bunkering piping should pass through a secondary enclosure meeting the requirements of 9.5.1.
8.3.1.5 Arrangements should be made for safe management of any spilled fuel.
8.3.1.6 Suitable means should be provided to relieve the pressure and remove ammonia contents from pump suctions and bunker lines. Ammonia is to be discharged to the fuel tanks or other suitable location.
8.3.1.7 The surrounding hull or deck structures should not be exposed to unacceptable cooling, in case of leakage of fuel.

Additional requirement, 1: Enclosed or semi-enclosed bunkering stations should be provided with an effective mechanical primary ventilation system of the extraction type, enabling a ventilation rate of at least 30 air changes per hour. The ventilation system should ensure a negative differential pressure between toxic spaces and surrounding spaces.
Comment on the additional requirement, 1: For semi-enclosed bunkering stations, achieving a negative differential pressure relative to surrounding spaces may not be feasible due to the open nature of the space. In such cases, the required air change rate should be calculated based on the volume of the space assuming the open side is temporarily enclosed.

Additional requirement, 2:
A water spray system suitable for diluting the ammonia toxic vapours in a leakage scenario should be arranged at the bunker manifold area, covering all possible leakage points. The system is to be operated in the control location for bunkering operations and from another safe location. An arrangement to collect leakages on deck should be provided in accordance with Section 5.8 (bilge system) and Section 5.9 (drip trays). The water spray system design should ensure that water is not sprayed directly onto liquid ammonia collected in the drip trays, as this may increase evaporation and exacerbate the release of toxic vapours. The size and capacity of the leakage collection system should be arranged to safely handle probable maximum spills and water from the spray system provided at the manifold area. Draining overboard of the collection should be accepted only in case of an emergency. Alternative arrangements to mitigate ammonia leakages and/or limit the vapour dispersion may be evaluated separately, under the alternative design approach requirements.
Comments on the on the additional requirement, 2:

- Ammonia can be easily absorbed in water, so a water spray system may be used to reduce the rate of gas dispersion by absorbing any ammonia clouds caused by leakages. However, it is to be noted that the ammonia cloud dispersion will be largely affected by the release phase, whether it is pure vapor, a two-phase aerosol mixture, or cold liquid, as well as by ambient conditions and leak volumes. These factors require further investigation.
- Precautions are also to be made for the resulting aqueous ammonia solution (ammonium hydroxide) which is caustic and can corrode surfaces.

- The water spray system installed either on the receiving or supplier vessel, should be capable of remote activation and located in an accessible area.

- **Ship's fuel hoses**

8.3.2.1 Liquid and vapour hoses used for fuel transfer should be compatible with the fuel and suitable for the fuel temperature.
8.3.2.2 Hoses subject to tank pressure, or the discharge pressure of pumps or vapour compressors, should be designed for a bursting pressure not less than five times the maximum pressure the hose can be subjected to during bunkering. Hoses should be regularly visually inspected, and hydrostatic pressure tested periodically at not more than a five-year interval.

Comment on MSC.1/Circ.1687, 8.3.2.2: The prescribed five-year interval for hydrostatic pressure testing of hoses appears excessive given the high risks associated with ammonia bunkering operations. It is suggested that tests should be based on manufacturer's recommendations. Besides this, there are industry standards requiring annual test intervals (ref. ANSI/CGA G-2.1-2014 Requirements for the Storage and Handling of Anhydrous Ammonia)

8.3.2.3 Where fuel hoses are stored on the open deck or in a storage room, arrangements should be made for safe storage of the hoses.

Suggested additional requirements:

- To prevent ignition by electrical arcing caused by static electricity buildup in the bunker hoses during bunkering, or differences in electrical potential between the receiving ship and bunker facility, an insulating gasket flange should be fitted at the one end of the bunker hose, in addition to an electrically continuous bunker hose connection on the other end, following the recommendation provided by SIGTTO in its publication "*A Justification into the Use of Insulation Flanges (and Electrically Discontinuous Hoses) at the Ship/Shore and Ship/Ship Interface".*
- Bunker hoses are also to comply with ISO 5771:2024 *"Rubber Hoses and Hoses Assemblies for Transferring Anhydrous Ammonia – Specification"*. This international standard specifies the minimum requirements for rubber hoses used to transfer ammonia in liquid or in gaseous forms at temperatures from -40° C to +55° C.

Recommendation:

- It is recommended that the bunker hoses be stored horizontally, blanked from both ends, and slightly pressurised with inert gas to avoid corrosion.

Comment on MSC.1/Circ.1687, 8.3.2.1-8.3.2.3:

- It is currently unclear which authority should be responsible for reviewing and implementing criteria related to bunkering hoses and corresponding operational items. Fuel hoses are typically not installed on a receiving vessel and not covered under SOLAS certification, falling outside the scope of Flag Administrations.

- **Bunkering manifold**

8.4.1 The bunkering manifold should be designed to withstand the external loads during bunkering. The connections at the bunkering station should be arranged in order to achieve a dry-disconnect operation in one of the followings ways:

.1 a dry-disconnect/connect coupling.

.2 a manual connect coupler or hydraulic connect coupler, used to connect the bunker system to the receiving vessel bunkering manifold presentation flange; or

.3 a bolted flange to flange assembly.

8.4.2 When intended to use either of the connections specified above, these should be combined with operating procedures that ensure a dry-disconnect is achieved. The arrangement should be subject to special consideration informed by a bunkering arrangement risk assessment conducted at the design stage and considering dynamic loads at the bunkering manifold connection, the safe operation of the ship and other hazards that may be relevant to the ship during bunkering operation. The fuel handling manual shall include documentation that the bunkering arrangement risk assessment was conducted, and that special consideration was granted under this requirement.

8.4.3 An emergency release coupler (ERC)/emergency release system (ERS) or equivalent means should be provided, unless installed on the bunkering supply side of the bunkering line. It should enable a quick physical disconnection "dry break-away" of the bunker system in an emergency event.

Comment on MSC.1/Circ.1687, 8.4.1-8.4.3:

- ISO is expected to develop standards for dry-disconnect type couplings for ammonia bunkering in the same way as ISO 21593:2019 *"Technical Requirements for Dry-Disconnect/Connect Couplings for Bunkering Liquefied Natural Gas"* was developed for LNG dry-disconnect couplings. Additional safety measures such as dry breakaway or self-sealing quick-release couplings need to be further investigated.

- **Bunkering system**

8.5.1 An arrangement for purging fuel bunkering lines with inert gas should be provided.

8.5.2 The bunkering system should be so arranged that no gas is discharged to the atmosphere during filling of storage tanks. Vapour return line, where fitted, should be sized adequately taking into consideration the expansion ratio of the fuel during bunkering operations.

8.5.3 A manually operated stop valve and a remote operated shutdown valve in series, or a combined manually operated and remote valve should be fitted in every bunkering line close to the connecting point. It should be possible to operate the remote valve in the control location for bunkering operations and/or from another safe location.

Suggested additional requirement : The remote -operated valve should be of the fail -close type (closed on loss of actuating power), as well as capable of local manual closure, and display indicating the actual valve position.

8.5.4 A bunkering-safety link (BSL), or an equivalent means for automatic and manual ESD communication to the bunkering source should be fitted.

8.5.5 Means should be provided for draining any fuel from the bunkering pipes upon completion of operation.

8.5.6 Bunkering lines should be arranged for inerting and gas freeing. Means to confirm the absence of residual liquid should be provided. When not engaged in bunkering, the bunkering pipes should be free of gas, or residual liquid, unless the consequences of not gas freeing are evaluated and approved by the Administration.

8.5.7 In case bunkering lines are arranged with a cross-over, it should be ensured by suitable isolation arrangements that no fuel is transferred inadvertently to the ship side not in use for bunkering.

8.5.8 If not demonstrated to be required at a higher value due to pressure surge considerations a default time as calculated in accordance with 16.7.3.7 of the IGF Code from the trigger of the alarm to full closure of the remote operated valve required by 8.5.3 should be adjusted.

*IGF: 16.7.3.7 The closing time of the valve (i.e. time from shutdown signal initiation to complete valve closure) shall not be greater than: 3600*U / BR (second), where:*

U = ullage volume at operating signal level (m^3);

BR= maximum bunkering rate agreed between ship and shore facility (m^3/h); or 5 seconds, whichever is the least. *The bunkering rate shall be adjusted to limit surge pressure on valve closure to an acceptable level, taking into account the bunkering hose or arm, the ship and the shore piping systems, where relevant.* *8.5.9 Sampling valves, if fitted, should be arranged at suitable locations in the bunkering line to allow verification procedures to confirm that the bunkering line is safe before opening any flanges. A double shut-off, blank flange or plug should be installed on sampling valves in the bunkering line.* **Recommendation:** • Filters are to be provided in the ammonia bunkering system to prevent any debris, dirt, and foreign particles or impurities from entering the fuel storage tanks or damaging critical instrumentation. Differential pressure sensors with alarm functions shall be installed to detect clogging and ensure timely maintenance (ref. EMSA- Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 - Risk Assessment of a Generic Ship Design).
Further Recommendations
N/A

Section 9 - Fuel Supply to Consumers

HAZARDS
Hazards of relevance to the fuel supply to consumers relate to: • Overpressure • Ammonia release • Thermal issues (stresses, unintentional phase change) • Contamination • Fuel starvation • Material incompatibility (corrosion) • Loss of function
GOAL
Ensure safe and reliable distribution of fuel to the consumers
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
9.2.1: The fuel supply system should be designed so as to avoid direct release of ammonia to the atmosphere during normal operation and during any foreseeable and controllable abnormal scenario, while providing safe access for operation and inspection. *9.2.2: The piping system for fuel transfer to the fuel consumers should be designed in a way that a failure of one barrier cannot lead to a leak from the piping system into the surrounding area causing danger to the persons on board, the environment or the ship.* *9.2.3: Fuel lines outside the machinery spaces should be installed and protected so as to minimize the risk of injury to personnel and damage to the ship in case of leakage.* *9.2.4: The fuel supply system should be designed and arranged not to cause unintentional phase changes within the fuel supply system.* *9.2.5: Operational gas releases should be collected and handled by a suitable ammonia release mitigation system.*
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **Redundancy** *9.3.1 For single fuel installations, the fuel supply system should be arranged with full redundancy and segregation all the way from the fuel tanks to the fuel consumer, so that a leakage in one system does not lead to an unacceptable loss of power.* *9.3.2 For single fuel installations, the fuel storage should be divided between two or more tanks. The tanks should be located in separate compartments.* *9.3.3 For type C tank only, one tank may be accepted if two completely separate tank connection spaces are installed for the one tank.* **Suggested rewording:** *For single fuel installations with a type C tank, one tank may be accepted if two completely separate tank connection spaces are arranged for that tank.*

Suggested additional requirement:

- For single fuel installations, the propulsion, auxiliary arrangements and fuel supply system should be arranged so that in the case of emergency shutdown of the fuel gas supply, the propulsion and manoeuvring capability, together with power for essential services, can be maintained. Dual fuel engine installations are considered to meet this redundancy objective by their inherent provision of independent gas and liquid fuel systems.
- For dual-fuel installations the storage capacity of oil fuel should be sufficient to provide the necessary redundancy in case of loss of ammonia fuel supply.

Recommendation:

- A list of critical spare parts for the ammonia fuel supply system shall be provided by the system designer. This list shall include components essential for maintaining system operability and maintenance activities. The identification of these critical items shall be based on reliability assessments, manufacturer recommendations, and the outcomes of risk assessment (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships – Part 2 – Safety Assessment and Reliability Analysis of Main Components, Equipment, Sub-systems and Systems & Part 3 - Risk Assessment of a Generic Ship Design).

- **Safety functions**

9.4.1 Fuel storage tank inlets and outlets should be provided with valves located as close to the tank as possible. Valves required to be operated during normal operation which are not accessible should be remotely operated. Tank valves, whether accessible or not, should be automatically operated when the safety system required in 15.2.2 is activated.

Comment on MSC.1/Circ.1687, 9.4.1: *Normal operation* in this context is when fuel is supplied to fuel consumers and during bunkering operations.

Suggested additional requirement, 1: Tank valves should be of the fail-to-close type (i.e., close on loss of actuating power) and be capable of local manual closure with positive indication of the actual valve position.

9.4.2 The main fuel supply line and return lines to each fuel consumer or set of consumers should be equipped with a manually operated stop valve and an automatically operated "master fuel valve" coupled in series or a combined manually and automatically operated valve. The valves should be situated in the part of the piping that is outside the machinery space containing fuel consumers and placed as near as possible to the installation for heating the fuel, if fitted. The master fuel valve should automatically cut off the fuel supply when activated by the safety system required in 15.2.2.
9.4.3 The automatic master fuel valve should be operable from safe locations on escape routes inside a machinery space containing a fuel consumer, the engine control room, if applicable; outside the machinery space, and from the navigation bridge.

Suggested addition to MSC.1/Circ.1687, 9.4.3 : The activation device for the master fuel valve(s) should be arranged as a physical button, duly marked and protected against inadvertent operation and operable under emergency lighting.

9.4.4 The fuel supply lines to fuel preparation rooms should be equipped with automatically operated shut-off valves situated at the bulkhead inside the fuel preparation room.

Suggested additional requirement, 2: The automatic fuel preparation shutdown valve required in 9.4.4 may be the fuel tank valve as referred to in 9.4.1 subject to detailed evaluation during the risk assessment.

9.4.5 Each fuel consumer should be provided with "double block and bleed" valves arrangement. These valves should be arranged as outlined in .1 or .2 so that when the safety system required in 15.2.2 is activated, this will cause the shutoff valves that are in series to close automatically and the bleed valve to open automatically, and:

.1 the two shutoff valves should be in series in the fuel pipe to the fuel consuming equipment. The bleed valve should be in a pipe that vents to a suitable ammonia release mitigation system that portion of the fuel piping that is between the two valves in series; or

.2 the function of one of the shutoff valves in series and the bleed valve can be incorporated into one valve body, so arranged that the flow to the fuel utilization unit will be blocked and the ventilation opened.

9.4.6 The two valves should be of the fail-to-close type, while the ventilation valve should be fail-to-open.

9.4.7 The fuel supply system should include an ammonia release mitigation system capable of collecting and handling ammonia releases, including but not limited to:

.1 bleed from double block and bleed arrangements on the fuel piping systems;

.2 releases from the opening of pressure relief valves in the fuel piping system; and

.3 releases from purging and draining operations of fuel pipes.

Suggested addition to MSC.1/Circ.1687, 9.4.7 : The need to manage other potential ammonia leaks or releases, such as those coming from engine combustion processes or from the ammonia-effluent bilge system, should be assessed as part of the risk assessment.

9.4.8 The release mitigation system should be capable of reducing the ammonia concentration to below 110 ppm. Discharges from the release mitigation system should be arranged in accordance with 6.7.2.7.

9.4.9 Where fuel supply systems supply ammonia in the liquid state, relevant bleed lines and vent lines should be led to the fuel tank or gas-liquid separator or similar device to prevent ammonia liquid from being released to the atmosphere.

Suggested additional requirement, 3: All fuel pipelines or components that may be isolated in a liquid -full condition should be provided with thermal relief valves. The vent lines from these valves should be routed to a safe discharge point, such as the Ammonia Release Mitigation System (ARMS), or back to the fuel tank, or an equivalent containment system, depending on the system design and safety considerations.

9.4.10 The double block and bleed valves should also be used for normal stop of the engine.

9.4.11 In cases where the master fuel valve is automatically shut down when the safety system as required in 15.2.2 is activated, the complete fuel supply branch downstream of the double block and bleed valve should be automatically purged through the ammonia release mitigation system.

9.4.12 There should be one manually operated shutdown valve in the fuel supply line to each engine upstream of the double block and bleed valves to assure safe isolation during maintenance on the engine. Where fuel is recirculated from each engine to the fuel supply piping, one manually operated shutoff valve should also be provided downstream of the double block bleed valve in the fuel return piping for each engine.

9.4.13 For single-engine installations and multi-engine installations, where a separate master valve is provided for each engine, the master fuel valve and the double block and bleed valve functions can be combined.

Suggested addition to MSC.1/Circ.1687, 9.4.13: The combined master fuel valve and double block and bleed valves should be located outside the machinery space. Where such valves are within fuel preparation rooms, that room should be protected by another automatic shutdown valve located outside the room.

Recommendation: The components of the fuel supply system incorporating the *"double block and bleed"* valve arrangement (i.e. commonly referred to as the Fuel Valve Train (FVT), Gas Valve Unit (GVU), or Gas Valve Train (GVT)) may be located within a dedicated gas-tight space which can be the Fuel Preparation Room or a dedicated GVU/GVT room. If installed in double barrier enclosure, this can be positioned between the fuel preparation room and the fuel consumer room, in accordance with the manufacturer's recommendations, with the aim of minimising the inventory of toxic gas that could be released in the event of a piping system failure.

9.4.14 Where gaseous ammonia fuel is supplied to a consumer, provisions should be made to prevent ammonia condensate from entering the consumer.

Additional recommendations:

- In the event of a main electrical power failure and following an emergency shutdown of the fuel supply system, appropriate means for managing the residual ammonia remaining in the fuel piping shall be provided in accordance with the system's safety concept and the outcomes of risk assessment as required in Section 4 (ref. EMSA – Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 - Risk Assessment of a Generic Ship Design).
- Where the ARMS utilize water scrubbing or treatment systems, these should be arranged to be independent of other water treatment or bilge systems and arranged to collect residues or contaminated water in holding tanks for further processing or disposal ashore.
- The transient response characteristics of the fuel supply and control systems should be such that transient variations in fuel demand would not cause unintended shutdown of the fuel supply system.
- The fuel supply system shall be designed to prevent or effectively mitigate pressure surges and hydraulic hammer effects during normal and transient operating conditions (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 - Risk Assessment of a Generic Ship Design).
- Mechanical spray shields, or equivalent means designed to avoid accumulation of ammonia gas, with suitable drainage line should be arranged for all potential leakage points of fuel piping not protected by a secondary enclosure. Collected ammonia from the leakages should be drained to drip trays or bilge holding ammonia drain tank as referred in Section 5.
- Where applicable, gaseous ammonia fuel supply piping systems should be sufficiently heated to maintain the gaseous phase until supplying to the consumers. The monitoring and control system to maintain the fuel in a gaseous state should be arranged to cover the monitoring of fuel temperature, pressure, and the heating system subject to the engine safety concept and the risk assessment.

- **Fuel supply/distribution system outside of machinery space**

9.5.1 Fuel pipes should be protected by a secondary enclosure. This enclosure can be a duct or a double wall piping system. The duct or double wall piping system should be fitted with gas detection as required in 15.8. Other solutions providing an equivalent safety level may also be accepted by the Administration.
9.5.2 The provision in 9.5.1 need not to be applied for fuel pipes located in a fuel preparation room or tank connection space.

Comment on MSC.1/Circ.1687, 9.5.1 & 9.5.2: Bunkering pipes located on an open deck may not be arranged with a secondary enclosure as referred to in Section 9.5.1. In such cases, the bunkering pipes should be provided with appropriate mechanical protection. Bunkering pipes passing through enclosed or semi-enclosed spaces should always be provided with a secondary enclosure.

9.5.3 Where gas detection as required in 15.8.2.2 is not fit for purpose, the secondary enclosures around liquefied fuel pipes shall be provided with leakage detection by means of pressure or temperature monitoring systems, or any combination thereof.
9.5.4 The provision in 9.5.1 also applies for fuel vent pipes, except for open-ended fully welded fuel vent pipes in open air.
9.6 The IGF Code chapter 9 should be taken into account, where applicable, in order to fulfil the functional requirements.

Other applicable references from the IGF Code:

Fuel supply /distribution system

IGF: 9.6.1 Fuel piping in gas-safe machinery spaces shall be completely enclosed by a double pipe or duct fulfilling one of the following conditions:

.1 the gas piping shall be a double wall piping system with the gas fuel contained in the inner pipe. The space between the concentric pipes shall be pressurized with inert gas at a pressure greater than the gas fuel pressure. Suitable alarms shall be provided to indicate a loss of inert gas pressure between the pipes. When the inner pipe contains high pressure gas, the system shall be so arranged that the pipe between the master gas valve and the engine is automatically purged with inert gas when the master gas valve is closed; or
.2 the gas fuel piping shall be installed within a ventilated pipe or duct. The air space between the gas fuel piping and the wall of the outer pipe or duct shall be equipped with mechanical under pressure ventilation having a capacity of at least 30 air changes per hour. This ventilation capacity may be reduced to 10 air changes per hour provided automatic filling of the duct with nitrogen upon detection of gas is arranged for. The fan motors shall comply with the required explosion protection in the installation area. The ventilation outlet shall be covered by a protection screen and placed in a position where no flammable gas-air mixture may be ignited; or
.3 other solutions providing an equivalent safety level may also be accepted by the Administration.

Comment on IGF Code, 9.6.1: In lieu of the IGF 9.6.1.1-9.6.1.3 requirements, the following are suggested with regards to the secondary enclosures of ammonia piping :

Secondary enclosures around ammonia fuel piping that are capable of safely contain any leakages should be designed by fulfilling one of the following conditions:

.1 Secondary enclosures should be pressurised with inert gas at a pressure greater than the design gas fuel pressure. Suitable alarms should be provided to indicate a loss of inert gas pressure between the inner and outer pipes; or
.2 Secondary enclosures should be equipped with mechanical under pressure ventilation having a capacity of at least 30 air changes per hour. The vent pipe outlet should be located at least 4 meters above deck or gangway and be designed to prevent ingress of water; or
.3 other solutions providing an equivalent safety level may also be accepted by the Administration.

IGF: 9.6.2 The connecting of gas piping and ducting to the gas injection valves shall be completely covered by the ducting. The arrangement shall facilitate replacement and/or overhaul of injection valves and cylinder covers. The double ducting is also required for all gas pipes on the engine itself, until gas is injected into the chamber.

Suggested rewording: "The connecting of gas piping and ducting to the gas injection valves shall be completely covered <u>by a secondary enclosure</u>. The arrangement shall facilitate replacement and/or overhaul of injection valves and cylinder covers. The double ducting is also required for all gas pipes on the engine itself, until gas is injected into the chamber."

Recommendation:

- If gas is supplied into the air inlet directly on each individual cylinder during air intake to the cylinder on a low-pressure engine, such that a single failure will not lead to release of fuel gas into the machinery space, a secondary enclosure may be omitted on the air inlet pipe.

Design of ventilated duct, outer pipe against inner pipe gas leakage

IGF: 9.8.1 The design pressure of the outer pipe or duct of fuel systems shall not be less than the maximum working pressure of the inner pipe.

Comment on IGF Code, 9.8.1: Considering the thermodynamic properties of ammonia in particular, the following updated requirement is suggested.
Suggested update to IGF Code, 9.8.1: "The design pressure of the secondary enclosure around fuel piping systems should not be less than 18 bar. A lower design pressure can be accepted if calculations show that the built-up pressure will be less than 18 bar after a leakage from the inner pipe."

IGF: 9.8.2 For high-pressure fuel piping the design pressure of the ducting shall be taken as the higher of the following:

.1 the maximum built-up pressure: static pressure in way of the rupture resulting from the gas flowing in the annular space;

.2 local instantaneous peak pressure in way of the rupture: this pressure shall be taken as the critical pressure given by the following expression:

$$p = p_0 \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$$

where:
p_0 = maximum working pressure of the inner pipe
k = Cp/Cv constant pressure specific heat divided by the constant volume specific heat
The tangential membrane stress of a straight pipe should not exceed the tensile strength divided by 1.5 (Rm/1.5) when subjected to the above pressures. The pressure ratings of all other piping components should reflect the same level of strength as straight pipes. As an alternative to using the peak pressure from the above formula, the peak pressure found from representative tests can be used. Test reports should then be submitted.

Comment on IGF Code, 9.8.2: Considering the thermodynamic properties of ammonia particularly, the factor "*k*", shall be assigned a value of 1.32.

IGF: 9.8.3 Verification of the strength shall be based on calculations demonstrating the duct or pipe integrity. As an alternative to calculations, the strength can be verified by representative tests.

Suggested additional requirement: The material of the secondary enclosure should have a design temperature corresponding with the lowest temperature it may be subjected to in a leakage scenario.

IGF: 9.8.4 For low pressure fuel piping the duct shall be dimensioned for a design pressure not less than the maximum working pressure of the fuel pipes. The duct shall be pressure tested to show that it can withstand the expected maximum pressure at fuel pipe rupture.

Compressors and pumps

IGF: 9.9.1 If compressors or pumps are driven by shafting passing through a bulkhead or deck, the bulkhead penetration shall be of gastight type.
IGF: 9.9.2 Compressors and pumps shall be suitable for their intended purpose. All equipment and machinery shall be such as to be adequately tested to ensure suitability for use within a marine environment. Such items to be considered would include, but not be limited to:

.1 environmental;
.2 shipboard vibrations and accelerations;
.3 effects of pitch, heave and roll motions, etc.; and
.4 gas composition

Comment on IGF Code, 9.9.2.2: Reference should be made to the IACS Unified Requirement M46 - *"Ambient conditions – Inclinations and Ship Accelerations and Motions".*

IGF: 9.9.3 Arrangements shall be made to ensure that under no circumstances liquefied gas can be introduced in the gas control section or gas-fuelled machinery, unless the machinery is designed to operate with gas in liquid state.
IGF: 9.9.4 Compressors and pumps shall be fitted with accessories and instrumentation necessary for efficient and reliable function.

Further Recommendations

Additional system specific recommendations:

Filters (Ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 – Risk Assessment of a Generic Ship Design)**:**

- Effective filtration shall be incorporated into the ammonia supply system to prevent the ingress of debris, dirt, foreign particles, or other impurities into the internal combustion engine.
- The filtration performance shall be appropriate to meet the operational requirements of the ammonia fuel consumers.
- Filters should be accessible and capable of being isolated for cleaning.
- Filters shall be equipped with differential pressure sensors integrated with alarm functions to detect clogging and prompt timely maintenance actions.
- For single fuel installations, fuel filters shall be arranged with redundancy (e.g. duplex-type configuration) to ensure uninterrupted engine operation in the event of clogging. The system shall allow for seamless switching between filters.
- An additional "*safety*" filter should be installed to protect the engine components, in case the main filter(s) breaks and releases dirt. The safety filter may be a coarse filter, having a bigger mesh size than the main filter.
- Safe practices and suitable procedures for maintenance, cleaning, and replacing of the filters should be available on the vessel.

Ammonia pumps (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 – Risk Assessment of a Generic Ship Design)**:**

- For single fuel installations, the fuel supply system shall be designed to ensure that a secondary (redundant, stand-by) pump can be readily engaged in the event of a failure or shutdown of the primary fuel supply pump/compressor.
- All pumps serving the ammonia supply system should be provided with dry-running protection systems to prevent overheating in the case of low or no-flow conditions.

Heat exchangers (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 – Risk Assessment of a Generic Ship Design)**:**

- A fouling margin should be included in the thermal and hydraulic design of all heat exchangers serving the ammonia supply system, to account for the anticipated increase in flow resistance and reduction in heat transfer efficiency due to fouling caused by particle deposition over time. The selected fouling resistance values shall be documented in the design documentation in accordance with applicable industry standards.
- All drain and venting valves associated with ammonia heat exchangers shall be fitted with physical locking mechanisms and clearly visible warning signs to ensure they remain securely closed during normal operation.
- All draining arrangements associated with ammonia heat exchangers shall be designed and constructed to discharge into the dedicated bilge system, in accordance with the provisions outlined in Section 5.8.1.
- Where ammonia is heated or cooled, an intermediate heating or cooling medium should be utilised in an independent, closed system. This intermediate heating or cooling medium shall be equipped with a comprehensive alarm and monitoring system to ensure safe operation. The system shall function in accordance with defined design parameters and operational limits, providing timely alerts in the event of deviations or abnormal conditions. The intermediate media to be additionally provided with means to detect the presence of ammonia.

Inerting system (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 – Risk Assessment of a Generic Ship Design)**:**

- The inert gas system should be designed with sufficient storage capacity to enable purging of the internal combustion engine system a minimum of two times following a fuel change over operation triggered by safety action / function.
- The inert gas supply system shall be equipped with a drying unit to ensure that the delivered gas is free of moisture.
- Purging systems must be established and verified through appropriate testing protocols to ensure that all ammonia-related components can be safely gas-freed prior to any maintenance activities.

Section 10 - Power Generation including Propulsion and other Fuel Consumers

HAZARDS
Systems concerned: Internal Combustion Engines (ICEs), Engine Control Module, Hydraulic and Sealing Oil Systems, Exhaust gas treatment systems. Engines, exhausts, and auxiliary systems are designed to handle ammonia safely, preventing any accumulation of unburned fuel and providing proper venting and pressure relief mechanisms. Hazards to be considered include: • Explosion caused by the ignition of flammable fuels • Exposure of individuals to toxic gases • Cross-boundary contamination between toxic and non-toxic zones • Loss of electrical power • Ammonia-slip with safety and environmental effects
GOAL
Provide safe and reliable delivery of mechanical, electrical or thermal energy.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
10.2.1.1: the exhaust systems should be configured to prevent any accumulation of unburnt fuel; *10.2.1.2: unless designed with the strength to withstand the worst-case overpressure due to ignited fuel leaks, engine components or systems containing or likely to contain an ignitable ammonia gas and air mixture should be fitted with suitable pressure relief systems. Dependent on the particular engine design this may include the air inlet manifolds and scavenge spaces;* *10.2.1.3: the explosion venting should be led away from where persons may normally be present;* *10.2.1.4: all fuel consumers should have a separate exhaust system;* *10.2.1.5: the possibility of ammonia leakage from fuel consumers into the auxiliary system, such as cooling water systems and its consequences, should be minimized.*
Further Recommendations
Suggested additional requirement: Ammonia concentration in exhaust gases at point of release, including from emissions abatement systems, if fitted, should not exceed 110 ppm during normal operation.
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **Reference to the IGF Code** *10.3 The IGF Code chapter 10 should be taken into account, where applicable, in order to fulfil the functional requirements.* <ins>**Applicable references from the IGF Code**</ins>: <ins>**Internal combustion engines of piston type**</ins>

IGF: 10.3.1.1 The exhaust system shall be equipped with explosion relief ventilation sufficiently dimensioned to prevent excessive explosion pressures in the event of ignition failure of one cylinder followed by ignition of the unburned gas in the system.
IGF: 10.3.1.1.1 For ships constructed on or after 1 January 2024, the exhaust system shall be equipped with explosion relief systems unless designed to accommodate the worst-case overpressure due to ignited gas leaks or justified by the safety concept of the engine. A detailed evaluation of the potential for unburnt gas in the exhaust system is to be undertaken covering the complete system from the cylinders up to the open end. This detailed evaluation shall be reflected in the safety concept of the engine.

Suggested update to IGF Code, 10.3.1.1: The exhaust system shall be equipped with explosion relief systems unless designed to accommodate the worst-case overpressure due to ignited gas leaks or justified by the safety concept of the engine. A detailed evaluation of the potential for unburnt gas in the exhaust system is to be undertaken, covering the complete system from the cylinders up to the open end. The evaluation should also cover the options to safely handle the release once the explosion relief device is activated. This detailed evaluation should be reflected in the safety concept of the engine.

IGF: 10.3.1.2 For engines where the space below the piston is in direct communication with the crankcase a detailed evaluation regarding the hazard potential of fuel gas accumulation in the crankcase shall be carried out and reflected in the safety concept of the engine.

Suggested addition to IGF 10.3.1.2: *"*...Accordingly, all engines except for the two-stroke crosshead types are to be fitted with independent vent systems for crankcases and sumps that are separated from other engine's vent systems. Where applicable and practicable, gases extracted from the crankcase and sumps should be routed to the Ammonia Release Mitigation System (ARMS) or other suitable mitigation measures to prevent the release of ammonia into the atmosphere. Monitoring of crankcase breather(s), or under piston space(s), should be in accordance with Section 15.*"*

IGF: 10.3.1.3 Each engine other than two-stroke crosshead diesel engines shall be fitted with vent systems independent of other engines for crankcases and sumps.
IGF: 10.3.1.4 Where gas can leak directly into the auxiliary system medium (lubricating oil, cooling water), an appropriate means shall be fitted after the engine outlet to extract gas in order to prevent gas dispersion. The gas extracted from auxiliary systems media shall be vented to a safe location in the atmosphere.

Suggested update to IGF Code, 10.3.1.4 : "Where ammonia can leak directly into the auxiliary system medium (i.e., lubricating oil, cooling water), an appropriate means should be fitted after the engine outlet to extract gas in order to prevent ammonia gas dispersion in safe spaces. The gas extracted from auxiliary systems media should be discharged as in accordance with Section 6.7.2.7 or directed to the ARMS. Detection, alarm and monitoring functions should be arranged in accordance with Section 15. Such events should be analysed and evaluated in detail, and to be reflected in the Safety Concept of ammonia fuelled engines."

IGF: 10.3.1.5 For engines fitted with ignition systems, prior to admission of gas fuel, correct operation of the ignition system on each unit shall be verified.
IGF: 10.3.1.6 A means shall be provided to monitor and detect poor combustion or misfiring. In the event that it is detected, gas operation may be allowed provided that the gas supply to the concerned cylinder is shut off and provided that the operation of the engine with one cylinder cut-off is acceptable with respects to torsional vibrations.

IGF: 10.3.1.7 For engines starting on fuels covered by this Code, if combustion has not been detected by the engine monitoring system within an engine specific time after the opening of the fuel supply valve, the fuel supply valve shall be automatically shut off. Means to ensure that any unburnt fuel mixture is purged away from the exhaust system shall be provided.

Dual fuel engines

IGF: 10.3.2.1 In case of shutoff of the gas fuel supply, the engines shall be capable of continuous operation by oil fuel only without interruption.

IGF: 10.3.2.2 An automatic system shall be fitted to change over from gas fuel operation to oil fuel operation and vice versa with minimum fluctuation of the engine power. Acceptable reliability shall be demonstrated through testing. In the case of unstable operation on engines when gas firing, the engine shall automatically change to oil fuel mode. Manual activation of gas system shutdown shall always be possible.

Suggested addition to IGF 10.3.2.2 : *"…*Changeover to and from ammonia fuel operation is only to be possible at a power level and under conditions where it can be done with acceptable reliability and safety.*"*

IGF: 10.3.2.3 In case of a normal stop or an emergency shutdown, the gas fuel supply shall be shut off not later than the ignition source. It shall not be possible to shut off the ignition source without first or simultaneously closing the gas supply to each cylinder or to the complete engine.

Suggested additional requirement: For dual fuel engines, the test loads required in IACS Unified Requirement M88.5.3 are to be carried out in all operating modes (fuel oil mode, gas mode, variable fuel oil / gas ratio mode), as applicable. Tests performed should demonstrate smooth changeover from ammonia fuel to oil fuel mode and from oil fuel to ammonia fuel mode at the test load points. The rapid (emergency) changeover testing is only required from ammonia fuel to oil fuel mode. This test should be done during the sea/gas trial at high fuel flow and high engine load in order to demonstrate that the Fuel Gas Supply System (FGSS) can handle this event without triggering ammonia release or venting through the PRV's. The engine manufacturer should specify the lowest permissible operating speeds for both oil fuel and fuel modes, and these speeds should be demonstrated during the type tests.

Multi fuel engines

IGF: 10.3.4.1 In case of shutoff of one fuel supply, the engines shall be capable of continuous operation by an alternative fuel with minimum fluctuation of the engine power.
IGF: 10.3.4.2 An automatic system shall be fitted to change over from one fuel operation to an alternative fuel operation with minimum fluctuation of the engine power. Acceptable reliability shall be demonstrated through testing. In the case of unstable operation on an engine when using a particular fuel, the engine shall automatically change to an alternative fuel mode. Manual activation shall always be possible.

Suggested requirements with reference to IGF Code, section 10.3 : Consideration should be given to the following with respect to ammonia fuel injection valves.

.1 Ammonia fuel injection valves should possess satisfactory operating characteristics and durability for the assumed service period, including after long periods of time when engine is running on fuel oil mode only, for dual fuel vessels;

.2 Ammonia fuel valves should be provided with sealing systems to effectively prevent fuel from leaking through spaces around valve spindles, and
.3 Appropriate means should be provided in cases where fuel injection valve actuating oil is required to be kept clean.

Suggested additional requirements for dual-fuel and multi-fuel ammonia engines:

- The engine transient response characteristics should be appropriate for the intended application and to the satisfaction of the Administration. Consideration may be given to the use of performance criteria such as the ISO 8528, where appropriately matched with the vessel power management system.
- Internal combustion engines intended to burn ammonia as fuel should be designed, tested, and certified to the satisfaction of the Administration. The fuel specification required by the engine should be declared by the manufacturer and detailed in the operation and maintenance manuals.

Main and auxiliary boilers

IGF: 10.4.1 Each boiler shall have a dedicated forced draught system. A crossover between boiler force draught systems may be fitted for emergency use providing that any relevant safety functions are maintained.
IGF: 10.4.2 Combustion chambers and uptakes of boilers shall be designed to prevent any accumulation of gaseous fuel.
IGF: 10.4.3 Burners shall be designed to maintain stable combustion under all firing conditions.
IGF: 10.4.4 On main/propulsion boilers an automatic system shall be provided to change from gas fuel operation to oil fuel operation without interruption of boiler firing.
IGF: 10.4.5 Gas nozzles and the burner control system shall be configured such that gas fuel can only be ignited by an established oil fuel flame, unless the boiler and combustion equipment is designed and approved by the Administration to light on gas fuel.
IGF: 10.4.6 There shall be arrangements to ensure that gas fuel flow to the burner is automatically cut off unless satisfactory ignition has been established and maintained.
IGF: 10.4.7 On the fuel pipe of each gas burner a manually operated shutoff valve shall be fitted.
IGF: 10.4.8 Provisions shall be made for automatically purging the gas supply piping to the burners, by means of an inert gas, after the extinguishing of these burners.

Comment on IGF Code, 10.4.8: The wording needs to be changed so that it refers to the use of ARMS for purging purposes of the gas supply piping.
Suggested rewording: "Provisions shall be made for the automatic purging of the gas supply piping to the burners with inert gas, which shall be directed to the ARMS system, following burner shutdown."

IGF: 10.4.9 The automatic fuel changeover system required by 10.4.4 shall be monitored with alarms to ensure continuous availability.
IGF: 10.4.10 Arrangements shall be made that, in case of flame failure of all operating burners, the combustion chambers of the boilers are automatically purged before relighting.
IGF: 10.4.11 Arrangements shall be made to enable the boilers purging sequence to be manually activated.

Suggested additional requirements:

- Where Selective Catalytic Reduction (SCR) exhaust aftertreatment equipment is installed to meet NO_x emissions limits, or ammonia safe limits, with or without dedicated ammonia control catalysts, the arrangements are to the satisfaction of the Administration. Monitoring of exhaust(s) should be in accordance with Section 15.

• A Failure Modes and Effects Analysis (FMEA) should be carried out by the ammonia -fuelled engine manufacturer to determine necessary additional safeguards to address the hazards associated with the use of ammonia as a fuel, for example, protection against explosion, cylinder overpressure, etc. The analysis should identify all plausible scenarios of fuel leakage and the resulting hazards. Then the analysis should identify necessary means to control the identified hazards. **Note:** Reference may be made to EMSA Study Investigating the Safety of Ammonia as Fuel on Ships – Part 2 – Safety Assessment and Reliability Analysis of Main Components, Equipment, Sub-systems and Systems focusing on: 1. A qualitative assessment to build fault tree failure scenarios structured based on a critical component list belonging to ammonia internal combustion engine and fuel supply system entailing how each component can fail, and 2. A quantitative assessment detailing the frequency of each failure scenario using the Windchill Risk and Reliability simulation tool.
Further Recommendations
N/A

Section 11 – Fire Safety

HAZARDS
Systems concerned: fixed fire-extinguishing system, fire detection and fire alarm, water spray system, other fire protection arrangements Hazards to be considered include: • Damage of ammonia-related equipment or piping due to direct or indirect exposure to fire and high temperatures; • Hazardous chemical reactions due to gas or materials incompatibility; • Insufficient firefighting capability due to chemical reactions of fire fire-extinguishing medium and ammonia.
GOAL
Provide adequate fire protection, detection and fighting for all system components related to the storage, conditioning, transfer and use of ammonia as ship fuel.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
Functional requirements are like those that appear in sections 3.2.2, 3.2.4, 3.2.5 - 3.2.7, 3.2.13, 3.2.15 - 3.2.16, 3.2.18.
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **Reference to the IGF Code** *11.3 The IGF Code chapter 11 should be taken into account, where applicable, in order to fulfil the functional requirements.* **Applicable references from the IGF Code**: **Fire protection** **Comment on MSC.1/Circ.1687, 11.3:** The provisions in this section are applicable in addition to the provisions in SOLAS Chapter II-2. *IGF: 11.3.1 Any space containing equipment for the fuel preparation such as pumps, compressors, heat exchangers, vaporizers and pressure vessels shall be regarded as a machinery space of category A for fire protection purposes.* **Comment on IGF Code, 11.3.1**: Fuel preparation rooms should, for the purpose of the application of SOLAS regulation II-2/9, be regarded as a machinery space of category A. Only structural fire protection requirements in SOLAS II-2/9 to be considered applicable, not including means of escape.

Any enclosed spaces containing equipment for fuel preparation, such as pumps or compressors or other potential ignition sources, should comply with the IGF Section 11.8. (Refer to IACS Unified Interpretation GF13 – *"Fire protection of spaces containing equipment for the fuel preparation*.").

IGF: 11.3.2 Any boundary of accommodation spaces, service spaces, control stations, escape routes and machinery spaces, facing fuel tanks on open deck, shall be shielded by A-60 class divisions. The A-60 class divisions shall extend up to the underside of the deck of the navigation bridge, and any boundaries above that, including navigation bridge windows, shall have A-0 class divisions. In addition, fuel tanks shall be segregated from cargo in accordance with the requirements of the International Maritime Dangerous Goods (IMDG) Code where the fuel tanks are regarded as bulk packaging. For the purposes of the stowage and segregation requirements of the IMDG Code, a fuel tank on the open deck shall be considered a class 2.1 package.

IGF: 11.3.3 The space containing the fuel containment system shall be separated from the machinery spaces of category A or other rooms with high fire risks. The separation shall be done by a cofferdam of at least 900 mm with insulation of A-60 class. When determining the insulation of the space containing the fuel containment system from other spaces with lower fire risks, the fuel containment system shall be considered as a machinery space of category A, in accordance with SOLAS regulation II-2/9. For type C tanks, the fuel storage hold space may be considered as a cofferdam.
IGF: 11.3.3.1 Notwithstanding the last sentence in 11.3.3, the fuel storage hold space may be considered as a cofferdam provided that:

.1 the type C tank is not located directly above machinery spaces of category A or other rooms with high fire risk; and

.2 the minimum distance to the A-60 boundary from the outer shell of the type C tank or the boundary of the tank connection space, if any, is not less than 900 mm.

IGF: 11.3.4 The fuel storage hold space shall not be used for machinery or equipment that may have a fire risk.

Comment on IGF Code, 11.3.4: It is important to emphasize the guidance provided in MSC.1/Circ.1687, section 5.7.1.1, which *states, "Fuel process equipment should be arranged in a fuel preparation room in accordance with the provisions of these Interim Guidelines. As an exception, vaporizers, heat exchangers, and motors for pumps submerged in tanks may also be located in tank connection spaces."* In such cases, it is suggested that fire risks associated with that equipment installed in tank connection spaces should be assessed as part of the overall risk assessment.

Suggested requirement: When determining the insulation of the space containing the fuel containment system from other spaces with lower fire risks, the fuel containment system should be considered as a machinery space of category A, in accordance with SOLAS regulation II-2/9.

IGF: 11.3.5 The fire protection of fuel pipes led through ro-ro spaces shall be subject to special consideration by the Administration depending on the use and expected pressure in the pipes.
IGF: 11.3.6 The bunkering station shall be separated by A-60 class divisions towards machinery spaces of category A, accommodation, control stations and high fire risk spaces, except for spaces such as tanks, voids, auxiliary machinery spaces of little or no fire risk, sanitary and similar spaces where the insulation standard may be reduced to class A-0.

Fire main

IGF: 11.4.1 The water spray system required below may be part of the fire main system provided that the required fire pump capacity and working pressure are sufficient for the operation of both the required numbers of hydrants and hoses and the water spray system simultaneously.
IGF: 11.4.2 When the fuel storage tank(s) is located on the open deck, isolating valves shall be fitted in the fire main in order to isolate damaged sections of the fire main. Isolation of a section of fire main shall not deprive the fire line ahead of the isolated section from the supply of water.

Water spray system

IGF: 11.5.1 A water spray system shall be installed for cooling and fire prevention to cover exposed parts of fuel storage tank(s) located on open deck.
IGF: 11.5.2 The water spray system shall also provide coverage for boundaries of the superstructures, compressor rooms, pump-rooms, cargo control rooms, bunkering control stations, bunkering stations and any other normally occupied deck houses that face the storage tank on open decks unless the tank is located 10 metres or more from the boundaries.
IGF: 11.5.3 The system shall be designed to cover all areas as specified above with an application rate of 10 L/min/m2 for the largest horizontal projected surfaces and 4 l/min/m2 for vertical surfaces.

Comment on IGF Code, 11.5.3, 11.6.1 & 11.6.2: The necessary concentrations/application rates required for extinguishing ammonia -sourced fire may need further investigation.

IGF: 11.5.4 Stop valves shall be fitted in the water spray application main supply line(s), at intervals not exceeding 40 metres, for the purpose of isolating damaged sections. Alternatively, the system may be divided into two or more sections that may be operated independently, provided the necessary controls are located together in a readily accessible position not likely to be inaccessible in case of fire in the protected areas.
IGF: 11.5.5 The capacity of the water spray pump shall be sufficient to deliver the required amount of water to the hydraulically most demanding area as specified above in the areas protected.
IGF: 11.5.6 If the water spray system is not part of the main fire system, a connection to the ship's fire main through a stop valve shall be provided.
IGF: 11.5.7 Remote start of pumps supplying the water spray system and remote operation of any normally closed valves to the system shall be located in a readily accessible position which is not likely to be inaccessible in case of fire in the protected areas.
IGF: 11.5.8 The nozzles shall be of an approved full-bore type, and they shall be arranged to ensure an effective distribution of water throughout the space being protected.

Dry chemical powder fire-extinguishing system

IGF: 11.6.1 A permanently installed dry chemical powder fire-extinguishing system shall be installed in the bunkering station area to cover all possible leak points. The capacity shall be at least 3.5 kg/s for a minimum of 45 s. The system shall be arranged for easy manual release from a safe location outside the protected area.
IGF: 11.6.2 In addition to any other portable fire extinguishers that may be required elsewhere in IMO instruments, one portable dry powder extinguisher of at least 5 kg capacity shall be located near the bunkering station.

Fire detection and alarm system

IGF: 11.7.1 A fixed fire detection and fire alarm system complying with the Fire Safety Systems Code shall be provided for the fuel storage hold spaces and the ventilation trunk to the tank connection space and in the tank connection space, and for all other rooms of the fuel gas system where fire cannot be excluded.
IGF: 11.7.2 Smoke detectors alone shall not be considered sufficient for rapid detection of a fire.

Comment on IGF Code, 11.7.2: Smoke detectors alone should not be considered sufficient for rapid detection of a fire. Smoke detectors as required under IGF Code 11.7.2, should be combined with either temperature, flame or other alternative detectors to increase possibility for detection of a fire.

Fuel preparation room fire-extinguishing systems

IGF: 11.8 Fuel preparation rooms containing pumps, compressors or other potential ignition sources shall be provided with a fixed fire-extinguishing system complying with the provisions of SOLAS regulation II-2/10.4.1.1 and taking into account the necessary concentrations/application rate required for extinguishing gas fires.

SOLAS: regulation II-2/10.4.1.1 A fixed fire-extinguishing system may be any of the following systems:

.1 a fixed gas fire-extinguishing system complying with the provisions of the Fire Safety Systems Code;
.2 a fixed high-expansion foam fire-extinguishing system complying with the provisions of the Fire Safety Systems Code; and
.3 a fixed pressure water-spraying fire-extinguishing system complying with the provisions of the Fire Safety Systems Code.

Further Recommendations

Suggested additional requirements:

- Fire-extinguishing medium used within the toxic spaces is to be compatible with the extinguishing of ammonia fires. A portable dry chemical powder extinguisher of at least 5 kg capacity should be located near the entrance to the fuel preparation room, as well as in proximity to other potential sources of ammonia fire.
- Machinery spaces where ammonia-fuelled engines and/or fuel supply systems are located should be protected by an approved fixed fire-extinguishing system in accordance with SOLAS Ch.II-2, Reg.10.4.1.1 and the Fire Safety Systems (FSS) Code.
- Tank connection spaces containing fuel pump electric motors or any other associated rotating parts, where permitted by the risk assessment required in Section 4, should be provided with a fixed fire-extinguishing system complying with the provisions of SOLAS regulation II-2/10.4.1.1.
- Portable water spray systems or water curtains should be available onboard to mitigate the dispersion of toxic gas clouds beyond the ship’s boundaries.

Comment: Currently, there is a general lack of type-approved fire extinguishing systems specifically engineered for ammonia fires within the maritime sector. CO2, foams, dry powders and water mist systems can all possibly work on ammonia fires. However, for the time being, specific extinguishing agents cannot be specified, as certain options, particularly foam-based agents, may exhibit unpredictable behaviour under conditions involving ammonia in gaseous or liquid form.

Section 12 – Explosion Prevention

HAZARDS
Hazards to be considered include: • Explosion; • Fire.
GOAL
Provide for the prevention of explosions and for the limitation of effects from explosion
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
12.2.2 The probability of explosions should be reduced to a minimum by: *.1 reducing the number of sources of ignition; and* *.2 reducing the probability of the formation of ignitable mixtures.*
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **Reference to the IGF Code** *12.3 The IGF Code chapter 12 should be taken into account, where applicable, in order to fulfil the functional requirements.* **Applicable references from the IGF Code**: **Prevention of explosions** *IGF: 12.3.1 Hazardous areas on open deck and other spaces not addressed in this chapter shall be decided based on a recognized standard*. The electrical equipment fitted within hazardous areas shall be according to the same standard.* *Note: Refer to IEC standard 60092-502, part 4.4: Tankers carrying flammable liquefied gases as applicable.* **Comment on IGF Code, 12.3.1:** According to the IEC 60079-10-1: *"Experience has shown that a release of ammonia in the open air will often dissipate rapidly, so an explosive gas atmosphere can be, in most cases considered of negligible extent."* On this basis, it is proposed that, particularly in the context of ammonia, the IGF Code section 12.3.1 is updated as follows. **Suggested rewording:** "Hazardous areas in other spaces not addressed in this Section (see the updated hazardous zones below) shall be decided based on a recognized standard, such as the IEC 60092-502. The electrical equipment fitted within hazardous areas shall be according to the same standard."

IGF: 12.3.2 Electrical equipment and wiring shall in general not be installed in hazardous areas unless essential for operational purposes based on a recognized standard.*

Note: Refer to IEC 60092-502:1999 Electrical Installations in Ships – Tankers – Special Features and IEC 60079-10-1:2008 Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres, according to the area classification.

IGF: 12.4.1 Area classification is a method of analysing and classifying the areas where explosive gas atmospheres may occur. The object of the classification is to allow the selection of electrical apparatus able to be operated safely in these areas.

IGF: 12.4.2 In order to facilitate the selection of appropriate electrical apparatus and the design of suitable electrical installations, hazardous areas are divided into zones 0, 1 and 2. See also 12.5 below.*

Note: Refer to standards IEC 60079-10-1:2008 Explosive atmospheres part 10-1: Classification of areas – Explosive gas atmospheres and guidance and informative examples given in IEC 60092-502:1999, Electrical Installations in Ships – Tankers – Special Features for tankers.

IGF: 12.4.3 Ventilation ducts shall have the same area classification as the ventilated space.

Hazardous area zones

IGF: 12.5.1 Hazardous area zone 0 - This zone includes, but is not limited to the interiors of fuel tanks, any pipework for pressure-relief or other venting systems for fuel tanks, pipes and equipment containing fuel.

IGF: 12.5.2 Hazardous area zone 1 - This zone includes, but is not limited to:

.1 tank connection spaces, fuel storage hold spaces and interbarrier spaces

.2 fuel preparation room arranged with ventilation according to Section 13.6

.3 areas on open deck, or semi-enclosed spaces on deck, within 3 m of any fuel tank outlet, gas or vapour outlet, bunker manifold valve, other fuel valve, fuel pipe flange, fuel preparation room ventilation outlets and fuel tank openings for pressure release provided to permit the flow of small volumes of gas or vapour mixtures caused by thermal variation;

.4 areas on open deck or semi-enclosed spaces on deck, within 1.5 m of fuel preparation room entrances, fuel preparation room ventilation inlets and other openings into zone 1 spaces;

.5 areas on the open deck within spillage coamings surrounding gas bunker manifold valves and 3 m beyond these, up to a height of 2.4 m above the deck;

.6 enclosed or semi-enclosed spaces in which pipes containing fuel are located, e.g. ducts around fuel pipes, semi-enclosed bunkering stations;

.7 the ESD-protected machinery space is considered a non-hazardous area during normal operation, but will require equipment required to operate following detection of gas leakage to be certified as suitable for zone 1;

.8 a space protected by an airlock is considered as non-hazardous area during normal operation, but will require equipment required to operate following loss of differential pressure between the protected space and the hazardous area to be certified as suitable for zone 1; and

.9 except for type C tanks, an area within 2.4 m of the outer surface of a fuel containment system where such surface is exposed to the weather.

IGF: 12.5.3.1 Hazardous area zone 2 - This zone includes, but is not limited to areas within 1.5 m surrounding open or semi-enclosed spaces of zone 1.

IGF: 12.5.3.2 Space containing bolted hatch to tank connection space.

Comment on IGF Code, 12.5.1 to 12.5.3: Although ammonia is not classified as a flammable cargo under the IMO's IGC Code, its potential explosiveness under specific conditions (e.g., confined spaces, high concentrations) is acknowledged. Chapter 12 of the IGF Code may be relevant for establishing goals and functional requirements for explosivity, but it may not be appropriate in the case of ammonia, for determining the hazardous area classifications as specified in IGF 12.5, which are developed based on hydrocarbon fuels.
Similarly, although the IEC 60092-502 which is referenced in IGF Code Chapter 12, is not directly applicable, it can still serve as guidance, particularly for the classification of enclosed or semi-enclosed areas. It is suggested that, particularly in the context of ammonia, the IGF Code section 12.5 be updated as follows.

Suggested update to IGF Code, 12.5.1 - 12.5.3 related to ammonia:

- 12.5.1: "Hazardous area zone 0 includes, but is not limited to, the interiors of fuel tanks, any pipework for pressure-relief or other venting systems for fuel tanks, pipes and equipment containing fuel and interbarrier spaces."
- 12.5.2: "Hazardous area zone 1 includes, but is not limited to:
  - .1 tank connection spaces and fuel storage hold spaces;
  - .2 fuel preparation rooms;
  - .3 other enclosed or semi-enclosed spaces in which single-walled piping containing fuel are located (e.g. bunkering station); and
  - .4 annular spaces of secondary enclosures around fuel pipes."

Comment: As per the IACS UI GF14, for the purposes of hazardous area classification, fuel storage hold spaces containing Type C tanks with all potential leakage sources in a tank connection space and having no access to any hazardous area, shall be considered non-hazardous. Where the fuel storage hold spaces include potential leak sources, e.g. tank connections, they shall be considered hazardous area zone 1. Where the fuel storage hold spaces include bolted access to the tank connection space, they shall be considered hazardous area zone 2.

- 12.5.3: "Hazardous area zone 2 includes, but is not limited to:
  - .1 airlocks; and
  - .2 space containing bolted hatch to tank connection space."

Suggested additional requirement: Hazardous areas are to be inaccessible to any unauthorized person at all times. Permanent notices are to be posted in the vicinity of the hazardous areas concerned.

Further Recommendations

N/A

Section 12bis – Prevention of Exposure to Toxicity

HAZARDS
Hazards to be considered include: • Potential exposure to toxic gases of crew, passengers, and personnel in the vicinity of the vessel.
GOAL
Provide for the prevention of exposure to toxic gases.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
12bis.2.2 The probability of exposure to toxic gases should be reduced to a minimum by considering arrangement and location of: *.1 potential sources of ammonia release, such as valves flanges and fittings;* *.2 outlet from pressure relief valves;* *.3 openings from spaces where ammonia leakages may occur;* *.4 bunker stations;* *.5 active or passive systems to prevent ammonia propagation to adjacent spaces or areas;* *.6 openings to the vessel interior needing to be protected from intake of toxic gas; and* *.7 safe havens, life-saving appliances and emergency escapes.*
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
12bis.3.1 Toxic area and space classification is a method of analysing and classifying the areas where ammonia vapor is or may be expected to be present. The objective of the classification is to limit the risk of direct exposure to ammonia for persons on board. **Comment on MSC.1/Circ.1687, 12bis.3.1**: This content appears to serve more as a definition than a technical requirement. It is suggested that it is relocated to the 'Definitions' section of the Guidelines. *12bis.3.2 Toxic areas and spaces are defined to allow for a safe arrangement preventing cross-contamination from ammonia releases, and to facilitate safe arrangement of life-saving appliances, emergency escapes, air intakes, outlets and other openings into the accommodation, service and machinery spaces, control stations and other non-toxic spaces.* **Comment on MSC.1/Circ.1687, 12bis.3.2**: This appears to be a functional requirement. It is suggested that it is relocated under the functional requirements section. *12bis.4.1 Toxic areas include, but are not limited to:* *.1 areas on open deck within 10 m of any flanges, valves, and other potential leakage sources in ammonia fuel systems;*

.2 areas on open deck within B or 25 m, whichever is less, from outlets from the pressure relief valves installed on a liquefied fuel gas tank and all other fuel gas vent outlets;
.3 areas on open deck within B or 25 m, whichever is less, from outlets from interbarrier spaces for tanks of IMO type A;
.4 areas on open deck within 10 m from outlets from interbarrier spaces for tanks of IMO type B;
.5 areas on open deck within 10 m from outlets from secondary enclosures around ammonia piping, ventilation outlets from tank connection spaces and fuel preparation rooms and other spaces containing ammonia leakage sources;
.6 areas on open deck within 5 m from inlets to secondary enclosures around ammonia piping, ventilation inlets to tank connection spaces and fuel preparation rooms and other spaces containing ammonia leakage sources; and
.7 areas on open deck within 5 m from entrance openings to spaces containing ammonia leakage sources.

12bis.4.2 Toxic spaces include, but are not limited to:
.1 the interiors of fuel tanks, any pipework for pressure-relief or other venting systems for fuel tanks, pipes and equipment containing fuel;
.2 tank connection spaces, interbarrier spaces and fuel storage hold spaces for tank containment systems requiring secondary barriers;
.3 fuel preparation rooms;
.4 annular space of secondary enclosures around fuel pipes; and
.5 enclosed and semi-enclosed spaces in which potential sources of release, such as single-walled piping containing fuel, are located

12bis.4.3 In addition to the toxic area requirements in this section, a dispersion analysis should be carried out in order to determine the extent of a toxic area. The gas dispersion analysis should demonstrate that ammonia concentrations exceeding 220 ppm do not reach:
.1 air intakes, outlets and other openings into the accommodation;
.2 service and machinery spaces;
.3 control stations;
.4 other non-toxic spaces in the ship; and
.5 other areas, as specified by the Administration.

Comment on MSC.1/Circ.1687, 12bis.4.3: This paragraph requires gas dispersion analysis to be conducted in addition to, rather than as a substitute for, the prescriptive Toxic Areas defined in 12bis.4.1. The call for gas dispersion to be conducted for all potential sources of release in semi-enclosed spaces and open deck arrangements could be a significant challenge for the design of ammonia-fuelled ships. Gas dispersion analysis is generally to be developed using inputs that, in theory, should be derived from risk assessment outputs, based on the evaluation of likelihood and consequence. Currently, there is virtually no formal guidance or requirements for conducting consistent evaluation of maritime ammonia gas dispersion, and this may result in inconsistent vessel design criteria. It is suggested that the toxic areas, as determined by IMO in paragraph 12bis.4.1, be used as the default standard for ammonia -fuelled vessel designs. Any deviations or alternative proposals should be then assessed on a case-by-case basis through risk assessment processes, supported by dedicated gas dispersion analysis.

12bis.4.4 The toxic area determined by the dispersion analysis should extend the minimum area as defined in 12bis.4.1, or lead to additional mitigation measures.

Comments on MSC.1/Circ.1687, 12bis.4.4:

- The mitigation measures already considered by the IMO in establishing the prescriptive minimum areas defined in 12bis.4.1 are not clearly identified. It is likely that gas dispersion analysis may indicate larger affected areas than those minimums. In such cases, for additional mitigation measures to be effectively applied, the baseline measures assumed in the minimum areas should be already known.
- Ammonia is readily absorbed in water, making water spray systems a potentially effective mitigation measure for limiting the spread of ammonia gas during an emergency release or leakage event. However, the effectiveness of such systems can vary significantly under different ambient conditions, and this should be carefully considered during their design and deployment. Furthermore, appropriate precautions must be taken when handling the resulting aqueous ammonia solution (ammonium hydroxide), as it is caustic and may corrode exposed steel surfaces.

12bis.4.5 The dispersion analysis boundary conditions should be approved by the Administration. The analysis should include:

.1 Discharges from the pressure relief valves protecting the tank containment system,
.2 Discharges from secondary barriers around fuel tanks,
.3 Discharges from secondary enclosures around ammonia leakage sources.

Comment 1, on MSC.1/Circ.1687, 12bis.4.5:
In accordance with the top-level functional requirement 3.2.11, ammonia release is not expected during normal operations or any foreseeable and controllable abnormal conditions. It should be noted that the analysis scenarios described in 12bis.4.5 are intended to address single-failure events. Emergency conditions involving gas releases triggered by more than a single system fault or failure are not addressed within the scope of this provision.

Suggested additional gas dispersion study scenarios:

.4 *…"Discharges from secondary enclosures around fuel piping in machinery spaces where ammonia fuelled engines are located." (Justification: Despite the gas-safe concept imposed for the engine room of ammonia-fuelled vessels, it seems that the risk of ammonia leakage appears to remain under consideration. This is further confirmed by the fact that, according to 15.8.2, gas detection is also required in machinery spaces containing ammonia fuel consumers)*

.5 *"Discharges and accidental releases during bunkering operations at port or during ship-to-ship operations".*

.6 Subject to the results of Risk Assessment as required in Section 4, additional gas dispersion studies may be required, such as the following examples:
- *Discharges from vent pipe outlets serving ammonia bilge/drain tanks*
- *Diluted ammonia releases from the ventilation outlets from toxic spaces*

Comment 2, on MSC.1/Circ.1687, 12bis.4.5:
A recognized standard or guidance document for performing ammonia gas dispersion simulations should be made available. This would support the adoption of unified requirements regarding the quality of gas dispersion modelling, assumptions, and the reporting of results to ensure a consistent approach among Administrations. At a minimum, guidance should be provided on the following topics:

.1 determination of the assumed extent of a release from equipment, piping system and fittings,
.2 determination of governing parameters to be used for gas dispersion analysis (e.g. environmental parameters, boundary conditions, modelling assumptions),
.3 definition of the range of operational conditions and scenarios to be evaluated.

In the absence of a suitable standard for gas dispersion studies, the review and acceptance of their results should be at the discretion of the authorities (i.e. the Administration or a recognized organization acting on its behalf). The following information should be provided, and detailed documentation should be supplied where applicable:

a. Basic information of the CFD model (i.e., methodology followed, main assumptions, governing equations used, boundary conditions, and turbulence model employed).
b. Model validation (e.g. mesh size and time step sensitivity studies, a comparison with benchmarking results from similar CFD studies, experimental data, or analytical formulations)
c. Model setup parameters used (e.g. description of system arrangements, range of scenarios investigated, characteristics of gas release, ambient conditions)
d. Results should be integrated in the overall hazard assessment, covering the most critical or representative cases and explaining the criteria used for their selection. Results may be presented in tables, graphs, or other visual formats (i.e., 2D plots or 3D views) provided that:
    - Sufficient labelling and legends are included,
    - Gas concentration values are provided at representative points surrounding areas of interest (i.e. assumed leakage points) and other sensitive areas (e.g. air intakes, access openings to non-hazardous areas),
    - Ammonia gas cloud formation depicted with contour lines representing distinct toxicity thresholds.

Recommendations:

- The ventilation outlets from toxic spaces may be grouped together in the same location on open deck to limit the toxic areas. In such cases, arrangements should prevent backflow into adjacent systems. Ventilation air intakes and outlets of the spaces should be so arranged as to minimize the possibility of recycling of hazardous and toxic vapours through the ventilation system.
- Openings and ventilation outlets of the spaces normally unmanned (i.e., bosun stores, deck stores, workshops, etc.) may be allowed to be located within toxic areas provided that the space is fitted with an independent mechanical extraction ventilation system, providing a minimum of 8 air changes per hour. Ventilation inlets of such spaces should be from a safe area. In addition, the ventilation system should be activated before any personnel enter such spaces.
- LSA equipment, muster stations, and escape routes should be located outside toxic areas.
- A water spray system should be arranged to cover any exposed parts of the bunkering piping on the open deck fitted with any source of release (i.e. pipe fittings). The design must ensure that water is not sprayed directly onto liquid ammonia collected in the drip trays, as this may increase evaporation and exacerbate the release of toxic vapours. The bunker manifold and bunker station area should be protected with a water spray system and provided with a means for a readily accessible remotely operated isolation valve at the bunker control station. Remote start of pumps supplying the water spray system and remote operation of any normally closed valves to the system should be located in a readily accessible position at the bunker control station.
- The water spray coverage may be provided by a separate system or provided by the water spray system required by IGF Code 11.5.2. With respect to the application of IGF Code 11.5.2, the system should be provided regardless of the distance of the bunker station from the fuel tank.
- Manual activation points of water spray systems should be located in a safe area as detailed in the approved fire and safety plans.
- Toxic areas and toxic spaces should be inaccessible to any unauthorized person at all times. Permanent notices should be posted in the vicinity of the concerned areas and spaces.

Comment: Currently, detailed design requirements for water spray systems intended to mitigate ammonia cloud dispersion, including parameters such as water flow rate, coverage area, and nozzle type cannot be established. It is anticipated that industry standards will be developed to define these performance criteria and provide a framework for validating system effectiveness.

<u>Safe havens</u>

12bis.5 A safe haven providing refuge in case of a release of ammonia should be arranged in one or more enclosed spaces with a cumulative total capacity to accommodate all persons on board. Safe

havens should be arranged, as necessary, at essential locations for the ship's operation. The space should be designed to minimize the risk of exposure to ammonia during release of ammonia. This may be achieved by measures including, but not limited to, arrangement of ventilation systems or by arranging self-sustaining air supply for the space. **Comments on MSC.1/Circ.1687, 12bis.5**: • Although the intent of this clause appears to be the use of existing spaces on the ship as safe havens, the creation of new spaces for this purpose is not excluded. In such cases, specific criteria such as minimum area, internal volume, ventilation arrangements, and essential equipment need to be defined to ensure the space can accommodate all persons on board while also maintaining continuity of essential services. However, depending on the location of each safe haven, not all *essential* ship operations may be feasible. Further clarification is needed of what have to be considered essential during a large ammonia-release event. • Access arrangements should be designed to allow safe and quick entry of personnel from any point on the ship, within a defined time limit. Relevant calculations need to be carried out and the time required from the start of the alarm and activation of an emergency shutdown process plus the time for each crew member to reach the safe haven need to be taken into account. The time can be calculated by multiplying the inverse of the nominal speed of travel of a person (1.0 m/s based on the values taken from MSC/Circ.1033) times the distance to be travelled (Refer to IACS Recommendation 100). **Suggested additional requirement:** Ventilation inlet and outlet openings should be isolated from inside the space. Ventilation inlets to the safe havens should be arranged with: .1 Gastight closing dampers operable from inside the space, or .2 Water screen system operable from inside the space and suitable to operate in all ambient conditions, .3 ammonia gas detector that should automatically activate the water screen system.
Further Recommendations
N/A

Section 13 – Ventilation

HAZARDS
Systems concerned: Venting, Ventilation Hazards to be considered include: • Explosion caused by the ignition of flammable fuels; • Exposure of individuals to toxic gases; • Cross-boundary contamination between toxic and non-toxic zones; • Loss of function.
GOAL
Provide for the ventilation required for safe operation of ammonia-fuelled machinery and equipment where ammonia is used as fuel.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
3.2.2: Probability and consequences of ammonia-related hazards should be limited to a minimum. *3.2.5: Equipment installed in hazardous areas should be minimized to that required for operational purposes and should be suitably and appropriately certified.* *3.2.8: Sources of ignition in hazardous areas should be minimized.* *3.2.9: Sources of ammonia release should be minimized to reduce the probability of ammonia exposure to humans and the environment.* *3.2.11: Direct release of ammonia into the atmosphere during normal operation and during any foreseeable and controllable abnormal scenario should be avoided.* *3.2.13: Piping systems, containment and overpressure relief arrangements that are of suitable design, construction and installation for their intended application should be provided.* *3.2.14: Machinery, systems and components should be designed, constructed, installed, operated, maintained and protected to ensure safe and reliable operation.* *3.2.17: Fire detection, protection and extinction measures appropriate to the hazards concerned should be provided.*
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
13.3 The IGF Code chapter 13 should be considered, where applicable, to fulfil the functional requirements. **Applicable references from the IGF Code**: **General**

IGF 13.3.1: Any ducting used for the ventilation of hazardous spaces shall be separate from that used for the ventilation of non-hazardous spaces. The ventilation shall function at all temperatures and environmental conditions the ship will be operating in.

Comment on IGF Code, 13.3.1: The requirement should not be limited solely to the ducting system but should emphasize that the entire ventilation system must be fully independent for each designated toxic space.
Suggested rewording: "Each toxic space should have independent ventilation systems, including ducting systems, to eliminate the possibility of toxic gases spreading to other spaces. The ventilation shall function at all temperatures and environmental conditions the ship will be operating in, including high humidity."

IGF 13.3.2: Electric motors for ventilation fans shall not be located in ventilation ducts for hazardous spaces unless the motors are certified for the same hazard zone as the space served.
IGF 13.3.3: Design of ventilation fans serving spaces containing gas sources shall fulfil the following…[Refer to the original IGF Code for full requirement details].
IGF 13.3.4: Ventilation systems required to avoid any gas accumulation shall consist of independent fans, each of sufficient capacity, unless otherwise specified in this Code.
IGF 13.3.5: Air inlets for hazardous enclosed spaces shall be taken from areas that, in the absence of the considered inlet, would be non-hazardous. Air inlets for non-hazardous enclosed spaces shall be taken from non-hazardous areas at least 1.5 m away from the boundaries of any hazardous area. Where the inlet duct passes through a more hazardous space, the duct shall be gas tight and have overpressure relative to this space.
IGF 13.3.6: Air outlets from non-hazardous spaces shall be located outside hazardous areas
IGF 13.3.7: Air outlets from hazardous enclosed spaces shall be located in an open area that, in the absence of the considered outlet, would be of the same or lesser hazard than the ventilated space.
IGF 13.3.8: The required capacity of the ventilation plant is normally based on the total volume of the room. an increase in required ventilation capacity may be necessary for rooms having a complicated form.
IGF 13.3.9: Non-hazardous spaces with entry openings to a hazardous area shall be arranged with an airlock and be maintained at overpressure relative to the external hazardous area. The overpressure ventilation shall be arranged according to the following…[Refer to the original IGF Code for full requirement details].
IGF 13.3.10: Non-hazardous spaces with entry openings to a hazardous enclosed space shall be arranged with an airlock and the hazardous space shall be maintained at under-pressure relative to the non-hazardous space.

Comment on IGF Code, 13.3.10: In the event of a toxic gas leak within an enclosed space, it is likely that the only effective method for restoring safe atmospheric conditions is the use of enhanced ventilation (i.e. emergency ventilation). However, the application of mechanical ventilation for the dispersion and dilution of toxic gases requires further investigation. Unlike the methodology prescribed for flammable gases in IEC 60079-10-1, which allows for the determination of the theoretical minimum ventilation flow rate of fresh air and the theoretical time required to reduce the concentration of a flammable substance below a specific threshold (e.g., Lower Flammability Limit, LFL), the efficacy of the analogous semi-empirical equations for toxic gases remains unverified.

Tank connection space

IGF 13.4.1: The tank connection space shall be provided with an effective mechanical forced ventilation system of extraction type. a ventilation capacity of at least 30 air changes per hour shall *be provided. The rate of air changes may be reduced if other adequate means of explosion protection are installed. The equivalence of alternative installations shall be demonstrated by a risk assessment.*

Comment on IGF Code, 13.4.1 & 13.6.1: The requirements concerning the ventilation capacity of tank connection spaces, fuel preparation rooms, and other designated toxic areas may be consolidated under a single general provision, as follows:
Suggested rewording: "All toxic spaces shall be provided with an effective mechanical primary ventilation system of the extraction type, enabling a ventilation rate of at least 30 air changes per hour. The ventilation system should ensure a negative differential pressure between toxic spaces and surrounding spaces".

IGF 13.4.2 Approved automatic fail-safe fire dampers shall be fitted in the ventilation trunk for the tank connection space.

Comment on IGF Code, 13.4.2: To ensure clarity, particularly in the context of ammonia, the following wording is recommended:
Suggested rewording: "Approved automatic fail-safe fire dampers shall be fitted in the ventilation trunk for all toxic spaces, as applicable."

Machinery spaces

IGF 13.5.1: the ventilation system for machinery spaces containing gas-fuelled consumers shall be independent of all other ventilation systems.

Fuel preparation room

IGF 13.6.1: Fuel preparation rooms shall be fitted with effective mechanical ventilation system of the underpressure type, providing a ventilation capacity of at least 30 air changes per hour.
IGF 13.6.2: The number and power of the ventilation fans shall be such that the capacity is not reduced by more than 50%, if a fan with a separate circuit from the main switchboard or emergency switchboard or a group of fans with common circuit from the main switchboard or emergency switchboard, is inoperable.
IGF 13.6.3: Ventilation systems for fuel preparation rooms shall be in operation when pumps or compressors are working.

Bunkering station

IGF 13.7: Bunkering stations that are not located on open deck shall be suitably ventilated to ensure that any vapour being released during bunkering operations will be removed outside. if the natural ventilation is not sufficient, mechanical ventilation shall be provided in accordance with the risk assessment.

Comment on IGF Code, 13.7 related to ammonia: To ensure clarity, particularly in the context of ammonia, the following wording is recommended:
Suggested update: "Enclosed and semi-enclosed bunkering stations shall be arranged in compliance with the requirements applicable for toxic spaces in this Section."

Ducts and double pipes

Comment on IGF Code, 13.8.1 to 13.8.4: The provisions in these sections apply when the mechanical ventilation option is used, in accordance with IGF Section 9.6.1.2.

IGF 13.8.1: Ducts and double pipes containing fuel piping shall be fitted with effective mechanical ventilation system of the extraction type, providing a ventilation capacity of at least 30 air changes per hour.
IGF 13.8.2: The ventilation system for double piping and for gas valve unit spaces in gas safe engine-rooms shall be independent of all other ventilation systems.
IGF 13.8.3: The ventilation inlet for the double wall piping or duct shall always be located in a non-hazardous area away from ignition sources. The inlet opening shall be fitted with a suitable wire mesh guard and protected from ingress of water.
IGF 13.8.4: The capacity of the ventilation for a pipe duct or double wall piping may be below 30 air changes per hour if a flow velocity of minimum 3 m/s is ensured. The flow velocity shall be calculated for the duct with fuel pipes and other components installed.

Further Recommendations

Suggested additional requirements:

- All toxic spaces should be continuously ventilated. Consequently, ventilation inlets and outlets for such spaces should be located at sufficient height above deck to avoid requirements for closing appliances according to the International Load Line Convention.
- All toxic spaces where crew can have access should be equipped with effective mechanical emergency ventilation that needs to be activated as specified in Table 1 of Section 15. The capacity should be not less than 45 air-changes per hour. The combined capacity of the primary and emergency ventilation fans may be considered to meet this capacity requirement.
- The required capacity of the ventilation plant should be based on the total volume of the toxic space. An increase in ventilation capacity may be required for spaces having a complicated form.
- Primary and emergency ventilation provided for toxic spaces should be arranged such that a failure of an active component or a failure in the power supply system to the fans cannot cause loss of both the primary and emergency fans.
- The number and power supply system of the primary and emergency ventilation fans for toxic spaces should be such that if one fan or a group of fans on the same circuit from the main switchboard or emergency switchboard is out of service, the capacity of the remaining ventilation fan(s) is not to be less than 100% of the total required.
- Where a ventilation duct passes through a space with a different toxic zone classification, possible leakages to the non-toxic zone should be prevented. This should be obtained by ensuring that the non-toxic space or duct has an over-pressure relative to the toxic space or duct. Such ventilation ducts should be of a gas-tight construction.
- Ventilation inlet ducts in toxic spaces should be positioned as low as practicable in the space and exhaust ducts should be arranged both at the lowest and highest points and at opposite sides to the inlet duct so that ammonia vapour cannot accumulate in the space.
- Air intakes and outlets for ventilation systems serving accommodation, service, and machinery spaces, control stations, and other safe spaces should be arranged outside toxic areas. Closing devices capable of being operated from inside the space should be arranged for air intakes and outlets. Such closing devices need not be arranged in machinery spaces and spaces not normally manned, such as deck stores, forecastle stores, and workshops.
- During normal operation, to facilitate crew accessing to a toxic space, when permitted, a push button for temporary stop (i.e., 3 to 5 seconds) of ventilation to reduce differential pressure is to be arranged adjacent to the door(s). The ventilation system is to be provided with an interlock arrangement to prevent activating automatic safety functions during access to the space.

- The efficiency and effectiveness of ventilation arrangements in designated toxic spaces shall be verified through demonstration tests conducted on board the vessel.

Section 14 – Electrical Installations

HAZARDS
Hazards to be considered include: • Loss of containment due to loss of power; • Fire and explosion in hazardous areas; • Electrical equipment malfunction.
GOAL
Provide for electrical installations that minimize the risk of ignition in the presence of a flammable atmosphere.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
14.2.2: Electrical generation and distribution systems, and associated control systems, should be designed such that a single fault will not result in the loss of ability to maintain fuel tank pressure and temperature within normal operating limits.
Further Recommendations
Suggested requirement: Failure modes and effects of single failure for electrical generation and distribution systems shall be analysed and documented to be at least equivalent to those acceptable to the Organization. **Note:** Reference should be made to the IEC 60812, as applicable.
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **Reference to the IGF Code** *The IGF Code chapter 14 should be taken into account, where applicable, in order to fulfil the functional requirements.* **Applicable references from the IGF Code**: *IGF 14.3.1: electrical installations shall be in compliance with a standard at least equivalent to those acceptable to the organization Note: refer to IEC 60092 series standards, as applicable.* *IGF: 14.3.2 electrical equipment or wiring shall not be installed in hazardous areas unless essential for operational purposes or safety enhancement.* **Comment on IGF Code, 14.3.2:** For the purposes of application of IEC standards and selection of electrical equipment, ammonia should be treated as anhydrous ammonia with IEC Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL) limits of 15% and 28% respectively. Electrical equipment should meet ISO/IEC 80079-20-1 group IIA class T1. **Suggested addition to IGF code, 14.3.2:** Where electrical equipment is installed in hazardous areas as provided in Section 14.3.2 it should be selected, installed, and maintained in accordance with standards at least equivalent to those acceptable to the Organization; i.e. refer to the

recommendation published by the International Electrotechnical Commission, in particular to publication IEC 60092-502:1999. *IGF: 14.3.3: Equipment for hazardous areas shall be evaluated and certified or listed by an accredited testing authority or notified body recognized by the Administration.* *IGF: 14.3.4 Failure modes and effects of single failure for electrical generation and distribution systems in 14.2 shall be analysed and documented to be at least equivalent to those acceptable to the organization.* **Comment on IGF Code, 14.3.4:** Reference should be made to the IEC 60812, as applicable. *IGF: 14.3.5 the lighting system in hazardous areas shall be divided between at least two branch circuits. all switches and protective devices shall interrupt all poles or phases and shall be located in a non-hazardous area.* *IGF: 14.3.6 the installation on board of the electrical equipment units shall be such as to ensure the safe bonding to the hull of the units themselves.* *IGF: 14.3.7 arrangements shall be made to alarm in low liquid level and automatically shutdown the motors in the event of low-low liquid level. the automatic shutdown may be accomplished by sensing low pump discharge pressure, low motor current, or low-liquid level. this shutdown shall give an audible and visual alarm on the navigation bridge, continuously manned central control station or onboard safety centre.* *IGF: 14.3.8 Submerged fuel pump motors and their supply cables may be fitted in liquefied gas fuel containment systems. Fuel pump motors shall be capable of being isolated from their electrical supply during gas-freeing operations.* *IGF: 14.3.9 For non-hazardous spaces with access from hazardous open deck where the access is protected by an airlock, electrical equipment which is not of the certified safe type shall be de-energized upon loss of overpressure in the space.* *IGF: 14.3.10 electrical equipment for propulsion, power generation, manoeuvring, anchoring and mooring, as well as emergency fire pumps, that are located in spaces protected by airlocks, shall be of a certified safe type.*
Further Recommendations
N/A

Section 15 – Control, Monitoring and Safety

HAZARDS
Any potentially hazardous condition as a result of: • Overfilling or overpressurisation of the fuel tanks, leading to loss of containment • Interruption or failure of electrical power supply • Inadequate or failure of ventilation in toxic spaces • Loss of inerted atmosphere • Malfunction of control systems or of critical safety components
GOAL
Provide for the arrangement of control, monitoring and safety systems that support an efficient and safe operation of the ammonia-fuelled installation.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
15.2.1.1: The control, monitoring and safety systems of the ammonia-fuelled installation should be so arranged that the remaining power for propulsion and power generation is in accordance with 9.3.1 in the event of single failure; *15.2.1.2: An ammonia safety system should be arranged to close down the fuel supply system automatically, upon failure in systems as described in table 1 and upon other fault conditions which may develop too fast for manual intervention;* *15.2.1.3: The safety functions should be arranged in a dedicated gas safety system that is independent of the gas control system in order to avoid possible common cause failures. This includes power supplies and input and output signal;* *15.2.1.4: The safety systems including the field instrumentation should be arranged to avoid spurious shutdown, e.g. as a result of a faulty gas detector or a wire break in a sensor loop;* *15.2.1.5: Where two or more fuel supply systems are required to meet the provisions, each system should be fitted with its own set of independent fuel control and fuel safety systems.*
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **General** *15.3 Suitable instrumentation devices should be fitted to allow a local and a remote reading of essential parameters to ensure a safe management of the whole fuel gas equipment including bunkering.* - **Level indicators for fuel tanks** *15.4.1. With regard to level indicators for fuel tanks:* *.1 Each fuel tank should be fitted with liquid level gauging device(s), arranged to ensure a level reading is always obtainable whenever the fuel tank is operational. The device(s) should be*

designed to operate throughout the design pressure range of the liquefied gas fuel tank and at temperatures within the fuel operating temperature range;
.2 Where only one liquid level gauge is fitted, it should be arranged so that it can be maintained in an operational condition without the need to empty or gas-free the tank; and
.3 Fuel tank liquid level gauges may be of the following types:
.1 indirect devices, which determine the amount of fuel by means such as weighing or in-line flow metering; or
.2 closed devices, which do not penetrate the fuel tank, such as devices using radioisotopes or ultrasonic devices.

- **Overflow control**

15.4.2. With regard to overflow control:
.1 each fuel tank should be fitted with a high liquid level alarm operating independently of other liquid level indicators and giving an audible and visual warning when activated;
.2 an additional sensor operating independently of the high liquid level alarm should automatically actuate a shutoff valve in a manner that will both avoid excessive liquid pressure in the bunkering line and prevent the fuel tank from becoming liquid full;
.3 the position of the sensors in the fuel tank should be capable of being verified before commissioning. At the first occasion of full loading after delivery and after each dry-docking, testing of high-level alarms should be conducted by raising the fuel liquid level in the fuel tank to the alarm point;
.4 all elements of the level alarms, including the electrical circuit and the sensor(s), of the high, and overfill alarms, should be capable of being functionally tested. Systems should be tested prior to fuel operation; and
.5 where arrangements are provided for overriding the overflow control system, they should be such that inadvertent operation is prevented. When this override is operated, a continuous visual indication is to be provided at the navigation bridge, continuously manned central control station or onboard safety centre.

Recommendation: The sensor for the automatic shutoff valve for overflow control as required in 15.4.2.2 may be combined with the liquid level indicators required by Section 15.4.1.

15.4.3 The vapour space of each fuel tank should be provided with a direct pressure reading gauge. Additionally, an indirect pressure indication should be provided on the navigation bridge, continuously manned central control station or onboard safety centre.
15.4.4 The pressure indicators should be clearly marked with the highest and lowest pressure permitted in the fuel tank.
15.4.5 A high-pressure alarm and, if vacuum protection is required, a low-pressure alarm should be provided on the navigation bridge and at a continuously manned central control station or onboard safety centre. Alarms should be activated before the set pressures of the safety valves are reached.
15.4.6 Each fuel pump discharge line and each liquid and vapour bunker manifold should be provided with at least one local pressure indicator.
15.4.7 The local pressure indicators should be provided to indicate the pressure between ship's bunker manifold valves and hose connections to the bunkering facility.
15.4.8 Fuel storage hold spaces and interbarrier spaces without open connection to the atmosphere should be provided with pressure indicator.
15.4.9 For submerged fuel pump motors and their supply cables, arrangements should be made to alarm in low-liquid level and automatically shut down the motors in the event of low-low liquid level. The automatic shutdown may be accomplished by sensing low pump discharge pressure, low motor

current, or low-low liquid level. This shutdown should give an audible and visual alarm on the navigation bridge, continuously manned central control station or onboard safety centre.
15.4.10 Each fuel tank should be provided with devices to measure and indicate the temperature of the fuel.

- **Bunkering control**

15.5.1 Control of the bunkering should be possible from a safe location remote from the bunkering station. At this location the tank pressure, tank temperature, and tank level should be monitored. Remotely controlled valves required by 8.5.3 should be capable of being operated from this location. Overfill alarm and automatic shutdown should also be indicated at this location.
15.5.2 If ammonia leakage is detected in the secondary enclosure around the bunkering lines, an audible and visual alarm should be provided at the bunkering control location. The bunker valve and other valves required to isolate the leakage should be automatically closed by the safety system in accordance with table 1.

Suggested additional requirement,1: The bunkering control system should incorporate an emergency shutdown function to stop bunker flow in the event of an emergency and comply with the following requirements:

.1 The ESD should be activated by the manual and automatic inputs listed in the (updated) Table 1.
.2 The ESD system should be engineered as a fail-safe system, ensuring that any malfunction does not result in an unsafe condition.
.3 The ESD system should always be active when there is a bunkering operation on the ship. The ESD system should be designed to clearly indicate when it is inhibited or switched off and it should not permit fuel transfer operations in these conditions.
.4 The bunkering system should be designed to not permit fuel transfer operations unless the ESD system and a Ship to Shore link (SSL) are connected and active. The status of the ESD and SSL systems should be clearly visible at the navigation bridge, the bunker control station, and any other operational positions where officers on watch may be present (e.g., engine control room, cargo control room, and emergency response stations).
.5 As a minimum, the ESD action should be capable of manual operation by a single control on the bridge, the safe control position required by 15.5.1 and at least two strategic positions around the bunker manifold area.
.6 The ESD function should operate the remote valve required by 8.5.3.
.7 The ESD, and alarm systems are to be tested before the fuel bunkering operation as part of pre-arrival tests, in the 24 hours before bunkering operations. (ref. IGC 18.6.2, 18.10.5).
.8 Safety systems should be designed to ensure that it is practical to test all parts of the system. Operation and maintenance documentation should provide clear guidance on how to test the safety system and the required intervals for this to ensure that the safety system is maintained in operational condition.
.9 The ESD system may be manually activated by personnel in response to an emergency situation. Personnel should be trained and given clear instructions on when they can activate ESD.
.10 The SSL should be inspected and tested as part of the pre-arrival test and after manifold connection as part of the pre-transfer test. For the pre-transfer test, the SSL is tested after connection to check that the link is communicating properly. ESD should be activated once from the receiving ship and once from the bunkering facility, to check that the signal is transmitted in both directions
.11 The design of the ESD system should avoid the potential generation of surge pressures within bunker transfer pipework.
.12 A functional flowchart of the bunkering control system and ESD functions should be provided in the fuel bunkering control station and on the bridge.

.13 The ESD system's activation and design requirements should be to the satisfaction of the Administration. ESD should be activated when the threshold pressure is reached, and the coupling must be compatible. Some examples of events that could initiate an ESD system include high tank pressure, excessive ship movement, abnormal pressure in the transfer system, loss of instrument pressure or electricity, gas detection, manually initiated shutdown, fire detection.

Note: The ESD system may be arranged to provide different levels of automatic response functionalities, depending on operational events. The following is provided as an example:

- ESD level 1: Initiates a controlled shutdown of the ammonia transfer process, including stopping of transfer pumps and closing associated valves.
- ESD level 2: Activates the Emergency Release Coupling (ERC) to safely disconnect bunker transfer connections.

Suggested additional requirement, 2: Where bunkering lines are enclosed in double pipes or ducts, the ventilation should always be in operation during bunkering operations.

- **Gas compressor monitoring**

15.6.1 Gas compressors should be fitted with audible and visual alarms both on the navigation bridge and in the engine control room. As a minimum, the alarms should include low gas input pressure, low gas output pressure, high gas output pressure and compressor operation.
15.6.2 Where bulkhead penetrations are used to separate the drive from a hazardous space, temperature monitoring for the bulkhead shaft glands and bearings should be provided, which automatically give a continuous audible and visual alarm on the navigation bridge or in a continuously manned central control station.

- **Engine monitoring**

15.7.1 In addition to the instrumentation provided in accordance with part C of SOLAS chapter II-1, indicators should be fitted on the navigation bridge, the engine control room and the manoeuvring platform for:

.1 operation of the engine in case of ammonia-only engines; or

.2 operation and mode of operation of the engine in the case of dual fuel engines.

Comment on MSC.1/Circ.1687, 15.7.1:
Control and monitoring instrumentation of ammonia engines should be in line with manufacturer's requirements and comply with the results of engine safety concept, FMEA and HAZOP studies.

- **Leakage detection**

15.8.1 Where gas detection should cause shutdown in accordance with table 1, detector voting should be applied where two units should detect gas to activate shutdown. A failed detector should be considered as an active detection.

Comment on MSC.1/Circ.1687, 15.8.1: Voting principle for the detectors may be used to reduce the number of unwanted alarms/safety actions but should not reduce the ability of the system to respond to a real incident. For example, in a zone/area with three or more detectors, an alarm or safety action should only be activated when at least two detectors have been triggered.

15.8.2 Permanently installed gas detectors should be fitted in:

.1 tank connection spaces;
.2 all secondary enclosures around fuel pipes;
.3 machinery spaces containing gas piping, gas equipment or gas consumers;
.4 fuel preparation rooms;
.5 bunkering stations and other enclosed spaces containing fuel piping or other fuel equipment not protected by a secondary enclosure;
.6 other enclosed or semi-enclosed spaces where fuel vapours may accumulate including interbarrier spaces and fuel storage hold spaces of independent tanks other than type C;
.7 airlocks and entry spaces to tank connection spaces;
.8 gas heating circuit expansion tanks;
.9 motor rooms for compressors as specified in 15.6.2 (if fitted);
.10 at ventilation inlets to accommodation and machinery spaces where required based on the risk assessment in 4.2;
.11 at ventilation inlets for safe haven; and
.12 at outlet from tank pressure relief valves.

15.8.3 The number of detectors in each space should be considered taking into account the size, layout and ventilation of the space, and each space shall be covered by a sufficient number of detectors to allow for voting in accordance with table 1.
15.8.4 The detection equipment should be located where gas may accumulate and in the ventilation outlets. Gas dispersal analysis should be used to find the best location of gas detectors.
15.8.5 Gas detection equipment should be designed, installed and tested in accordance with a recognized standard.

Comment on MSC.1/Circ.1687, 15.8.5: The IEC 62990-1 Workplace atmospheres - Part 1: Gas detectors - Performance requirements of detectors for toxic gases – could serve as a basis for such equipment. Further investigation may be necessary to determine whether it can fully address the specific challenges of using ammonia as a fuel onboard the ship. Different sensor technologies offer distinct advantages and limitations. Detectors utilizing optical infrared sensor technology generally perform well across a wide range of ammonia concentrations but are unable to detect levels below 200 ppm. In contrast, electrochemical sensors can measure concentrations as low as 10 ppm, however, they are susceptible to depletion when exposed to high ammonia levels, requiring several hours to recover. Due to these limitations, electrochemical sensors may be more suitable for deployment in areas where ammonia presence is not anticipated (Refer to EUROMOT Position Paper, May 2025).

15.8.6 Fuel piping should also be arranged with the detection of liquid leakages in the secondary enclosure at the lowest point.
15.8.7 Each tank connection space, fuel preparation room and bunker station should be provided with liquid leakage detection. Alarm should be given at high liquid level and low temperature indication should activate the safety system.

Suggested addition on MSC.1/Circ.1687, 15.8.7: *"...Such arrangements may also be provided for other enclosed spaces containing potential sources of ammonia release/leakage such as secondary enclosures around ammonia fuel piping, interbarrier spaces or tank hold spaces except containing Type C fuel tanks."*

15.8.8 An audible and visible alarm should be activated at an ammonia vapour concentration of 110 ppm as specified in table 1. The safety system should be activated at an ammonia vapour concentration of 220 ppm with actions as specified in table 1. In addition, at an ammonia vapour concentration, a visual local indication should be given at all entrances to enclosed spaces affected.

15.8.9 Audible and visible alarms from the leakage detection equipment should be located on the navigation bridge, in the continuously manned central control station and inside and outside the space where the leakage is detected.
15.8.10 Gas detection required by this section should be continuous without delay.

Suggested additional requirements:

- Audible toxicity alarms should be distinct from other alarms on board and should give warning to all individuals on board, including non-crew personnel.
- At least one standby gas sampling connection point should be provided at the outside of toxic spaces boundaries. These sampling points should support the use of portable gas detection devices for monitoring ammonia concentrations, particularly in situations where the fixed gas detection sensors in the toxic space may be non-operational.

- **Condensation in fuel supply line**

15.9.1 Where gaseous ammonia fuel is supplied to a consumer, the following should be monitored:
.1 fuel pipe wall temperature; and
.2 fuel pressure.
15.9.2 The control system should be capable of calculating the dynamic dew point based on measurements of fuel pressure and fuel pipe wall temperature. If fuel pipe wall temperature falls within 10°C of the calculated dew point of the fuel, the fuel system should shut down and fuel system should be purged of ammonia fuel.

- **Ventilation**

15.10 Any reduction of the required ventilating capacity in tank connection spaces, fuel preparation rooms or other enclosed spaces containing fuel piping or other fuel equipment not protected by a secondary enclosure should give an audible and visual alarm on the navigation bridge or in a continuously manned central control station or safety centre. Loss of ventilation should result in automatic closing of valves as specified in table 1.

Comment on MSC.1/Circ.1687, 15.10: Acceptable means to confirm the ventilation system is fully operational could be one of the following:
.1 Monitoring of the ventilation electric motor or fan operation combined with under -pressure indication; or
.2 Monitoring of the ventilation electric motor or fan operation combined with ventilation flow indication; or
.3 Monitoring of ventilation flow rate to indicate that the required air flow rate is established.

Suggested additional requirements:

- Loss of ventilation in the fuel preparation room and tank connection space should automatically shut down the pumps and compressors, and other available equipment located in the spaces.
- Ventilated secondary enclosures around fuel piping should be fitted with flow sensor(s) to monitor and alarm in case of any failure in the ventilation system.

- **Safety functions of fuel supply systems**

15.11.1 If the fuel supply is shut off due to activation of an automatic valve, the fuel supply should not be opened until the reason for the disconnection is ascertained and the necessary precautions taken. A readily visible notice giving instruction to this effect should be placed at the operating station for the shutoff valves in the fuel supply lines.

15.11.2 A caution placard or signboard should be permanently fitted in the machinery space containing gas-fuelled engines, stating that heavy lifting, implying danger of damage to the fuel pipes, should not be done unless the fuel supply lines are free from ammonia.
15.11.3 Compressors, pumps and fuel supply should be arranged for manual remote emergency stop from the following locations as applicable:
.1 navigation bridge;
.2 cargo control room;
.3 onboard safety centre;
.4 engine control room;
.5 fire-control station; and
.6 adjacent to the exit of fuel preparation rooms.
15.11.4 The ammonia compressor should also be arranged for manual local emergency stop.

Suggested additional requirements:

- Means to monitor the pressure at each ammonia fuel pump discharge should be provided locally and remotely.
- Means of manual emergency shutdown of fuel supply to the consumers or set of consumers should be provided on the primary and secondary escape routes from the consumer compartment, at a location outside consumer space, outside the fuel preparation space and at the bridge. The activation device should be arranged as a physical button, clearly marked and protected against inadvertent operation and operable under emergency lighting.
- The heating medium circuit for the fuel as well as the heated fuel in the supply lines to consumers should be provided with temperature monitoring at the heat exchanger outlet. The heat exchanger outlet of the heating medium circuit should have a low temperature alarm.
- The venting arrangements of any expansion tank fitted in the closed circuit for heating or cooling purposes, should be evaluated as part of the risk assessment required in Section 4 (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 – Risk Assessment of a Generic Ship Design).

Further Recommendations

Suggested additions to MSC.1/Circ.1687, Table 1:

Monitored Parameters	**Alarm**	**Automatic shutdown of bunker valve**	**Automatic shutdown of tank valve(s)**	**Automatic shutdown of fuel preparation room valve(s)**	**Automatic shutdown of master valve(s)**	**Comments** (A)Automatic (M)Manual
Ammonia detection in enclosed spaces at 25 ppm	X					Local indication at all entrances to space, no alarm at the alarm system
High-level fuel tank	X					
High-high level fuel tank	X	X	X			
Submerged fuel pumps,	X					Stop fuel pumps at low-

low level in tank						low liquid level (A)
Ammonia detection in bunker station at 110 ppm	X					
Ammonia detection in bunker station at 220 ppm		X				
Liquid leakage detection in bunker station	X	X				Close valve at low temperature (A)
Ammonia detection in secondary enclosure around bunkering lines at 110 ppm	X					
Ammonia detection in secondary enclosure around bunkering lines at 220 ppm		X	X			All valves required to isolate the leakage should close (A)
Liquid leakage detection in secondary enclosure around bunkering lines	X	X	X			All valves required to isolate the leakage should close (A)
Ammonia detection in tank connection space at 110 ppm	X					
Ammonia detection on two detectors in tank	X		X			Stop all equipment in tank connection space (M)

connection space at 220 ppm						Activation of increased ventilation (A) Activation of water screen system (M)
Liquid leakage detection in tank connection space	X		X			Close valve at low temperature (A)
Ammonia detection in fuel preparation room at 110 ppm	X					
Ammonia detection on two detectors in fuel preparation room at 220 ppm	X			X		Stop all equipment in fuel preparation room (M) Activation of increased ventilation (A) Activation of water screen system (M)
Liquid leakage detection in Fuel preparation room	X			X		Close valve at low temperature (A)
Ammonia detection in secondary enclosure of fuel supply piping at 110 ppm	X					
Ammonia detection on two detectors in secondary enclosure of fuel supply piping at 220 ppm	X		X	X	X	All valves required to isolate the leakage should close (A) Transient releases which are expected in normal operation of the consumers

						should not cause shutdown of the consumers. Purge fuel system through ARMS (A)
Ammonia detection in ventilation inlet or other openings of safe haven at 25 ppm	X					As applicable: Activation of water screen (A) Ventilation dampers close (A)
Liquid leakage detection in secondary enclosure of fuel supply pipes	X		X	X	X	All valves required to isolate the leakage should close (A)
Ammonia detection in machinery space containing ammonia consumers at 25 ppm	X					
Ammonia detection in machinery space containing ammonia consumers at 50 ppm	X			X		
Reduced ventilation in tank connection space	X					
Loss of ventilation in tank connection space			X			Stop all equipment in tank connection space (A)
Reduced ventilation in fuel preparation room	X					

Loss of ventilation in fuel preparation room				X		Stop all equipment in fuel preparation room (A)
Loss or reduced ventilation or low inert gas pressure within the secondary enclosure of fuel piping	X			X	X	
Loss of ventilation in enclosed or semi-enclosed bunker station	X	X				
Manually activated emergency shutdown of master fuel valve(s) engine	X				X	
Ammonia concentration from discharge of ARMS at 110 ppm	X					
Ammonia detection in engine auxiliary system (cooling, lube oil, etc.)	X					

Comments on the MSC.1/Circ.1687, Table 1:

- Regarding the ammonia detection thresholds of 110/220 ppm within secondary enclosures of fuel supply piping, industry feedback suggests that achieving these thresholds under all operating conditions is challenging and other protective measures shall be considered.

Section 16 – Manufacture, Workmanship and Testing

HAZARDS
Material defects lead to failure and loss of containment.
GOAL
Ensure the manufacture, testing, inspection, and documentation are in accordance with recognized standards.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
The provisions of the IGF Code, part B-1, chapter 16, should apply to ships using ammonia as fuel, where appropriate.
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
The provisions of the IGF Code, part B-1, chapter 16, should apply to ships using ammonia as fuel, where appropriate. **Applicable references from the IGF Code**: **General** *IGF: 16.1.1 The manufacture, testing, inspection and documentation shall be in accordance with recognized standards and the regulations given in the IGF Code.* *IGF: 16.1.2 Where post-weld heat treatment is specified or required, the properties of the base material shall be determined in the heat-treated condition, in accordance with the applicable tables of chapter 7, and the weld properties shall be determined in the heat-treated condition in accordance with 16.3. In cases where a post-weld heat treatment is applied, the test regulations may be modified at the discretion of the Administration.* **General test regulations and specifications** ***Tensile test*** *IGF: 16.2.1.1 Tensile testing shall be carried out in accordance with recognized standards.* *IGF: 16.2.1.2 Tensile strength, yield stress and elongation shall be to the satisfaction of the Administration. For carbon-manganese steel and other materials with definitive yield points, consideration shall be given to the limitation of the yield to tensile ratio.* ***Toughness test***

IGF: 16.2.2.1 Acceptance tests for metallic materials shall include Charpy V-notch toughness tests unless otherwise specified by the Administration. The specified Charpy V-notch regulations are minimum average energy values for three full size (10 mm × 10 mm) specimens and minimum single energy values for individual specimens. Dimensions and tolerances of Charpy V-notch specimens shall be in accordance with recognized standards. The testing and regulations for specimens smaller than 5.0 mm in size shall be in accordance with recognized standards. Only one individual value may be below the specified average value, provided it is not less than 70% of that value. Minimum average values for sub-sized specimens shall be:

Charpy V-notch specimen size (mm)	*Charpy V-notch specimen size (mm)*
10 x 10	*KV*
10 x 7.5	*5/6 KV*
10 x 5.0	*2/3 KV*

where: KV = the energy values (J) specified in tables 7.1 to 7.4.
Only one individual value may be below the specified average value, provided it is not less than 70% of that value.
IGF: 16.2.2.2 For base metal, the largest size Charpy V-notch specimens possible for the material thickness shall be machined with the specimens located as near as practicable to a point midway between the surface and the centre of the thickness and the length of the notch perpendicular to the surface.
IGF: 16.2.2.3 For a weld test specimen, the largest size Charpy V-notch specimens possible for the material thickness shall be machined, with the specimens located as near as practicable to a point midway between the surface and the centre of the thickness. In all cases the distance from the surface of the material to the edge of the specimen shall be approximately 1 mm or greater. In addition, for double-V butt welds, specimens shall be machined closer to the surface of the second welded section. The specimens shall be taken generally at each of the following locations, as shown in figure 16.2, on the centreline of the welds, the fusion line and 1 mm, 3 mm and 5 mm from the fusion line.
IGF:16.2.2.4 If the average value of the three initial Charpy V-notch specimens fails to meet the stated regulations, or the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, three additional specimens from the same material may be tested and the results combined with those previously obtained to form a new average. If this new average complies with the regulations and if no more than two individual results are lower, than the required average and no more than one result is lower than the required value for a single specimen, the piece or batch may be accepted.

Bend test

IGF: 16.2.3.1 The bend test may be omitted as a material acceptance test but is required for weld tests. Where a bend test is performed, this shall be done in accordance with recognized standards.
IGF: 16.2.3.2 The bend tests shall be transverse bend tests, which may be face, root or side bends at the discretion of the Administration. However, longitudinal bend tests may be required in lieu of transverse bend tests in cases where the base material and weld metal have different strength levels.

Section observation and other testing

IGF: 16.2.4 Macro-section, microsection observations and hardness tests may also be required by the Administration, and they shall be carried out in accordance with recognized standards, where required.

Welding of metallic materials and non-destructive testing for the fuel containment system

IGF: 16.3.1 General This section shall apply to primary and secondary barriers only, including the inner hull where this forms the secondary barrier. Acceptance testing is specified for carbon, carbon-manganese, nickel alloy and stainless steels, but these tests may be adapted for other materials. At the discretion of the Administration, impact testing of stainless steel and aluminium alloy weldments may be omitted, and other tests may be specially required for any material.

IGF: 16.3.2 Welding consumables: Consumables intended for welding of fuel tanks shall be in accordance with recognized standards. Deposited weld metal tests and butt weld tests shall be required for all consumables. The results obtained from tensile and Charpy V-notch impact tests shall be in accordance with recognized standards. The chemical composition of the deposited weld metal shall be recorded for information.

IGF: 16.3.3 Welding procedure tests for fuel tanks and process pressure vessels

IGF: 16.3.3.1 Welding procedure tests for fuel tanks and process pressure vessels are required for all butt welds.

IGF: 16.3.3.2 The test assemblies shall be representative of:

.1 each base material;
.2 each type of consumable and welding process; and
.3 each welding position.

IGF: 16.3.3.3 For butt welds in plates, the test assemblies shall be so prepared that the rolling direction is parallel to the direction of welding. The range of thickness qualified by each welding procedure test shall be in accordance with recognized standards. Radiographic or ultrasonic testing may be performed at the option of the fabricator.

IGF: 16.3.3.4 The following welding procedure tests for fuel tanks and process pressure vessels shall be done in accordance with 16.2 with specimens made from each test assembly:

.1 cross-weld tensile tests;
.2 longitudinal all-weld testing where required by the recognized standards;
.3 transverse bend tests, which may be face, root or side bends. However, longitudinal bend tests may be required in lieu of transverse bend tests in cases where the base material and weld metal have different strength levels;
.4 one set of three Charpy V-notch impacts, generally at each of the following locations, as shown in figure 16.2:
  .1 centreline of the welds;
  .2 fusion line;
  .3 1 mm from the fusion line;
  .4 3 mm from the fusion line; and
  .5 5 mm from the fusion line;
.5 macro-section, microsection and hardness survey may also be required.

IGF: 16.3.3.5 Each test shall satisfy the following:

.1 tensile tests: cross-weld tensile strength is not to be less than the specified minimum tensile strength for the appropriate parent materials. For aluminium alloys, reference shall be made to 6.4.12.1.1.3 with regard to the regulations for weld metal strength of under-matched welds (where the weld metal has a lower tensile strength than the parent metal). In every case, the position of fracture shall be recorded for information;

.2 bend tests: no fracture is acceptable after a 180° bend over a former of a diameter four times the thickness of the test pieces; and,

.3 Charpy V-notch impact tests: Charpy V-notch tests shall be conducted at the temperature prescribed for the base material being joined. The results of weld metal impact tests, minimum average energy (KV), shall be no less than 27 J. The weld metal regulations for sub-size specimens and single energy values shall be in accordance with 16.2.2. The results of fusion line and heat affected zone impact tests shall show a minimum average energy (KV) in

accordance with the transverse or longitudinal regulations of the base material, whichever is applicable, and for sub-size specimens, the minimum average energy (KV) shall be in accordance with 16.2.2. If the material thickness does not permit machining either full-size or standard sub-size specimens, the testing procedure and acceptance standards shall be in accordance with recognized standards.

IGF: 16.3.3.6 Procedure tests for fillet welding shall be in accordance with recognized standards. In such cases, consumables shall be so selected that exhibit satisfactory impact properties.

IGF: 16.3.4 Welding procedure tests for piping: Welding procedure tests for piping shall be carried out and shall be similar to those detailed for fuel tanks in 16.3.3.

Production weld tests

IGF: 16.3.5.1 For all fuel tanks and process pressure vessels except membrane tanks, production weld tests shall generally be performed for approximately each 50 m of butt-weld joints and shall be representative of each welding position. For secondary barriers, the same type of production tests as required for primary tanks shall be performed, except that the number of tests may be reduced subject to agreement with the Administration. Tests, other than those specified in 16.3.5.2 to 16.3.5.5 may be required for fuel tanks or secondary barriers.

IGF: 16.3.5.2 The production tests for types A and B independent tanks shall include bend tests and, where required for procedure tests, one set of three Charpy V-notch tests. The tests shall be made for each 50 m of weld. The Charpy V-notch tests shall be made with specimens having the notch alternately located in the centre of the weld and in the heat affected zone (most critical location based on procedure qualification results). For austenitic stainless steel, all notches shall be in the centre of the weld.

IGF: 16.3.5.3 For type C independent tanks and process pressure vessels, transverse weld tensile tests are required in addition to the tests listed in 16.3.5.2. Tensile tests shall meet regulation 16.3.3.5.

IGF: 16.3.5.4 The quality assurance/quality control (QA/QC) program shall ensure the continued conformity of the production welds as defined in the material manufacturers quality manual (QM).

IGF: 16.3.5.5 The test regulations for membrane tanks are the same as the applicable test regulations listed in 16.3.3.

Non-destructive testing

IGF: 16.3.6.1 All test procedures and acceptance standards shall be in accordance with recognized standards, unless the designer specifies a higher standard in order to meet design assumptions. Radiographic testing shall be used in principle to detect internal defects. However, an approved ultrasonic test procedure in lieu of radiographic testing may be conducted, but in addition supplementary radiographic testing at selected locations shall be carried out to verify the results. Radiographic and ultrasonic testing records shall be retained.

IGF: 16.3.6.2 For type A independent tanks where the design temperature is below -20°C, and for type B independent tanks, regardless of temperature, all full penetration butt welds of the shell plating of fuel tanks shall be subjected to non-destructive testing suitable to detect internal defects over their full length. Ultrasonic testing in lieu of radiographic testing may be carried out under the same conditions as described in 16.3.6.1.

IGF: 16.3.6.3 In each case the remaining tank structure, including the welding of stiffeners and other fittings and attachments, shall be examined by magnetic particle or dye penetrant methods as considered necessary.

IGF: 16.3.6.4 For type C independent tanks, the extent of non-destructive testing shall be total or partial according to recognized standards, but the controls to be carried out shall not be less than the following:

.1 Total non-destructive testing referred to in 6.4.15.3.2.1.3 Radiographic testing:
.1 all butt welds over their full length. Non-destructive testing for surface crack detection:
.2 all welds over 10% of their length;
.3 reinforcement rings around holes, nozzles, etc. over their full length. As an alternative, ultrasonic testing, as described in 16.3.6.1, may be accepted as a partial substitute for the radiographic testing. In addition, the Administration may require total ultrasonic testing on welding of reinforcement rings around holes, nozzles, etc.
.2 Partial non-destructive testing referred to in 6.4.15.3.2.1.3: Radiographic testing:
.1 all butt-welded crossing joints and at least 10% of the full length of butt welds at selected positions uniformly distributed. Non-destructive testing for surface crack detection:
.2 reinforcement rings around holes, nozzles, etc. over their full length. Ultrasonic testing:
.3 as may be required by the Administration in each instance.
IGF: 16.3.6.5 The quality assurance/quality control (QA/QC) program shall ensure the continued conformity of the non-destructive testing of welds, as defined in the material manufacturer's quality manual (QM).
IGF: 16.3.6.6 Inspection of piping shall be carried out in accordance with the regulations of chapter 7.
IGF: 16.3.6.7 The secondary barrier shall be non-destructive tested for internal defects as considered necessary. Where the outer shell of the hull is part of the secondary barrier, all sheer strake butts and the intersections of all butts and seams in the side shell shall be tested by radiographic testing.

Other regulations for construction in metallic materials

IGF: 16.4.1 General
Inspection and non-destructive testing of welds shall be in accordance with regulations in 16.3.5 and 16.3.6. Where higher standards or tolerances are assumed in the design, they shall also be satisfied.
IGF: 16.4.2 Independent tank
For type C tanks and type B tanks primarily constructed of bodies of revolution the tolerances relating to manufacture, such as out-of-roundness, local deviations from the true form, welded joints alignment and tapering of plates having different thicknesses, shall comply with recognized standards. The tolerances shall also be related to the buckling analysis referred to in 6.4.15.2.3.1 and 6.4.15.3.3.2.
IGF: 16.4.3 Secondary barriers
During construction the regulations for testing and inspection of secondary barriers shall be approved or accepted by the Administration (see also 6.4.4.5 and 6.4.4.6).
IGF: 16.4.4 Membrane tanks
The quality assurance/quality control (QA/QC) program shall ensure the continued conformity of the weld procedure qualification, design details, materials, construction, inspection and production testing of components. These standards and procedures shall be developed during the prototype testing programme.

Testing

IGF: 16.5.1 Testing and inspections during construction
IGF: 16.5.1.1 All liquefied gas fuel tanks and process pressure vessels shall be subjected to hydrostatic or hydro-pneumatic pressure testing in accordance with 16.5.2 to 16.5.5, as applicable for the tank type.
IGF: 16.5.1.2 All tanks shall be subject to a tightness test which may be performed in combination with the pressure test referred to in 16.5.1.1.
IGF: 16.5.1.3 The gas tightness of the fuel containment system with reference to 6.3.3 shall be tested.
IGF: 16.5.1.4 Regulations with respect to inspection of secondary barriers shall be decided by the Administration in each case, taking into account the accessibility of the barrier (see also 6.4.4).

IGF: 16.5.1.5 The Administration may require that for ships fitted with novel type B independent tanks, or tanks designed according to 6.4.16 at least one prototype tank and its support shall be instrumented with strain gauges or other suitable equipment to confirm stress levels during the testing required in 16.5.1.1. Similar instrumentation may be required for type C independent tanks, depending on their configuration and on the arrangement of their supports and attachments.

IGF: 16.5.1.6 The overall performance of the fuel containment system shall be verified for compliance with the design parameters during the first fuel bunkering, when steady thermal conditions of the liquefied gas fuel are reached, in accordance with the requirements of the Administration. Records of the performance of the components and equipment, essential to verify the design parameters, shall be maintained on board and be available to the Administration.

IGF: 16.5.1.7 The fuel containment system shall be inspected for cold spots during or immediately following the first fuel bunkering, when steady thermal conditions are reached. Inspection of the integrity of thermal insulation surfaces that cannot be visually checked shall be carried out in accordance with the requirements of the Administration.

IGF: 16.5.1.8 Heating arrangements, if fitted in accordance with 6.4.13.1.1.3 and 6.4.13.1.1.4, shall be tested for required heat output and heat distribution.

IGF: 16.5.2 Type A independent tanks

All type A independent tanks shall be subjected to a hydrostatic or hydro-pneumatic pressure testing. This test shall be performed such that the stresses approximate, as far as practicable, the design stresses, and that the pressure at the top of the tank corresponds at least to the MARVS. When a hydropneumatic test is performed, the conditions shall simulate, as far as practicable, the design loading of the tank and of its support structure including dynamic components, while avoiding stress levels that could cause permanent deformation.

IGF: 16.5.3 Type B independent tanks

Type B independent tanks shall be subjected to a hydrostatic or hydro-pneumatic pressure testing as follows:

.1 The test shall be performed as required in 16.5.2 for type A independent tanks.

.2 In addition, the maximum primary membrane stress or maximum bending stress in primary members under test conditions shall not exceed 90% of the yield strength of the material (as fabricated) at the test temperature. To ensure that this condition is satisfied, when calculations indicate that this stress exceeds 75% of the yield strength the test of the first of a series of identical tanks shall be monitored by the use of strain gauges or other suitable equipment.

IGF: 16.5.4 Type C independent tanks and other pressure vessels

IGF: 16.5.4.1 Each pressure vessel shall be subjected to a hydrostatic test at a pressure measured at the top of the tanks, of not less than 1.5 P0. In no case during the pressure test shall the calculated primary membrane stress at any point exceed 90% of the yield strength of the material at the test temperature. To ensure that this condition is satisfied where calculations indicate that this stress will exceed 0.75 times the yield strength, the test of the first of a series of identical tanks shall be monitored by the use of strain gauges or other suitable equipment in pressure vessels other than simple cylindrical and spherical pressure vessels.

IGF: 16.5.4.2 The temperature of the water used for the test shall be at least 30°C above the nil-ductility transition temperature of the material, as fabricated.

IGF: 16.5.4.3 The pressure shall be held for 2 hours per 25 mm of thickness, but in no case less than 2 hours.

IGF: 16.5.4.4 Where necessary for liquefied gas fuel pressure vessels, a hydro-pneumatic test may be carried out under the conditions prescribed in 16.5.4.1 to 16.5.4.3.

IGF: 16.5.4.5 Special consideration may be given to the testing of tanks in which higher allowable stresses are used, depending on service temperature. However, regulation in 16.5.4.1 shall be fully complied with.

IGF: 16.5.4.6 After completion and assembly, each pressure vessel and its related fittings shall be subjected to an adequate tightness test, which may be performed in combination with the pressure testing referred to in 16.5.4.1 or 16.5.4.4 as applicable.

IGF: 16.5.5 Membrane tanks
IGF: 16.5.5.1 Design development testing
IGF: 16.5.5.1.1 The design development testing required in 6.4.15.4.1.2 shall include a series of analytical and physical models of both the primary and secondary barriers, including corners and joints, tested to verify that they will withstand the expected combined strains due to static, dynamic and thermal loads at all filling levels. This will culminate in the construction of a prototype scaled model of the complete liquefied gas fuel containment system. Testing conditions considered in the analytical and physical model shall represent the most extreme service conditions the liquefied gas fuel containment system will be likely to encounter over its life. Proposed acceptance criteria for periodic testing of secondary barriers required in 6.4.4 may be based on the results of testing carried out on the prototype scaled model.
IGF: 16.5.5.1.2 The fatigue performance of the membrane materials and representative welded or bonded joints in the membranes shall be determined by tests. The ultimate strength and fatigue performance of arrangements for securing the thermal insulation system to the hull structure shall be determined by analyses or tests.
IGF: 16.5.5.2 Testing
.1 In ships fitted with membrane liquefied gas fuel containment systems, all tanks and other spaces that may normally contain liquid and are adjacent to the hull structure supporting the membrane, shall be hydrostatically tested.
.2 All hold structures supporting the membrane shall be tested for tightness before installation of the liquefied gas fuel containment system.
.3 Pipe tunnels and other compartments that do not normally contain liquid need not be hydrostatically tested.

Welding, post-weld heat treatment and non-destructive testing

IGF: 16.6.1 General
Welding shall be carried out in accordance with 16.3.
IGF: 16.6.2 Post-weld heat treatment
Post-weld heat treatment shall be required for all butt welds of pipes made with carbon, carbon-manganese and low alloy steels. The Administration may waive the regulations for thermal stress relieving of pipes with wall thickness less than 10 mm in relation to the design temperature and pressure of the piping system concerned.
IGF: 16.6.3 Non-destructive testing
In addition to normal controls before and during the welding, and to the visual inspection of the finished welds, as necessary for proving that the welding has been carried out correctly and according to the regulations in this paragraph, the following tests shall be required:
.1 100% radiographic or ultrasonic inspection of butt-welded joints for piping systems with;
.1 design temperatures colder than minus 10°C; or
.2 design pressure greater than 1.0 MPa; or
.3 gas supply pipes in ESD protected machinery spaces; or
.4 inside diameters of more than 75 mm; or
.5 wall thicknesses greater than 10 mm.
.2 When such butt-welded joints of piping sections are made by automatic welding procedures approved by the Administration, then a progressive reduction in the extent of radiographic or ultrasonic inspection can be agreed, but in no case to less than 10% of each joint. If defects are revealed the extent of examination shall be increased to 100% and shall include inspection of previously accepted welds. This approval can only be granted if well documented quality assurance procedures and records are available to assess the ability of the manufacturer to produce satisfactory welds consistently.
.3 The radiographic or ultrasonic inspection regulation may be reduced to 10% for butt-welded joints in the outer pipe of double-walled fuel piping.

.4 For other butt-welded joints of pipes not covered by 16.6.3.1 and 16.6.3.3, spot radiographic or ultrasonic inspection or other non-destructive tests shall be carried out depending upon service, position and materials. In general, at least 10% of butt-welded joints of pipes shall be subjected to radiographic or ultrasonic inspection.

Testing regulations

System testing regulations

IGF: 16.7.3.1 The regulations for testing in this section apply to fuel piping inside and outside the fuel tanks. However, relaxation from these regulations for piping inside fuel tanks and open-ended piping may be accepted by the Administration.
IGF: 16.7.3.2 After assembly, all fuel piping shall be subjected to a strength test with a suitable fluid. The test pressure shall be at least 1.5 times the design pressure for liquid lines and 1.5 times the maximum system working pressure for vapour lines. When piping systems or parts of systems are completely manufactured and equipped with all fittings, the test may be conducted prior to installation on board the ship. Joints welded on board shall be tested to at least 1.5 times the design pressure.
IGF: 16.7.3.3 After assembly on board, the fuel piping system shall be subjected to a leak test using air, or other suitable medium to a pressure depending on the leak detection method applied.
IGF: 16.7.3.4 In double wall fuel piping systems the outer pipe or duct shall also be pressure tested to show that it can withstand the expected maximum pressure at pipe rupture.
IGF: 16.7.3.5 All piping systems, including valves, fittings and associated equipment for handling fuel or vapours, shall be tested under normal operating conditions not later than at the first bunkering operation, in accordance with the requirements of the Administration.
IGF: 16.7.3.6 Emergency shutdown valves in liquefied gas piping systems shall close fully and smoothly within 30 s of actuation. Information about the closure time of the valves and their operating characteristics shall be available on board, and the closing time shall be verifiable and repeatable.
*IGF: 16.7.3.7 The closing time of the valve (i.e. time from shutdown signal initiation to complete valve closure) shall not be greater than: 3600*U / BR (second), where:*

U = ullage volume at operating signal level (m^3).

BR= maximum bunkering rate agreed between ship and shore facility (m^3/h); or 5 seconds, whichever is the least.

The bunkering rate shall be adjusted to limit surge pressure on valve closure to an acceptable level, taking into account the bunkering hose or arm, the ship and the shore piping systems, where relevant.

The bunkering rate shall be adjusted to limit surge pressure on valve closure to an acceptable level, taking into account the bunkering hose or arm, the ship and the shore piping systems, where relevant.

Further Recommendations

Periodic testing should cover, but not be limited to, the following items, which are provided for guidance only.

.1 Fuel Storage system:
- External examination of storage tanks and secondary barrier if fitted and accessible;
- Examination of tank relief valves;
- Examination and testing of installed bilge alarms and drainage systems;
- Functional testing of the remote and local closing of the tank valve(s);
- Verification of satisfactory operation of tank monitoring system.

.2 Fuel Bunkering System
- Examination of bunker stations and bunkering piping for signs of corrosion, damage, deterioration of insulation, or evidence of dampness to the insulation, where fitted;

- Verification of satisfactory operation of the fuel bunkering control, monitoring, and shutdown systems.

.3 Fuel Supply System
- Examination of the fuel supply system during working conditions (e.g., piping, hoses, remote operating valves, relief valves, machinery, and equipment for venting, compressing, refrigerating, liquefying, heating, cooling, or otherwise handling the fuel);
- External examination of all pressure vessels in the system;
- Verification of satisfactory operation of the fuel supply system control, monitoring and shutdown systems, including stopping of pumps and compressors upon emergency;
- Examination of the means of inerting;
- Examination of the ventilation system, including portable ventilating equipment where fitted, in spaces such as air locks, pump rooms, compressor rooms, fuel preparation rooms, fuel valve rooms, control rooms, and spaces containing ammonia combustion equipment;
- Functional testing of differential pressure and loss of pressure alarms, where fitted;
- Examination of the portable and fixed drip trays and insulation for the protection of the ship’s structure in the event of leakage;
- Functional testing of the remote and local closing of the master fuel valve(s) (i.e. commonly referred to as the Fuel Valve Train (FVT), Gas Valve Unit (GVU), or Gas Valve Train (GVT));
- Examination of electrical equipment in hazardous or toxic areas;
- Examination of sealing arrangements in way of access openings and bulkhead/deck penetrations;
- Examination and verification of satisfactory operation of fire protection system(s) and fire extinguishing equipment in all areas where fuel storage, bunkering, and supply systems are installed;
- Examination and testing of installed bilge alarms and means of drainage in toxic spaces such as air locks, pump rooms, compressor rooms, fuel preparation rooms, fuel valve rooms;
- Examination of electrical bonding arrangements in hazardous areas, including bonding straps where fitted;
- Examination and operational testing of fuel treatment or vent control systems (i.e. ammonia release mitigation system (ARMS);
- Examination and operational testing of internal combustion engine exhaust after treatment systems

.4 Other safety equipment
- Examination and verification of satisfactory operation of the boil-off gas management system as applied in accordance with the MSC.1/Circ.1687, 6.9.1.1;
- Verification of satisfactory operation of gas detection, including indicators and alarms, and other leakage detection equipment in all areas where fuel storage, bunkering, and supply systems are installed. Recalibration of the gas detection systems should be verified in accordance with the manufacturers’ recommendations;
- Verification of installed interlocks in the gas detection system is to be verified in working condition;
- Verification of satisfactory operation of portable gas detectors for ammonia;
- Functional testing of water screens above access openings and ventilation openings, where fitted;
- Functional testing of the gas evacuation system (i.e., emergency ventilation), where fitted.
- Functional testing of eyewash and decontamination showers, where fitted;
- Examination of all other personnel safety, additional safety equipment suits & self-contained breathing apparatus, and other PPE specific to ammonia;
- Examination of toxic areas, electrical equipment hazardous ratings, and ventilation systems.

.5 Documentation

- Verification that the manufacturer/builder instructions and manuals covering the operations, safety and maintenance requirements, and occupational health hazards relevant to fuel storage, fuel bunkering, fuel supply, and associated systems for the use of fuel are available and being followed.
- Verification that logbooks are available and maintained, containing records of:
  - daily operating hours of prime movers, reliquefaction plant, gas combustion unit, as applicable;
  - boil-off gas rates;
  - gas detection events.

Section 17 – Drills and Emergency Exercises

HAZARDS
Hazards to be considered include: • Unclear roles during emergencies • Ineffective emergency response plans • Human errors or lack of awareness during emergencies (delayed responses, unintentional errors, oversights)
GOAL
N/A
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
17.1 Drills and emergency exercises on board should be conducted at regular intervals. *17.2 Such ammonia-related exercises could include, for example:* *.1 tabletop exercise;* *.2 review of fuelling procedures based on the fuel handling manual;* *.3 responses to potential contingencies;* *.4 tests of equipment intended for contingency response; and* *.5 reviews that assigned seafarers are trained to perform assigned duties during fuelling and contingency response.* *17.3 Ammonia-related exercises may be incorporated into periodical drills required by SOLAS.* *17.4 The response and safety system for hazards and accident control should be reviewed and tested.*
Further Recommendations
Suggested requirement: Emergency response plans should aim to: .1reducing to a minimum the duration and intensity of exposure; .2reducing to a minimum the number of workers exposed or likely to be exposed; .3ensure the safe containment and treatment of any released amounts of ammonia; .4minimize the release of ammonia to the environment.
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
N/A
Further Recommendations
Additional recommendations: 1. In accordance with the provisions of the ISM Code, the ship operating Company shall develop and maintain detailed emergency response procedures specifically addressing ammonia-related incidents. 2. These procedures shall be informed by vessel-specific risk assessments and operational scenarios, taking into account potential release conditions such as type, size, and duration within identified toxic areas. Emergency response plans shall be dimensioned to effectively address each scenario, ensuring adequate resources are in place. 3. Regular drills shall be conducted to validate preparedness and achieve targeted response times.

4. The emergency response protocols should include, but may not be limited to, the following potential contingencies:
   .1 Release of toxic liquids or gases:
   - Due to leakages in enclosed or semi-enclosed toxic spaces (e.g., fuel preparation rooms, tank connection spaces)
   - On open deck during bunkering operations (e.g., hose failure, emergency disconnection of loading arms, opening of pressure relief valves due to overpressure)
   - Due to opening of pressure relief valves associated with the storage tank venting system

   .2 Fire or explosion involving ammonia system (e.g., exhaust system explosion due to unburned ammonia)

   .3 Loss of power with the potential to disrupt the safety functionalities of the ammonia systems

   .4 Ship-level emergencies such as:
   - Collisions, groundings, floodings
   - Blackouts and communication failures during critical ammonia-related operations
   - Extreme weather conditions
5. Procedures addressing all the aforementioned scenarios shall be specifically designed to reflect the unique characteristics and operational requirements of a vessel's design. These procedures shall be fully integrated into the vessel's Safety Management System (SMS) and, as a minimum, shall include the following elements:
   .1 designated roles and responsibilities for all personnel involved in each ammonia-related emergency response
   .2 communication channels for reporting ammonia-related incidents to both internal and external responders
   .3 leakage isolation and mitigation measures for each emergency scenario (e.g. manual intervention, application of water screens or physical boundaries, forced ventilation, neutralization strategies)
   .4 firefighting procedures specifically for incidents involving ammonia-sourced fires or impacting ammonia-related equipment
   .5 evacuation plans and escape routes to muster stations and safe havens,
   .6 use and management of personal protective equipment and first aid kits
   .7 maintenance, inspection and functional testing of all ammonia-related safety and emergency response equipment
   .8 training programs and competency standards for crew, including both theoretical instructions and practical drills
   .9 continuous improvement policies based on lessons learnt from drills, audits, incidents that should be recorded

Suggested additional requirement: A detailed ship layout drawing shall be readily available onboard, clearly indicating all designated escape routes from each compartment, the locations of lifesaving equipment, muster station(s), and the designated safe haven position(s). The drawing must also highlight areas identified as high-risk in terms of toxicity, based on ship-specific operations and arrangements. This layout shall be kept up to date and accessible to all personnel as part of the vessel's emergency preparedness documentation (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 3 – Risk Assessment of a Generic Ship Design).

Section 18 – Operation

HAZARDS
Hazards to be considered include: • Exposure of individuals to flammable, toxic, or asphyxiating gases due to human error or lack of awareness • Accidental release of flammable or toxic gases due to operational mistakes
GOAL
Ensure that operational procedures for the loading, storage, operation, maintenance and inspection of systems for ammonia minimize the risk to persons, the ship, and the environment, and that they are consistent with practices for a conventional oil-fuelled ship whilst considering the nature of ammonia.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
18.2.1.1: A copy of these Interim Guidelines, or national regulations incorporating the provisions of the same, should be on board every ship covered by these Interim Guidelines; *18.2.1.2: maintenance procedures and information for all ammonia-related installations should be available on board;* *18.2.1.3: the ship should be provided with operational procedures including a suitably detailed fuel handling manual, such that trained personnel can safely operate the fuel bunkering, storage and transfer systems;* *18.2.1.4: the ship should be provided with suitable emergency procedures.*
Further Recommendations
Suggested requirement: Following the requirements of the ISM Code, detailed response procedures tailored for ammonia-specific emergency conditions should be developed under the responsibility of the ship operating company. Such detailed protocols should include crew actions, equipment usage, containment methods, and other tasks as applicable to ensure effective mitigation of hazards related to ammonia.
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **Reference to the IGF Code** *18.3: The IGF Code chapter 18 should be taken into account, where applicable, in order to fulfil the functional requirements.* **<u>Applicable references from the IGF Code</u>**: **<u>Maintenance</u>** *IGF Part C-1, 18.3.1: Maintenance and repair procedures shall include considerations with respect to the tank location and adjacent spaces.*

IGF Part C-1,18.3.2: In-service survey, maintenance and testing of the fuel containment system are to be carried out in accordance with their inspection/survey plan required by IGF 6.4.1.8:

> *An inspection/survey plan for the liquefied gas fuel containment system shall be developed and approved by the Administration. The inspection/survey plan shall identify aspects to be examined and/or validated during surveys throughout the liquefied gas fuel containment system's life and, in particular, any necessary in-service survey, maintenance and testing that was assumed when selecting liquefied gas fuel containment system design parameters. The inspection/survey plan may include specific critical locations as per the 6.4.12.2.8 or 6.4.12.2.9.*

IGF Part C-1,18.3.3: The procedures and information shall include maintenance of electrical equipment that is installed in explosion hazardous spaces and areas. the inspection and maintenance of electrical installations in explosion hazardous spaces shall be performed in accordance with a recognized standard.

Bunkering operations

IGF Part C-1: 18.4.1.1 Before any bunkering operation commences, the master of the receiving ship or his representative

and the representative of the bunkering source (Persons in Charge, PiC) shall agree in writing the transfer procedure, including cooling down and if necessary, gassing up; the maximum transfer rate at all stages and volume to be transferred, action to be taken in an emergency, complete and sign the bunker safety checklist.

IGF Part C-1: 18.4.1.2 Upon completion of bunkering operations the ship PiC shall receive and sign a Bunker Delivery

note for the fuel delivered, containing at least the information specified in the annex to part C-1, completed and signed by the bunkering source PiC.

IGF Part C-1: 18.4.2.1 The fuel handling manual required by 18.2.3 shall include but is not limited to:

> *.1 overall operation of the ship from dry-dock to dry-dock, including procedures for system cool down and warm up, bunker loading and, where appropriate, discharging, sampling, inerting and gas freeing;*
> *.2 bunker temperature and pressure control, alarm and safety systems;*
> *.3 system limitations, cool down rates and maximum fuel storage tank temperatures prior to bunkering, including minimum fuel temperatures, maximum tank pressures, transfer rates, filling limits and sloshing limitations;*
> *.4 operation of inert gas systems;*
> *.5 firefighting and emergency procedures: operation and maintenance of firefighting systems and use of extinguishing agents;*
> *.6 specific fuel properties and special equipment needed for the safe handling of the particular fuel;*
> *.7 fixed and portable gas detection operation and maintenance of equipment;*
> *.8 emergency shutdown and emergency release systems, where fitted; and*
> *.9 a description of the procedural actions to take in an emergency situation, such as leakage, fire or potential fuel stratification resulting in rollover.*

Comment on IGF Code, 18.4.2.1: Because of safety and toxicity concerns with ammonia as a fuel, the IMO's MEPC 81 amendments clarify that the usual fuel sampling rules in MARPOL Annex VI (Regulations 14 and 18) do not apply to gas fuels like ammonia, unless local Authorities instructs otherwise.

IGF Part C-1: 18.4.2.2 a fuel system schematic/piping and instrumentation diagram (P&iD) shall be reproduced and permanently mounted in the ship's bunker control station and at the bunker station

IGF Part C-1: 18.4.3.1 Prior to conducting bunkering operations, pre-bunkering verification including, but not limited to the following, shall be carried out and documented in the bunker safety checklist: all communications methods, including ship shore link (SSl), operation of fixed gas and fire detection equipment, operation of portable gas detection equipment, operation of remote-controlled valves, inspection of hoses and couplings.

Comment on IGF Code, 18.4.3.1: In addition, and particularly in the context of ammonia, the following items may be added:

.1 Operation of water spray system

.2 Verifying the condition and integrity of personal protective equipment (PPE), with particular attention given to the chemical protective suits.

IGF Part C-1: 18.4.3.2 Documentation of successful verification shall be indicated by the mutually agreed and executed bunkering safety checklist signed by both PiCs.

IGF Part C-1: 18.4.4.1 Communications shall be maintained between the ship PiC and the bunkering source PiC at all times during the bunkering operation. in the event that communications cannot be maintained, bunkering shall stop and not resume until communications are restored.

IGF Part C-1: 18.4.4.2 Communication devices used in bunkering shall comply with recognized standards for such devices acceptable to the administration.

IGF Part C-1: 18.4.4.3 PiCs shall have direct and immediate communication with all personnel involved in the bunkering operation.

IGF Part C-1: 18.4.4.4 the ship shore link (SSl) or equivalent means to a bunkering source provided for automatic ESD communications, shall be compatible with the receiving ship and the delivering facility ESD system.

IGF Part C-1: 18.4.5 Hoses, transfer arms, piping and fittings provided by the delivering facility used for bunkering shall be electrically continuous, suitably insulated and shall provide a level of safety compliant with recognized standards.

IGF Part C-1: 18.4.6.1 Warning signs shall be posted at the access points to the bunkering area listing fire safety precautions during fuel transfer.

Comment on IGF Code, 18.4.6.1: To ensure clarity, particularly in the context of ammonia, the following wording is recommended.

Suggested rewording: "*Warning signs shall be posted at the access points to the bunkering area listing fire and toxicity safety precautions during fuel transfer.*"

IGF Part C-1: 18.4.6.2 During the transfer operation, personnel in the bunkering manifold area shall be limited to essential staff only. all staff engaged in duties or working in the vicinity of the operations shall wear appropriate personal protective equipment (PPe). a failure to maintain the required conditions for transfer shall be cause to stop operations and transfer shall not be resumed until all required conditions are met.

Recommendation: ISO/TS 18683:2021 "Guidelines for Safety and Risk Assessment of LNG Fuel Bunkering Operations" may be used as a reference standard for ammonia bunkering operations.

Enclosed space entry

IGF Part C-1: 18.5.1 Under normal operational circumstances, personnel shall not enter fuel tanks, fuel storage hold spaces, void spaces, tank connection spaces or other enclosed spaces where gas or flammable vapours may accumulate, unless the gas content of the atmosphere in such space is determined by means of fixed or portable equipment to ensure oxygen sufficiency and absence of an explosive atmosphere.

Comment on IGF Code, 18.5.1: To ensure clarity, particularly in the context of ammonia, the following wording is recommended.
Suggested rewording: "Under normal operational circumstances, personnel shall not enter fuel tanks, fuel storage hold spaces, void spaces, tank connection spaces or other enclosed spaces where toxic gas or flammable vapours may accumulate, unless the gas content of the atmosphere in such space is determined by means of fixed or portable equipment to ensure oxygen sufficiency, absence of an explosive or toxic atmosphere".

Inerting and purging of fuel systems

IGF Part C-1: 18.6.1 the primary objective in inerting and purging of fuel systems is to prevent the formation of a combustible atmosphere in, near or around fuel system piping, tanks, equipment and adjacent spaces.
IGF Part C-1: 18.6.2 Procedures for inerting and purging of fuel systems shall ensure that air is not introduced into piping or a tank containing gas atmospheres, and that gas is not introduced into air contained in enclosures or spaces
adjacent to fuel systems.
IGF Part C-1: 18.7.1 Hot work in the vicinity of fuel tanks, fuel piping and insulation systems that may be flammable, contaminated with hydrocarbons, or that may give off toxic fumes as a product of combustion shall only be undertaken after the area has been secured and proven safe for hot work and all approvals have been obtained.

Hot works

IGF Part C-1: 18.7.1 Hot work in the vicinity of fuel tanks, fuel piping and insulation systems that may be flammable, contaminated with hydrocarbons, or that may give off toxic fumes as a product of combustion shall only be undertaken after the area has been secured and proven safe for hot work and all approvals have been obtained.

Further Recommendations

Additional recommendations:

- For bunkering operations, controlled zones should be defined based on the results of the gas dispersion analysis, risk assessments, relevant international requirements, and as they may be determined by the local Authorities. Such zones may be defined as follows:
  .1 Hazardous and Toxic areas where only essential personnel are allowed.
  .2 Safety zones where authorised persons and activities are allowed considering the ambient conditions and site-specific risk assessments.
  .3 Security zones to reduce possible external interference with the bunkering operation.
- The compatibility of the bunkering station's layout with the bunkering facility's emergency response and access requirements should be verified as part of the overall risk assessment process, in consultation with the local Authorities.
- A security risk assessment shall be conducted to evaluate potential threats to exposed ammonia system equipment such as bunkering stations, storage tanks or associated piping during operations that is important to protect. The potential threats should be identified, and procedural protective measures be implemented. The assessment and resulting measures shall comply with the provisions of the ISPS Code (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 5 – Risk Assessment of a RORO Ship Design).
- Simultaneous Operations (SIMOPS) during ammonia bunkering operations shall be carefully evaluated based on the results of relevant gas dispersion analysis, risk assessments, relevant operational requirements, and as may be determined by the local authorities (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships – PART 4 - Risk Assessment of a Bulk Carrier Ship Design & PART 5 – Risk Assessment of a RORO Ship Design). Special consideration should be given, but not limited to, the following topics:

.1 The identification and assessment of risks arising from the overlapping or interference of gas hazardous areas between vessels operating in close proximity.

.2 The potential interactions between ammonia and cargo environments shall be assessed, with a focus on chemical compatibility and risks of cargo dust interference.

Section 19 – Training

HAZARDS
Hazards to be considered include: • Poor or inadequate training to meet operational requirements • Unrecognised hazards during operational, maintenance, and emergency response operations • Lack of awareness or overconfidence due to insufficient reinforcement of safety practices
GOAL
Ensure that seafarers on board ships are adequately qualified, trained, and experienced.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
19.2.1: The company should ensure that seafarers on board ships using ammonia fuel should have completed training to attain the abilities that are appropriate to the capacity to be filled, and duties and responsibilities to be taken up. *19.2.2: The master, officers, ratings and other personnel on ships using ammonia fuel should have received training and be qualified in the use of gaseous fuel in accordance with the STCW Convention and the STCW Code, taking into account the specific hazards of ammonia.*
Further Recommendations
Comment on MSC.1/Circ.1687, 19.2.2: Regulations, and seafarer certification standards concerning training on the use of ammonia as a marine fuel should be developed through a harmonised and coordinated approach across the maritime industry. This process should consider the diverse roles of stakeholders, both onboard and ashore, to ensure consistency and recognition across different jurisdictions. A structured framework for training requirements may be outlined as follows: .1 Key characteristics of ammonia, such as toxicity, flammability, explosivity, corrosion, and material incompatibility .2 Ammonia safety and environmental hazards, risk awareness .3 Occupational health and safety awareness .4 Operational / Process Safety .5 Regulations, Requirements, Guidelines awareness .6 Ammonia Fuel Storage, Management and Transfer .7 Ammonia Gas Purging, Venting operations .8 Leak detection, Management, Isolation and Repair .9 Simultaneous Operations .10 Maintenance activities .11 Emergency response
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
N/A
Further Recommendations
Suggested requirements:

- All crew personnel must be provided with emergency procedures and receive training specific to their assigned roles and responsibilities that they may have during emergencies.
- Training, drills and exercises to prepare the crews for emergencies should be documented and integrated into the vessel's Safety Management System (SMS). Lessons learned from past operations should be incorporated to improve the emergency procedures. Procedures should cover all scenarios specific to the ship, type of incident, equipment, and associated areas.
- Emergency response training should be customised to the ship-specific equipment, system arrangements and plausible emergency scenarios relevant to each vessel, as identified through risk assessment. At a minimum, emergency training should involve:
  - .1 Emergency evacuation of crew from high-risk areas;
  - .2 First aid for ammonia related incidents;
  - .3 Leakage and spill response scenarios;
  - .4 Operational readiness in case of operational emergencies (e.g. manual shutdown protocols, response to system malfunctions);
  - .5 Mustering and sheltering procedures to designated safe havens.

Additional recommendations:

- Training shall be carried out in accordance with the Company's applicable ISM policies and must be properly documented, regularly reviewed, updated, and validated through periodic assessments or drills to ensure ongoing proficiency and compliance.
- A standardised crew experience matrix should be developed and implemented to ensure that personnel assigned to vessels operating with ammonia as fuel possess the appropriate combination of qualifications, training and operational experience. The matrix should define minimum experience thresholds for key roles, taking into account factors such as prior exposure to alternative fuel systems, familiarity with vessel-specific technologies, and participation in relevant drills and emergency response exercises.

Section 20 – Personnel Protection

HAZARDS
Hazards to be considered include: • Malfunction or failure of PPE or emergency response equipment • Insufficient availability or quantity of PPE or emergency equipment onboard • Improper placement or inadequate accessibility of PPE or emergency equipment in critical areas • Improper use of PPE or emergency equipment
GOAL
Ensure that protective equipment is provided for persons on board, considering both routine operations and emergency situations and possible short- or long-term effects of ammonia exposure.
FUNCTIONAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
20.2.1.1 for the protection of crew members who are engaged in operations, maintenance of ammonia fuel systems, and emergency response, the ship should have on board protective equipment suitable for ammonia exposure, taking the exposure risk of different operations into account; *20.2.1.2 for the protection and treatment of crew members affected by ammonia leakages, the ship should have on board suitable emergency equipment;* *20.2.1.3 suitable respiratory and eye protection for emergency escape purposes should be provided for every person on board.*
Further Recommendations
N/A
TECHNICAL REQUIREMENTS
IMO Interim Guidelines (MSC.1/Circ.1687)
- **Protective equipment** *20.3.1 Suitable protective equipment, including eye protection, to a recognized national or international standard, should be provided for the protection of crew members engaged in normal operations related to the ammonia fuel system.* **Suggested addition to MSC.1/Circ.1687, 20.3.1:** Protective equipment should cover the crew's entire body without any exposed skin and consist of face shield, large apron, long-sleeved gloves, full-body coverall, and footwear made of chemical-resistant materials. *20.3.2 Personal protective and safety equipment required in this chapter should be kept in suitable, clearly marked lockers located in readily accessible places.* **Suggested addition to MSC.1/Circ.1687, 20.3.2:** Based on the vessel's specific layout and the locations where ammonia-related operations are carried out, safety equipment should be positioned to ensure reasonable accessibility, taking into account proximity to potential exposure areas and the

need for rapid response. Detailed placement criteria should be determined based on the findings of risk assessments.

- **Emergency equipment**

20.4.1 Suitably marked decontamination showers and eyewashes should be available in convenient locations: close to bunkering stations, close to exit from tank connection spaces, close to exit from fuel preparation rooms, in machinery spaces for ammonia-fuelled consumers and close to lifeboat embarkation stations.
20.4.2 The showers and eyewashes should be operable in all ambient conditions. A heating system with temperature control is required if pipe routeing of the water supply exposes the piping to freezing conditions. Water supply capacity should be sufficient for simultaneous use of at least two units. Thermal insulation is not considered as an alternative to a system with temperature control.
20.4.3 A stretcher that is suitable for hoisting an injured person from spaces, such as tank hold spaces, should be kept in a readily accessible location.
20.4.4 The ship should have onboard medical first aid equipment, including oxygen resuscitation equipment, based on the requirements of the Medical First Aid Guide (MFAG) for ammonia.
20.4.5 Suitable respiratory and eye protection for emergency escape purposes should be provided for every person on board, subject to the following:
.1 filter-type respiratory protection is unacceptable,
.2 self-contained breathing apparatus should have at least 15 minutes of service time and
.3 emergency escape respiratory protection should not be used for fire-fighting, or cargo handling purposes and should be marked to that effect.

Suggested additional requirement: The availability and use of portable gas detectors as personal protective equipment for personnel working within potentially toxic areas could be considered as an additional layer of protection (ref. EMSA Study Investigating the Safety of Ammonia as Fuel on Ships - PART 5 - Risk Assessment of a RORO Ship Design).

- **Safety equipment**

20.5.1 Sufficient, but not less than three complete sets of safety equipment, should be provided in addition to fire-fighter's outfits required by SOLAS regulation II-2/10.10. These additional sets should provide adequate personal protection to permit entry and work in a gas-filled space and be equipped with two-way portable radiotelephone apparatus comprising of earpiece with microphone and push-to-talk units. This equipment should consider the nature of ammonia.

Comment on MSC.1/Circ.1687, 20.5.1: The number of compressed air safety equipment sets required should be determined based on the findings of risk assessments.

20.5.2 Each complete set of safety equipment should consist of one self-contained positive pressure air breathing apparatus incorporating full face mask not using stored oxygen and having a capacity of at least 1,200 litres of free air. Each set should be compatible with that required by SOLAS regulation II-2/10.10. gastight protective clothing, boots and gloves to a recognized standard, steel-cored rescue line with belt, and explosion-proof lamp.
20.5.3 An adequate supply of compressed air should be provided and should consist of at least one fully charged spare air bottle for each breathing apparatus required by 20.5.1, an air compressor of adequate capacity capable of continuous operation, suitable for the supply high-pressure air of

breathable quality and a charging manifold capable of dealing with sufficient spare breathing apparatus air bottles for the breathing apparatus required by 20.5. *20.5.4 The compressed air equipment should be inspected at least once a month by a responsible officer and the inspection should be logged in the ship's records. This equipment should also be inspected and tested by a competent person at least once a year.*
Further Recommendations

Comments:

.1 The Company shall ensure that the selection and use of PPE during all operations involving ammonia fuel are consistent with the risks identified through vessel-specific risk assessments and documented within the Company's Safety Management System (SMS). As a guideline:

   a. Routine tasks such as fuel handling during bunkering and system inspections, which typically present low to moderate exposure risk, may be addressed with limited splash protection in accordance with EN 13034 – Type 6, combined with chemical-resistant gloves and goggles;

   b. Higher-risk operations, including maintenance on fuel supply lines or emergency repairs where liquid contact or pressurized leaks are more likely, require liquid-tight or spray-tight suits in compliance with EN 14605 – Types 3 or 4, with sealed interfaces;

   c. Emergency scenarios involving significant leaks or vapor release necessitate gas-tight suits in accordance with EN 943-2 – Type 1, integrated with appropriate respiratory protection to prevent inhalation of toxic vapours.

.2 The company shall ensure that all PPE is properly maintained and that crew members are trained in its correct use.

.3 Drills shall be conducted at regular intervals to ensure crew proficiency in:

   a. Donning PPE within an acceptable timeframe;

   b. Performing essential operational tasks while wearing PPE (e.g., operating valves, checking sensors);

   c. Engaging in firefighting and other emergency procedures while equipped with PPE.

.4 As a best practice, it is recommended that the Company establish clear policies governing the use and management of PPE, including the following provisions:

   a. Certain chemical suits and PPEs should be dedicated exclusively for training purposes, such as safety drills, maintenance training, and familiarization exercises.

   b. A set of PPEs should be allocated for routine operations such as bunkering and maintenance. These must be thoroughly inspected and maintained after each use to mitigate risks of degradation (e.g. cracks or tears).

   c. A separate set of PPEs should remain sealed and reserved for emergency scenarios, to guarantee their integrity and readiness when deployed.

Appendix B List of Topics for Future Consideration

Topic: Human Factors and Human Centric design Future IMO regulatory framework could integrate human factors and human-centric design principles to ensure safe and efficient operations, particularly in the context of adopting ammonia as a marine fuel. Best practices from other high-reliability sectors, such as aviation and offshore where human-centred approaches have proven effective in minimizing risks by addressing usability, ergonomics, decision-making under complex conditions could be adapted to the maritime industry.
Topic: Handling of ammonia effluents The current provisions of the IBC Code may permit the discharge of small quantities of aqueous ammonia into the sea, subject to approval by the relevant authorities. However, for ammonia used as fuel, a unified regulatory approach is necessary. The IMO is expected to issue a dedicated guideline by the end of 2027. In the meantime, the recommended practice should be to collect any ammonia effluents onboard, while clear, standardised procedures for shore-based disposal are developed and implemented.
Topic: Ammonia exhaust gas emissions The current IMO framework for nitrogen-based emissions does not require continuous reporting activities similar to those applied for CO_2 emissions (IMO Data Collection System). Instead, compliance is verified during surveys and engine certification through its NO_x Technical File. Uncertainties around unburned ammonia (i.e. ammonia slip), direct N_2O emissions, and indirect reactive nitrogen releases from engines using ammonia as fuel require further investigation to understand their environmental impact across the full well-to-wake lifecycle.
Topic: Bunkering operations – Ship-shoreside interface The development of a standard for ammonia bunkering operations is critical to ensure clarity in roles, responsibilities, and operational coordination between the ship and external stakeholders. Such a framework should explicitly define safety zones demarcation, safety measures, and security protocols to mitigate risks associated with ammonia's toxicity properties. Additionally, structured training programs for all involved parties, coupled with emergency handling procedures, must be prioritised to enhance preparedness and response capabilities.

Topic: Long-term toxicity risks from chronic low-level ammonia exposure

Industry standards for ammonia exposure primarily define limits based on concentration thresholds, typically expressed in parts per million (ppm). For example, OSHA specifies PELs for 50 ppm as an 8-hour TWA and STEL for 35 ppm. Similarly, under EU REACH, the TWA is set at 20 ppm for an 8-hour period, and the STEL at 50 ppm for 15-minutes period. The current version of IMO Interim Guidelines adopts the 25-ppm as threshold for a visual local indication to be given at all entrances to enclosed spaces affected. While these thresholds aim to prevent acute toxicity and irritation, they may not appropriately address the temporal dimension of exposure to low doses. Chronic inhalation of ammonia, even at concentrations below these limits, may contribute to respiratory issues due to cumulative toxicity. This gap highlights the need for regulatory evolution to incorporate cumulative exposure and long-term health risks, rather than short-term concentration limits.

Topic: Safety systems for ammonia dispersion management

An important area for further regulatory development concerns the technical means for mitigating ammonia dispersion in the event of leaks or accidental releases. While several options—such as mechanical barriers, blast walls, and water screen systems—are considered applicable, the specific technical criteria governing their design and implementation remain undefined. For instance, water screen systems are widely regarded as the most cost-effective safety barrier; however, critical details such as required flow rates, spray coverage, and performance standards have yet to be established for ammonia application. Defining these parameters will be essential to ensure consistent safety outcomes and facilitate compliance across the industry.

Topic: Gas Dispersion Simulations

The current definition of toxic areas in the IMO Interim Guidelines relies heavily on gas dispersion analyses to validate the prescriptive distances provided. However, there is virtually no formal guidance or standardised requirements for conducting consistent evaluations of ammonia gas dispersion. This gap can lead to significant inconsistencies in vessel design criteria among Flag Administrations and Classification Societies, as assumptions and methodologies may vary widely. To ensure uniformity and reliability, a recognised standard or guidance document should be developed for performing gas dispersion simulations, clearly specifying required assumptions, governing parameters, and the range of operational conditions to be considered.

Topic: Lack of type approved fire safety extinguishing systems for toxic spaces

Although ammonia combustion is difficult to achieve under normal ambient conditions, fire risks cannot be entirely dismissed in enclosed spaces, where ignition scenarios may still occur. There is currently a general lack of type-approved fire extinguishing systems specifically designed for ammonia fires. While agents such as CO_2, foams, dry powders, and water mist systems can be effective, certain options, particularly foam-based agents, can exhibit unpredictable

behaviour when interacting with ammonia in gaseous or liquid form. Establishing clear performance criteria to assess the suitability of extinguishing agents should be considered.
Topic: Ammonia Release Mitigation System (ARMS) The current version IMO Interim Guidelines acknowledge the need for an ARMS in several clauses; however, they do not provide explicit technical or performance criteria for its design, integration and maintenance. This absence of clear requirements creates uncertainty for ship designers and operators, as critical factors such as system capacity, response characteristics, and effectiveness under varying operational conditions remain undefined. The development of standardised technical specifications, through ISO or other industry working groups, should be considered a priority.
Topic: Ammonia crew training Regulations, and seafarer certification standards concerning training on the use of ammonia as a marine fuel should be developed through a harmonised and coordinated approach across the maritime industry. This process should consider the diverse roles of stakeholders, both onboard and ashore, to ensure consistency and recognition across different jurisdictions.

European Maritime Safety Agency
Praça Europa 4
1249-206 Lisbon, Portugal
Tel +351 21 1209 200
Fax +351 21 1209 210
emsa.europa.eu