European Maritime Safety Agency

SAFETY OF AMMONIA FOR USE IN SHIPS

PART 3 – RISK ASSESSMENT OF A GENERIC SHIP DESIGN

Date: 06/06/2025

EMSA

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Document History

Version	Date	Changes	Prepared	Approved
1.0	09/12/2024	N/A	NTUA, ABS, FVP	-
2.0	30/01/2025	■ Update of the HAZOP Action Items' List ■ Update of the HAZOP Worksheet ■ Update of the CFD simulation results of E/R	NTUA, ABS, FVP	-
3.0	04/04/2025	■ Update of the AFSS subsystems descriptions ■ Update of the Scope of Work ■ Update of the HAZOP Recommendations ■ Update of the HAZOP Conclusions ■ Update of the HAZOP Action Items' List ■ Update of the HAZOP Worksheet ■ Address of miscellaneous comments/remarks	NTUA, ABS, FVP	-
4.0	06/06/2025	■ Address of miscellaneous comments/remarks	NTUA, ABS, FVP	EMSA

Executive Summary

The main goal of this study is to assess the safety of using ammonia as fuel in the maritime industry. To that end, in its first part the feasibility and safety of ammonia as a marine fuel was examined, focusing on its unique hazards such as toxicity, corrosiveness, and solubility in water. While ammonia has an extensive history in land-based applications and as a transported product via liquefied gas carriers, its recent adaptation for marine fuel use highlights regulatory and technological gaps. The first part also emphasised that the existing frameworks by the International Maritime Organisation (IMO) and classification societies remain under development.

To address these challenges, the second part of the study employed advanced fault tree analyses (FTA) and reliability modelling for critical systems, such as internal combustion engines, fuel supply systems, and bunkering operations, using insights from similar liquefied gas fuels like LPG. It also highlighted the more stringent safety requirements; proactive and preventive measures to prohibit equipment and component failures to manage ammonia's inherent risks, particularly the loss of containment. The analysis identified weak points across several systems, such as injector valve fatigue, corrosion risks in fuel injectors, and ammonia leakage in components from sources such as rupture of piping and failure of compressors. Reliability models and sensitivity analyses revealed that incorporating redundancy of critical equipment and components, especially in dual-fuel systems, significantly improves operational reliability. For instance, systems with dual-fuel redundancy showed longer mean time to failure (MTTF) than single-system designs. By leveraging data from industry standards and collaboration with equipment vendors, the second part outlined strategies to enhance system reliability, such as improving material properties and addressing operational and human error risks. These insights provided a foundation for further system design refinements and safety protocols, supporting the adoption of ammonia as a sustainable maritime fuel.

The following part of the ammonia safety study (i.e., part 3) aims to provide additional insights into the safety of ammonia, from perspectives that will be complementary to the ones in part 1. To that end, this report is split into three main sections:

- The report of a hazard and operability (HAZOP) study of an Ammonia Fuel Supply System (AFSS)
- The risk assessment approach from the ports' point of view, including simultaneous operations (SIMOPS) considerations, and
- The modelling of potential consequences in the event of an ammonia leak.

Overall, the study reveals that it is essential to thoroughly understand the unique characteristics of ammonia and their implications for risk assessment in order to establish effective safety measures that mitigate the inherent risks of using ammonia as a fuel.

While the safety principles outlined in the IGF Code for natural gas can be adapted for ammonia, significant modifications are necessary to address the increased toxicity risk in the event of a loss of containment. The IGF did not factor in fuel toxicity, highlighting the need to revise existing barriers and implement additional safety measures to protect against ammonia exposure during routine operations and emergencies. This has been addressed, after the first HAZOP study here reported, by the Interim Guidelines for the safety of ships using ammonia as fuel (MSC.1/Circ.1687), published in February 2025.

<u>HAZOP Study</u>

The HAZOP study mainly focuses on potential hazards and operability problems associated with the typical operation phases of an ammonia fuel supply system to be installed in a generic Very Large Crude Carrier. It was assumed that hazards and operability problems related to the manufacturing, installation, construction, commissioning, or decommissioning phases of the AFSS would be covered and controlled by the shipyard's safety management system, vendors' procedures, etc.

The systems that were analysed include the bunkering stations, the low-pressure system from the bunkering tanks up to (but excluding) the high-pressure (HP) system, the transfer of ammonia to the main engine via the HP system, the ammonia return from the M/E, the boil-off gas handling system, the glycol water system, and the N2 supply system. It should be noted that the HAZOP study does not cover hazards and operability problems associated with typical hull and marine systems such as ballast water systems, diesel oil systems, etc., which are not related to the

AFSS as it was assumed that those kinds of hazards would be controlled and managed by operators, based on relevant requirements such as Flag State regulations, International Maritime Organisation (IMO) requirements and classification society's rules.

In the context of this report, the study examined the AFSS developed by NIKKISO CEIG, according to the specifications of WINGD's X52DF-A engine.

The HAZOP workshop resulted in one hundred and thirty-six (136) scenarios identified by the HAZOP team. Fifteen (15) scenarios were categorised as low-risk and thirty-six (36) were categorised as moderate-risk. Forty-seven (47) scenarios were categorised as high-risk, while no scenarios were categorised as extreme risk as shown in the Risk Ranking table below. Thirty-eight (38) scenarios were not ranked either because i) those consisted of general remarks/considerations, or ii) there was not enough technical information (from the system designer) to carry out the scenario-based risk ranking. The unmitigated risk ranking is presented in the table below.

Risk Ranking

		Low	Minor	Moderate	Major	Critical
		3	4	5	6	7
Likelihood	Almost Certain **(0):** Occurs 1 or more times a ship year	**0**	**0**	**0**	**0**	**0**
	Likely **(-1):** Occurs once every 1-10 ship years	**20**	**19**	**13**	**0**	**0**
	Possible **(-2):** Occurs once every 10-100 ship years	**2**	**16**	**10**	**4**	**0**
	Unlikely **(-3):** Occurs once every 100-1000 ship years	**2**	**11**	**0**	**1**	**0**
	Rare **(-4):** Occurs once every 1000-10000 ship years	**0**	**0**	**0**	**0**	**0**

The HAZOP workshop also identified and analysed existing independent protection layers (IPL)/safeguards for which the risk ranking was re-examined and resulted in forty-one (41) scenarios categorised as low-risk and twenty (20) categorised as moderate-risk. Thirty-seven (37) scenarios were categorised as high-risk, while no scenarios were categorised as extreme risk as shown in the Residual (or mitigated) Risk table below.

Residual Risk

		Low 3	Minor 4	Moderate 5	Major 6	Critical 7
Likelihood	Almost Certain **(0):** Occurs 1 or more times a ship year	0	0	0	0	0
	Likely **(-1):** Occurs once every 1-10 ship years	6	14	11	0	0
	Possible **(-2):** Occurs once every 10-100 ship years	12	11	7	2	0
	Unlikely **(-3):** Occurs once every 100-1000 ship years	3	12	3	3	0
	Rare **(-4):** Occurs once every 1000-10000 ship years	1	12	1	0	0

Thirty-eight (38) scenarios were purposefully not ranked. Thirty-three (33) out of those unranked scenarios were general remarks/considerations that were either not node-specific (thus grouped under the 'General' node) or there was not enough technical information to carry out the risk ranking. For the remaining five (5) (out of 38) scenarios, the identified deviations/hazards could lead to major consequences with a high likelihood of occurrence. However, since the system's design was still deemed incomplete, with multiple components that had not been finalised yet, the HAZOP team decided not to rank those. For a detailed list of the scenarios, refer to the HAZOP Worksheet in Appendix B.

Provided that the existing safeguards are deemed insufficient to address the hazard or the operability issue within an acceptable level or if further assessments are required to allow for a better understanding of the hazard or the operability issue, one hundred and forty-eight (148) recommendations were identified and agreed upon with the HAZOP team during workshop For a detailed list of the recommendations, refer to the Action Items List in Appendix C.

Regarding the AFSS under examination, the following conclusions were drawn:

- Multiple subsystems like the fuel valve unit, the boil-off management system, the engine injectors' water-cooling system and the N2 system had not been described yet.
- Multiple subsystems' components, such as the high-pressure pump skid, glycol water pumps and boil-off gas compressors had not been detailed and described so far.
- The HAZOP team proposed additional safety measures to improve the safety level of the system (e.g., the redesign of the system so that re-circulation of N2 to the fuel tanks due to purging is not allowed)
- The design requirements were not fully met as required by the WinGD's X52DF-A engine specifications.

Taking into consideration the HAZOP findings, and provided that the technical system designs are updated accordingly, NIKKISO CEIG will be required to carry out Failure Modes, Effects, and Criticality Analysis (FMECA) of their Ammonia FSS as part of the class approval process. Carrying out a FMECA requires the system to be at late stages of development and is usually facilitated by the system designers.

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

The simulations presented in this section are sample case studies and they are not modelling of the NIKKISO CEIG and WinGD AFSS but are modelled on a typical set-up. The gas dispersion modelling was conducted using Computational Fluid Dynamics (CFD) to predict the air quality and to identify the effects of ammonia released. 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. However, 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. The analysis highlights critical ammonia concentration levels: 25 ppm (Recommended Exposure Limits and permissible Exposure Limits), 160 ppm (Acute Exposure Guideline Level), 1,000 ppm (Emergency Response Planning Guideline), and 15,000 ppm (10% of the Lower Explosive Limits). Three scenarios were considered:

1) Ship-to-Ship Bunkering of Ammonia at a Port. The results were produced for a landward and seaward wind. In the landward scenario, the high concentration level of 1,000 ppm nearly reached the fuel tank on the port side. After the leakage was closed at 60 seconds, the plume was advected away from the tanker and diluted over time. The concentration level of 25 ppm eventually vanished throughout the entire domain after 400 seconds. As for the seaward scenario, although the leakage direction was landward, the plume direction was countered and reversed by the wind and eventually moved into the sea. After the leakage was closed at 60 seconds, the ammonia concentration level of 25 ppm was diluted quickly. Within about 300 seconds, the plume was diluted to a concentration lower than 25 ppm across the entire domain.

2) Ammonia Release from a Vent Mast. The releases from the vent mast did not pose a safety risk for the crew members working there. The ammonia concentration was diluted to lower than 25 ppm behind the vessel after 400 seconds from the release start time.

3) Ammonia Accidental Releases in the Engine Room. The consequence of the released ammonia was an advected flow upward by the ambient air flow where:

> 1) negligible ammonia reached the lowest two deck levels and
>
> 2) high ammonia concentrations could appear underneath the deck floors or at corners where ventilation was not effective.

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List of Abbreviations

ABV	Ammonia Bunkering Vessel
ACH	Air Changes per Hour
AEGL	Acute Exposure Guideline Level
AFSS	Ammonia Fuel Supply System
ABS	American Bureau of Shipping
BOG	Boil-Off Gas
CCC	Carriage of Cargoes and Containers
CCP	Critical Control Point
CFD	Computational Fluid Dynamics
CP	Compressor
CT	Catch Tank
DT	Dilution Tank
ERPG	Emergency Response Planning Guideline
E/R	Engine Room
ESD	Emergency Shutdown
FGSS	Fuel Gas Supply System
FPRM	Fuel Preparation Room
FTA	Fault Tree Analysis
FVU	Fuel Valve Unit
GP	Glycol Water Pump
GT	Expansion Tank
GW	Glycol Water
HAZOP	Hazard and Operability
HP	High Pressure
HT	Heater
IMO	International Maritime Organisation
JSA	Job Safety Analysis
LEL	Lower Explosive Limits
LNG	Liquefied Natural Gas

LoC	Loss of Containment
LP	Low Pressure
MARVS	Maximum Allowable Relief Valves
MCV	Manual Controlled Valve
M/E	Main Engine
MLD	Moulded
MT	Maintenance Tool
MV	Manual Valve
N2	Nitrogen
NTUA	National Technical University of Athens
P&ID	Piping and Instrumentation Diagram
PALL	Low-Low Pressure Alarm
PAHH	High-High Pressure Alarm
PCV	Pressure Control Valve
PEL	Permissible Exposure Limits
PHA	Preliminary Hazard Analysis
PPM	Parts Per Million
PSV	Pressure Safety Valve
REL	Recommended Exposure Limits
SIMOPS	Simultaneous Operations
ST	Filter/Strainer
TCS	Tank Connection Space
TK	Fuel Tank
TSV	Thermal Safety Valves
VFD	Variable Frequency Drive
VLCC	Very Large Crude Carrier
WinGD	Winterthur Gas & Diesel
XV	Vapour Valve

1. Hazard and Operability (HAZOP) Study

1.1 Introduction

Ammonia is among the most prevalent options of new fuels to be used in commercial shipping for meeting the 2050 targets[2]. However, the maritime sector has significant experience with ammonia only as cargo, and research is still ongoing for the safe use of ammonia as fuel. Although there is proven experience in handling ammonia in the maritime sector, knowledge is limited to ships carrying ammonia. Its potential wide use as a bunker fuel implies a shift from one-off operations with ammonia to extensive use, which significantly increases the risks considerably and may have a direct impact on the risk of ammonia loss of containment (LoC). Other industries, such as the Oil and Gas and Fertilizer industries, have an already proven track record of safe production and use of ammonia as chemical, and technologies and relevant methodologies have already reached a high maturity level, including the respective regulatory and normative framework applicable to these industries.

Considering the above, in Spring 2023, the European Maritime Safety Agency (EMSA) awarded a framework contract for the provision of a study investigating the safety of ammonia as fuels on ships (EMSA/OP/6/2023)[3] to a Consortium led by the American Bureau of Shipping (ABS) that also included the School of Naval Architecture and Marine Engineering (NA&ME) from the National Technical University of Athens (NTUA), and Fundación Valenciaport (FV). The NTUA research team, is responsible for carrying out the risk assessment procedures and is led by Prof. Nikolaos P. Ventikos.

As part of the above study, NTUA was commissioned to carry out a Hazard and Operability (HAZOP) study for the function and operation of using ammonia as an alternative fuel of a generic VLCC ship design.

This report concerns Part 3 and constitutes the second report under Specific Contract 2 (SC2).

[2] https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx
[3] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=13603

1.2 System Description

1.2.1 Vessel General Information

The general arrangement of the generic VLCC is presented in Figure 1.

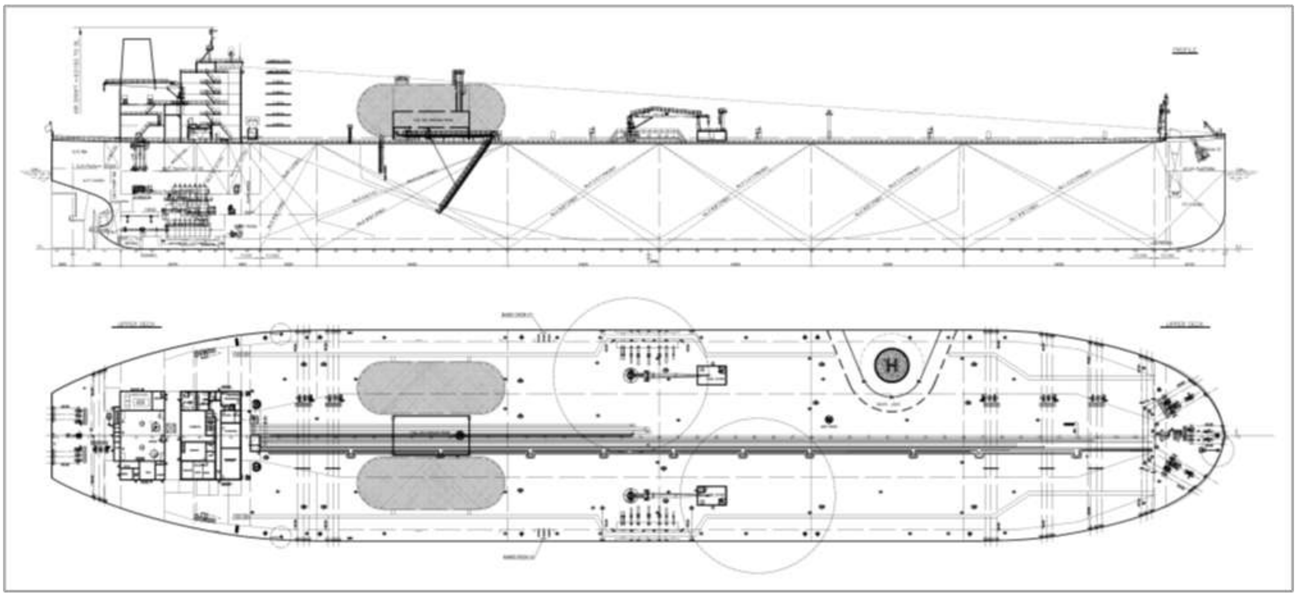


Figure 1: General arrangement of generic VLCC

The principal dimensions of the VLCC are listed in Table 1.

Table 1: Principal dimensions of generic VLCC

Particular	Description
Length (Overall)	333 m
Length (Between Perpendiculars)	327 m
Breadth (MLD)	60 m
Depth (MLD)	30 m
Draught (Design)	20.5 m
Draught (Scantling)	22 m

1.3 Ammonia-related Systems

The AFSS is designed to deliver ammonia at the required pressure and temperature and to flow to the ammonia dual-fuel main engine via the Fuel Valve Unit (FVU). It consists of:

- two (2) bunkering stations (Port & Stbd),
- two (2) fuel tanks (Port & Stbd) including two Low-Pressure deep well pumps in each tank,
- one (1) FSS conditioning skid including pumps,
- heaters and auxiliary systems such as the
  - glycol/water (GW) system,
  - Boil-off Gas (BOG) handling system
  - two (2) Vent systems with the respective masts
  - Nitrogen system,
  - Gas detection and ESD system, and
  - Safety system

The overall process flow schematic of the AFSS is presented in Figure 2.

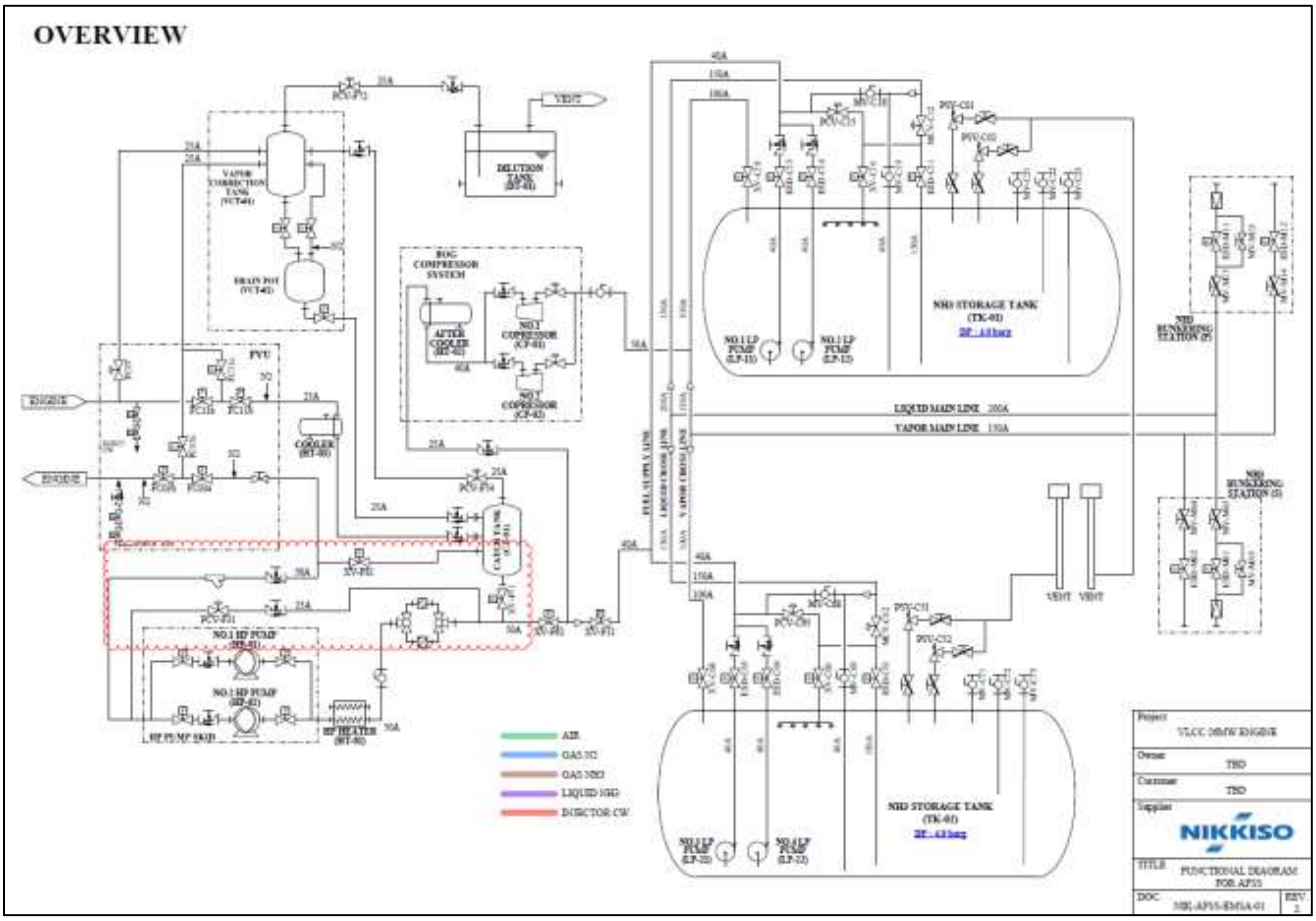


Figure 2: Overall Process Flow Schematic

1.3.1 Bunkering Stations (Port & Stbd)

Ammonia is stored in two IMO Type C fuel tanks (TK-01/02), each with a capacity of 3,200 m³ and operating at a pressure of 4.0 barg. Each tank has two (2) pressure safety valves, PSV-C01 & PSV-C02 in TK-01 and PSV-C51 & C52 in TK-02, as per page 07 of Document NIK-AFSS-EMSA-02 rev 02. These tanks are filled through the common liquid cross line and the corresponding fuel tank liquid filling valves MCV-C12 and ESD-C11 for TK-01 and MCV-C62 and ESD-C61 for TK-02 via bunkering through the manifolds located at the Port and Starboard (Port & Stbd) bunkering stations, as per page 08 and 10 of Document NIK-AFSS-EMSA-02 rev 02. Ammonia vapours are returned through the common vapour cross line, while the reverse process is utilised during de-bunkering by using low-pressure pumps LP-11, LP-12, LP-21, LP-22[4].

1.3.2 Ammonia Fuel Supply System (AFSS)

Ammonia stored in the tanks is pressurised to 20barg using low-pressure pumps (LP-11, LP-12, LP-21, and LP-22) and transferred to the high-pressure pumps, through the high-pressure heater (HT-01), where is heated to about 40ºC. The high-pressure pumps (HP-01 and HP-02) pressurise it again to 85barg,as per page 12 of Document NIK-AFSS-EMSA-02 rev 02. The ammonia flow rate is controlled by the high-pressure pump's variable frequency drive (VFD), and the recirculation valve (PCV-F31) is provided to ensure minimum flow conditions.

The ammonia returning from the engine combines with the ammonia from the tank in the Catch Tank (CT-01) before being resupplied to the high-pressure pump through valve XV-F71. At this time, the gas contained is mixed and condensed with a large amount of liquid ammonia supplied from the tank. If any gaseous ammonia remains, it is released to the Vapour Correction Tank (VCT-01).

[4] For every component name please refer to the P&IDs attached in Appendix A

1.3.3 Glycol Water (GW) System

Glycol water is made by mixing ethylene glycol and distilled water in a 1:1 ratio and is used as an intermediate heat medium. The purpose of using an intermediate heat medium is to prevent ammonia from entering the engine room if there is a leak from the heat exchanger. Glycol water is used to heat ammonia in the HP heater and to cool the heated BOG downstream of the BOG compressor.

The glycol water pressurised by the pumps (GP-01 and GP-02) is transferred to the GW/Steam heater (HT-12), or optionally to the GW/Jacket Water Heater (HT-11), as per page 14 of Document NIK-AFSS-EMSA-02 rev 02. The glycol water heated in this heat exchanger is transferred to the HP Heater (HT-01) and afterwards to a cooler (HT-02). The glycol water passed through each heat exchanger returns to the expansion tank (TK-11) and is transferred to the pump again.

When the engine's hot cooling water (jacket water) is used to heat glycol water, approximately half of the energy required to heat the glycol can be recovered from the waste energy in the hot cooling system. The 3-way valve, TCV-E03, installed in the hot temperature cooling water line controls the glycol water temperature. Gas detectors are installed in the glycol water expansion tank to check for leakage in the ammonia heat exchanger.

1.3.4 Boil of Gas (BOG) Handling System

Boil-off gas (BOG) is naturally generated in tanks. As per page 13 of Document NIK-AFSS-EMSA-02 rev 02, a BOG compressor (CP-01 and CP-02) exploits this. The gaseous ammonia from the BOG compressor meets a large amount of liquid ammonia supplied from the tank and becomes condensed, allowing it to be used in its liquid state. By design, all gaseous ammonia generated during ship operation is recirculated and used as fuel.

1.3.5 Vent Masts

Separate vent masts for each storage tank (TK-01 and TK-02) will be installed in accordance with page 13 of Document NIK-AFSS-EMSA-02 rev 02, to manage the corresponding relief and depressurisation lines. Adequate functionality for liquid relief and emergency depressurisation will be integrated at the base of the vent masts, along with associated level instrumentation.

1.3.6 Nitrogen System

The nitrogen system will be provided to generate LP & HP nitrogen and will comprise of the following equipment, as per page 16 of Document NIK-AFSS-EMSA-02 rev 02:

- One (1) feed air compressor with a nitrogen generator at 7 barg.
- One (1) nitrogen booster compressor at 120 barg.
- Twenty (20) high pressure bottles and pressure reduction system for high- and low-pressure nitrogen use.

The LP nitrogen will be used to:

- Provide nitrogen to the valve control at 4.5 barg.
- Carry out maintenance purging activities in line with standard practices at 30 barg and 5 barg.

The high-pressure nitrogen, maintained at 85 barg, will be used for testing the high-pressure pipes.

1.3.7 Gas Detection & ESD System

Safety functions for the AFSS will be incorporated through several detection points and cabinets along the vessel, such as the Fuel Preparation Room (FPRM), Tank Connection Space (TCS), E/R and Bridge. The Gas Detection System will receive control signals originating from the Gas Sampling Detection System and transmit them to the Ammonia Monitoring System (AMS) and the ESDS Cabinet. The breach of the Critical Control Point (CCP) will initiate process shutdowns. Additionally, an emergency shutdown (ESD) system will be provided to protect equipment of the AFSS. The ESD system will interface with the ship and cargo handling control systems.

1.3.8 Safety System

The safety systems for the AFSS will be provided according to the IGC Code as follows (ref. /2/):

- Gas detection and alarm system will be provided in the cargo compressor room.
- Fire detection and extinguishing system will be provided in the cargo compressor room. All pipelines or components that may become isolated in a liquid full condition will be protected with Thermal Safety Valves (TSVs).

Pressure Safety Valves (PSVs) will be provided for liquid pipelines that can be automatically isolated due to a fire.

1.4 Scope of Work

1.4.1 Boundary Limits

The HAZOP study mainly focuses on potential hazards and operability problems associated with the typical operation phases of the AFSS to be installed in the generic Very Large Crude Carrier (VLCC). It was assumed that hazards and operability problems related to the manufacturing, installation, construction, commissioning, or decommissioning phases of the AFSS would be covered and controlled by the shipyard's safety management system, vendors' procedures, etc.

The systems that were analysed include the bunkering stations, the low-pressure system from the bunkering tanks up to (but excluding) the high-pressure (HP) system, the transfer of ammonia to the main engine via the HP system, the ammonia return from the M/E, the boil-off gas handling system, the glycol water system, and the N2 supply system. The analysis was carried out to the extent that was deemed possible by the available technical information. For example, the P&IDs for the AFSS were more elaborate that those pertaining to the GW system. This is also reflected to the Action Items List and the HAZOP Worksheet Report.

It should be noted that the HAZOP study does not cover hazards and operability problems associated with typical hull and marine systems such as ballast water systems, diesel oil systems, etc., which are not related to the AFSS as it was assumed that those kinds of hazards would be controlled and managed by operators, based on relevant requirements such as Flag State regulations, International Maritime Organisation (IMO) requirements and classification society's rules.

Risk assessment should evaluate, *per* ship, the suitability of the safety concepts outlined in the current regulations and guidelines within the IGF Code, particularly considering ammonia fuel toxicity and corrosivity as per IMO's interim guidelines for the safety of ships using ammonia as fuel (MSC.1/Circ.1687). Results may recommend modifications to existing safety barriers designed for LNG installations onboard ships and the introduction of new safety barriers to safeguard against ammonia exposure during normal operations and in emergencies. Key safety measures include:

- Segregation measures to protect ammonia fuel installations from potential external hazards.
- Engine room must be regarded as a gas-safe zone.
- System integrity assurance to minimise leaks from ammonia fuel systems.
- Optimised engine and machinery positioning to ensure the shortest piping length to the ammonia inlet manifold.
- BOG management with unlimited holding time.
- Implementation of double barriers to protect the ship and crew from potential leaks.
- Advanced leak detection systems provide early warnings and enable rapid automatic safety responses.
- Automatic leak isolation to minimise potential releases' toxic and hazardous consequences.
- Ship layout design that ensures clear and accessible escape routes from all compartments.
- Provide a safe haven, possibly combined with a mustering function, to ensure the safety of the crew and passengers in the event of an ammonia release.
- Ship layout design that ensures gas freeing and gassing of ammonia storage tanks without interaction with adjacent decks and compartments.
- The location of lifesaving equipment, escape routes, and lifeboats should be selected with consideration to keep them away from potential ammonia gas releases.
- The implementation of specific material requirements in the IGC Code for ammonia storage tanks and associated systems because of ammonia's corrosive nature.

Furthermore, shipowners must incorporate detailed management and operational procedures tailored to the unique risks and hazards associated with ammonia and related potential shipboard emergencies.

1.4.2 Documents and Drawings

The basis for the HAZOP study is the documents and drawings provided by NIKKISO CEIG[5] and amended according to the engine specifications of the X52DF-A-1.0 engine provided by WinGD[6]. Those are presented in Table 2.

Table 2: Reviewed Documents & Drawings

Title	Document/Drawing No.	Rev. No.	Date
Approval in Principle (AIP) for “Ammonia Fuel Supply System”	WO0064992_HJK	-	-
Ammonia Fuel Supply System: Heat and Balance	NIK-AFSS-EMSA-00	R	29th Oct. 2024
Ammonia Fuel Supply System: Functional Diagram	NIK-AFSS-EMSA-01	0	4th Nov. 2024
Ammonia Fuel Supply System: Piping and Instrumentation Diagram	NIK-AFSS-EMSA-02	0	4th Nov. 2024
NH3 Fuel Supply System: Design Philosophy	NIK-NH3-EMSA-03	R	28th Oct. 2024
Ammonia Fuel Supply System: Cause and Effect Chart	NIK-AFSS-EMSA-04	R	28th Oct. 2024
Ammonia Fuel Supply System: NH3 tank PSV calculation	NIK-AFSS-EMSA-06	R	29th Oct. 2024
Ammonia Fuel System	PTAA059554	-	1st Oct. 2024
Marine Installation Manual: X52DF-A-1.0		03	April 2024

[5] https://www.nikkisoceig.com/
[6] https://www.wingd.com/en/engines/engine-types/x-df-dual-fuel-ammonia/ammonia-documentation/

1.5 HAZOP Workshop

1.5.1 Objective

The HAZOP study is a structured and systematic examination to identify process hazards and operability problems in processes or systems so that they can be assessed, eliminated at source (if possible), controlled and mitigated otherwise. The objectives of the HAZOP study for the AFSS of the generic VLCC are to:

- Identify possible deviations from the intended process operating parameters
- Identify possible causes and consequences of the deviations
- Identify safeguards for reducing or eliminating process hazards and operability problems
- Assess semi-quantitatively by using a risk matrix (i.e., risk ranking)
- Recommend additional measures to eliminate/reduce the risks

The HAZOP study was not intended to resolve all issues arising during the research but to flag action to appropriate personnel or parties for detailed follow-up after the HAZOP.

1.5.2 Procedure

The HAZOP study for the ammonia FSS of the generic VLCC was carried out as a brainstorming exercise in the HAZOP workshop (virtually) attended by a multidisciplinary team (i.e., the HAZOP team) from the project stakeholders. The detailed procedure applied in the HAZOP workshop follows the steps outlined below:

1. Identify systems and nodes to be studied
2. Define the design intent of the node and the standard operating parameters
3. Apply a HAZOP deviation to the node
4. Identify all possible causes for the deviation
5. Identify all possible consequences for each cause without regard for the safeguards in place
6. Identify all available safeguards to prevent the causes or to limit the consequences
7. Carry out risk ranking using a risk matrix
8. Recommend new safeguards (if necessary)
9. Repeat steps 4 to 8 using the subsequent HAZOP deviation
10. Repeat steps 3 to 9 until all HAZOP deviations have been applied to the node
11. Select the next node to be studied
12. Repeat steps 2 to 11 until all nodes are studied

1.5.3 Nodes

A structured approach is applied to ensure that all relevant process hazards and operability issues are revealed. The basis for this approach lies in dividing the AFSS into nodes that would be manageable enough to do a systematic review of each node. Then, the systematic review of each node is performed to identify the relevant process hazards and operability issues to which these nodes could be subjected.

In total, eight (8) HAZOP nodes were selected and reviewed during the workshop. The nodes are listed in Table 3 with the following details:

- the column ‘No.’ and ‘Node’ are for the serial number and title of the nodes;
- the column ‘Design Intent’ summarises the design intent of the nodes;
- the column ‘Drawing Title’, ‘Drawing Number’ and ‘Rev.’ list the drawing title, drawing number, and revision number of the P&IDs associated with each node (the drawings used during the HAZOP workshop are the most up-to-date revisions available at the time of the HAZOP workshop); and
- the node ‘General’ refers to hazards/deviations that were not pertinent to a specific sub-system and thus they were grouped under this node.

The HAZOP nodes listed are marked with distinct colours on the related P&IDs (Appendix A) and the marked-up P&IDs were projected during the HAZOP workshop.

Table 3: HAZOP Nodes

No.	Node	Design Intent	Drawing Title	Drawing Number	Rev.
1	General	Hazards/Deviations not pertinent to a specific node	-	-	-
2	Fuel tank filling	Ammonia is bunkered in two (2) IMO Type-C storage tanks (TK-01, TK-02). The tanks are routinely filled through the liquid main line and the fuel tank liquid filling valves (MCV-C12, MCV-C62), from shore/bunkering ship via the bunkering manifolds. During bunkering operations the vapours are being discharged through the vapour main line and the respective vapour valves (XV-C18, XV-C68). This node examines hazards and operability issues relevant to the fuel tank filling, excluding the examination of NH3 bunkering during SIMOPS. This will be covered in a separate SIMOPS W/S. As the two storage tanks and the two bunkering stations are identical, only TK-01 and the PORT bunkering station are examined.	Ammonia Fuel Supply System: Piping and Instrumentation Diagram	NIK-AFSS-EMSA-02	0
3	Ammonia transfer system for ammonia FSS	The FSS LP pumps (LP-11, LP-12, LP-21, LP-22), located within the fuel tanks, will pump ammonia at a pressure of approx. 20 barg from the fuel tanks towards the ammonia FSS conditioning skid. PCV-C15 and PCV-C65 will ensure minimum flow protection of the ammonia FSS LP pumps by recirculating flow back to the fuel tanks, if necessary. Prior to the ammonia reaching the ammonia FSS conditioning skid, it is filtered via a low-pressure dual filter (ST-F01, ST-F02), in order to protect the downstream skid equipment.	Ammonia Fuel Supply System: Piping and Instrumentation Diagram	NIK-AFSS-EMSA-02	0
4	Ammonia FSS – Ammonia Supply to M/E	After the ammonia catch tank (CT-01), ammonia passes through HP heater HT-01 which utilises a closed loop glycol water circuit to heat ammonia to a temperature of 42°C. The ammonia flow rate to the HP pumps is controlled by their variable frequency drive and the recirculation valve (PCV-F31) that ensures minimum flow conditions.	Ammonia Fuel Supply System: Piping and Instrumentation Diagram	NIK-AFSS-EMSA-02	0

No.	Node	Design Intent	Drawing Title	Drawing Number	Rev.
		The ammonia enters the AFSS HP pumps (HP-01, HP-02), which increase pressure to the FVU delivery pressure (approx. 85barg).			
5	Ammonia FSS – Ammonia Return from M/E	The return stream is cooled in the freshwater cooler (HT-03), then meets the fresh ammonia contained in the catch tank (CT-01) and is re-supplied to the high-pressure pump.	Ammonia Fuel Supply System: Piping and Instrumentation Diagram	NIK-AFSS-EMSA-02	0
6	BOG Handling System[7]	During the return of ammonia from the M/E, within the catch tank (CT-01), the contained ammonia in gaseous phase is mixed with a large amount of liquid phase ammonia and becomes condensed. If there is any ammonia remaining in gaseous phase, it is released to the vapour connection tank (VCT-01). To utilise the BOG naturally generated in the fuel tanks, BOG compressors CP-01 and CP-02 are used. The gaseous ammonia from the BOG compressor meets a large amount of liquid ammonia (right before the dual filter ST-F01 & ST-F0) supplied from the fuel tanks and becomes condensed. Any residual ammonia vapour from the Vapour Correction Tank (VCT-01) is dissolved in water in the dilution tank (DT-01) and discharged into the sea, following appropriate procedures.	Ammonia Fuel Supply System: Piping and Instrumentation Diagram	NIK-AFSS-EMSA-02	0
7	GW System	Glycol water is used to heat the ammonia in the HP heater (HT-01) and to cool the heated BOG at the downstream of the BOG compressors (after cooler HT-02). The glycol water pressurised by the pumps (GP-01, GP-02) is transferred to the Jacket water heated GW heater (HT-11). The glycol water heated in this heat exchanger is transferred to the HP Heater (HT-01) and after cooler (HT-02). The glycol water that has passed through each heat exchanger returns to the expansion tank (TK-11) and is transferred to the pump again. A steam heater is used to heat the glycol water, as a primary method.	Ammonia Fuel Supply System: Piping and Instrumentation Diagram	NIK-AFSS-EMSA-02	0

[7] Since there was no technical information available for the BOG system, no relevant hazards were identified

No.	Node	Design Intent	Drawing Title	Drawing Number	Rev.
		Gas detectors are installed in the glycol water expansion tank to check the leakage in the ammonia heat exchanger.			
8	N2 Supply System	The N2 supply system is provided to supply low-pressure nitrogen to the ammonia FSS for maintenance purging of the ammonia FSS.	Ammonia Fuel Supply System: Piping and Instrumentation Diagram	NIK-AFSS-EMSA-02	0

1.5.4 Deviations

After the identification of HAZOP nodes, predetermined HAZOP deviations were applied to each node. A HAZOP deviation is the combination of parameter and compatible guide word applicable to each node. Typical parameters such as flow, pressure, temperature level, etc. were applied. Representative guide words that can be associated to these parameters to characterise deviations were subsequently applied such as no, less, more, etc. The deviations applied to the ammonia FSS of the generic VLCC and typical causes for each deviation are listed in Table 4.

Table 4: HAZOP Deviations

No.	Deviation	Possible Causes
1	No Flow	Wrong routing, blockage, burst pipe, large leakage, equipment failure (check valve, isolation valve, pump, etc.), incorrect pressure differential, etc.
	Less Flow	Line restrictions, filter blockage, defective pumps, fouling of equipment (vessels, valves, orifice plates, etc.), density or viscosity problems, etc.
2	More Flow	Increased pumping capacity, increased suction pressure, reduced delivery head, greater fluid density, exchanger tube leaks, control failure, etc.
3	Misdirected Flow	Wrong routing, equipment failure, etc.
4	Reverse Flow	Defective check valve, incorrect differential pressure, incorrect operation, etc.
5	More Pressure	Surge problems, leakage from interconnected high-pressure systems, gas breakthroughs (inadequate venting), thermal overpressure, failed open PCVs, etc.
6	Less Pressure	Generation of vacuum condition, condensation, gas dissolving in liquid, restricted pump/compressor suction line, leakage, vessel drainage, etc.
7	More Temperature	Fouled or failed exchanged tubes, fire situation, loss of cooling, control failure, etc.
8	Less Temperature	Pressure decrease, fouled or failed exchanged tubes, loss of heating, etc.
9	More Level	Isolated or blocked outlet, inflow greater than outflow, control failure, faulty level measurement, filling operations, liquid in vapour lines, deactivated level alarm, etc.
10	Less Level	Inlet flow stops, leakage, drain valve left open, outflow greater than inflow, control failure, faulty level measurement, etc.
11	More Viscosity	Incorrect material or composition, incorrect temperature, high solids concentration, etc.
12	Less Viscosity	Incorrect material or composition, incorrect temperature, solvent flushing, etc.
13	Composition Change	Leakage through isolation valves, leakage from exchanger tubes, phase change, incorrect feedstock/specification, inadequate quality control, etc.
14	Contamination	Leakage from exchanger tubes or isolation valves, incorrect operations of system, inter-connected systems, effect of corrosion, wrong additives, ingress of air, etc.
15	Relief	Relief philosophy, relief valve discharge location, etc.
16	Instrumentation	Location of instruments, panel arrangement and location, fail safe philosophy, etc.
17	Sampling	Sampling procedure, calibration or automatic sampler, etc.
18	Corrosion/Erosion	Corrosion protection, engineering specifications, fluid velocity, splash zones, etc.
19	Maintenance	Isolation philosophy, drainage, purging, cleaning, access, pressure testing, etc.
20	Ignition Suppression	Grounding arrangements, electrical classification, flame arresters, hot work, hot surfaces, auto-ignition, pyrophoric materials, etc.
21	Reaction Issue	Wrong reactant mix, low temperature, insufficient catalyst, etc.
22	Service Failure	Failure of instrument (air, steam, nitrogen, cooling water, hydraulic power, electric power, telecommunications, etc.), heating and ventilation systems, etc.

No.	Deviation	Possible Causes
23	Abnormal Operation	Purging, flushing, start-up, normal shutdown, emergency shutdown, etc.
24	Spare Equipment	Installed/non-installed spare equipment, availability of spares, etc.
25	Safety	Toxic properties of process materials, noise levels, security arrangements, etc.
26	Others	Others

1.5.5 Causes

A cause refers to the circumstances or mechanisms that can lead to deviations. It is possible to identify multiple causes for a single deviation. During the HAZOP workshop, potential independent causes for each deviation were identified. The approach for the HAZOP study of the Ammonia SS in the generic VLCC, involved considering causes that arise within the examined node while also acknowledging that consequences may reach or become evident in other nodes and the node being analysed. Causes may be linked to human factors or hardware issues, and some can arise from a combination of events occurring either simultaneously or sequentially. This situation is known as double jeopardy. However, no instances of double jeopardy were considered during the HAZOP workshop.

1.5.6 Consequences

A consequence refers to the outcome of a cause, considering factors such as safety, asset loss, environmental impact, and reputation. It can involve both process hazards and operability issues. Notably, a single cause can lead to multiple consequences, while one consequence may arise from several causes. All credible consequences for each identified cause were thoroughly analysed to determine if they pushed the system beyond its intended operational range and evaluated without factoring in the effectiveness of safeguards. The implications within the node and any potential upstream or downstream effects stemming from the cause were examined during the HAZOP workshop. To that extend, the workshop comprehensively identified all outcomes, considering both immediate and delayed effects, as well as those occurring within and outside the section under study. Additionally, participants examined how these consequences evolve over time, paying particular attention to when alarms and trips are activated, as well as how and when operators will be notified.

1.5.7 Safeguards

A safeguard is defined as any design feature at a specific system level or other provisions that can prevent deviations (or reduce their frequency) or mitigate the severity or likelihood of their consequences. The safeguards for each consequence were reviewed and discussed during the HAZOP workshop for the ammonia FSS of the generic VLCC design, including the following elements:

- redundant items that ensure the continued operation of the system,
- alternative means of operation,
- monitoring and alarm devices or shutdown logic, and
- any other measures aimed at limiting consequences.

1.5.8 Risk Ranking

Risk ranking was performed for each identified scenario, using the risk matrix presented in Table 5 and it was a collective effort of the HAZOP team.

Table 5: HAZOP Risk Matrix

Category		**Consequence Severity**				
Asset		No shutdown, costs less than $10,000 to repair	No shutdown, costs less than $100,000 to repair	Operations shutdown, loss of day rate for 1-7 days and/or repair costs of up to $1,000,000	Operations shutdown, loss of day rate for 7-28 days and/or repair costs of up to $10,000,000	Operations shutdown, loss of day rate for more than 28 days and/or repair more than $10,000,000
Environmental Effects		No lasting effect. Low level impacts on biological or physical environment. Limited damage to minimal area of low significance.	Minor effects on biological or physical environment. Minor short-term damage to small area of limited significance.	Moderate effects on biological or physical environment but not affecting ecosystem function. Moderate short-medium term widespread impacts e.g. oil spill causing impacts on shoreline.	Serious environmental effects with some impairment of ecosystem function e.g. displacement of species. Relatively widespread medium-long term impacts.	Very serious effects with impairment of ecosystem function. Long term widespread effects on significant environment e.g. unique habitat, national park.
Community/ Government/ Media/ Reputation		Public concern restricted to local complaints. Ongoing scrutiny/ attention from regulator.	Minor, adverse local public or media attention and complaints. Significant hardship from regulator. Reputation is adversely affected with a small number of site focused people.	Attention from media and/or heightened concern by local community. Criticism by NGO's. Significant difficulties in gaining approvals. Environmental credentials moderately affected.	Significant adverse national media/public/ NGO attention. May lose license to operate or not gain approval. Environment/ management credentials are significantly tarnished.	Serious public or media outcry (international coverage). Damaging NGO campaign. License to operate threatened. Reputation severely tarnished. Share price may be affected.
Injury and Disease		Low level short-term subjective inconvenience or symptoms. No measurable physical effects. No medical treatment required.	Objective but reversible disability/impairment and/or medical treatment, injuries requiring hospitalisation.	Moderate irreversible disability or impairment (<30%) to one or more persons.	Single fatality and/or severe irreversible disability or impairment (>30%) to one or more persons.	Short- or long-term health effects leading to multiple fatalities, or significant irreversible health effects to >50 persons.
		Low	**Minor**	**Moderate**	**Major**	**Critical**
		3	**4**	**5**	**6**	**7**
Likelihood	Almost Certain **(0)** Occurs 1 or more times a ship year	**High**	**High**	**Extreme**	**Extreme**	**Extreme**
	Likely **(-1)** Occurs once every 1-10 ship years	**Moderate**	**High**	**High**	**Extreme**	**Extreme**
	Possible **(-2)** Occurs once every 10-100 ship years	**Low**	**Moderate**	**High**	**High**	**Extreme**
	Unlikely **(-3)** Occurs once every 100-1000 ship years	**Low**	**Low**	**Moderate**	**High**	**Extreme**
	Rare **(-4)** Occurs once every 1000-10000 ship years	**Low**	**Low**	**Low**	**Moderate**	**High**
Action Key	Low	No action is required, unless change in circumstances				
	Moderate	No additional controls are required, monitoring is required to ensure no changes in circumstances				
	High	Risk is high and additional control is required to manage risk				
	Extreme	Intolerable risk, mitigation is required				

1.6 HAZOP Result

1.6.1 HAZOP Worksheet

All the results of the HAZOP study were documented in the HAZOP worksheet using the Process Hazard Analysis (PHA) Software LEADER[8]. The HAZOP worksheet produced is included in Appendix B of this report. All the contents documented in the HAZOP worksheet were agreed with the HAZOP team.

1.6.2 Recommendations

In case that the provision of existing safeguards was identified to be insufficient to manage hazard or operability issue within acceptable level or that further assessments were required to obtain a better understanding of the hazard or operability issue, recommendations were raised. One hundred and forty-eight (148) recommendations were identified during the HAZOP workshop, as listed in Appendix C.

The most prominent hazards and operability issues identified per node, are summarised below. A detailed outline of the recommendations is provided in the Action Items List (Table 10), in Appendix C.

1. **General**
   - The control logic procedure must be provided for the engagement of the redundancy pumps. The secondary pumps should start immediately in case of a failure of the first pump.
   - A comprehensive study of all valves must be conducted to determine where a position indicator should be installed.
   - Mechanical spray shielding must be installed around ammonia bunkering flanges if they are not hot-welded, specifically in the case of bolted connections.
   - Procedures must be established for maintaining the filters and strainers.
   - Research must be conducted on the selected filter types, considering the possibility of filter rupture.
   - Consider implementing an automatic switch between filters.
   - A margin allowance for the resistance of heaters and coolers due to particle deposition must be considered.
   - The maintenance procedures for all system components must be detailed.
   - The AFSS system must be designed to prevent or minimise potential pressure surges and the effects of hammering.
   - Conduct a study to determine if each transmitter should be used solely for safety or if it should also include a trip function to shut down the system.
   - Pressure pumps are to be equipped with dry running protection.
   - Physical locking devices and warning signs must be installed to secure drain and heat exchanger venting valves in the closed position, preventing accidental opening due to operator error.
   - A list of critical spare parts for the AFSS should be provided or suggested.
   - Consider installing absorbing or elongation relief devices to reduce stress in the system.
   - The lowest possible temperature that the piping system can withstand must be determined.
   - Any redundancy heater that is not operating must be bypassed.

2. **Fuel Tank Filling.**
   - Consider the installation of an enclosed Tank Connection Space.
   - The storage tank must be insulated, and measures should control BOG.
   - The temperature of liquefied ammonia in the fuel tanks must be maintained at a maximum temperature of -30°C, achieved through either the reliquefication of vapours, thermal oxidation of vapours, or by cooling the liquefied ammonia fuel (IGF Code, Sec. 6.9.1.1).
   - The tank's maximum allowable filling level must be 95% according to the interim guidelines for ammonia as a fuel, in paragraph 6.8.2.
   - Appropriate bunkering procedures must be developed.
   - Liquid detection at the bunkering station due to low temperatures could trigger an Emergency Shutdown (ESD) if the high-level alarm installed in the drip tray is activated. It is essential to calibrate the sensor in the drip tray to work accurately in extremely low ambient temperatures.

[8] https://www.abs-group.com/Solutions/Software-Solutions/LEADER-PHA-Software/

- The drip tray discharge should be directed to a tank rather than being discharged overboard.
- The filters in the process line must be designed to protect both the system up to the tank and the components downstream from contaminants caused by particles from the pipes due to corrosion or erosion.
- Given that the fuel tank will be uninsulated and the Reliquification Plant system is disconnected in the current design, temperature monitoring and Emergency Shutdown (ESD) is to be provided upstream of the tank. This shall be such that the tank is: 1. insulated, 2. have means to control BOG, 3. temperature inside the tank shall be always monitored.

3. Ammonia Transfer System for AFSS

- Conduct a study on all return discharges from Pressure Safety Valves (PSVs) to the storage tanks to investigate the potential for a high-pressure scenario affecting the tanks.
- To prevent clogging, it is essential to properly maintain the suction filters of low-pressure deep-well pumps.
- A comprehensive monitoring of the deep well pump operation is advised. Control signals such as temperature monitoring, high current alarms for the pumps, and failures of the Pressure Control Valve (PCV) should be included in the control logic.
- Assessment of installing a High Temperature Alarm (TAL) in the Thermal Safety Valve (TSV) return line.

4. Ammonia FSS - Ammonia Supply to M/E

- Automatically operated shutoff valves are to be situated at the bulkhead inside the fuel preparation room.
- A study is necessary to ensure compliance with the engine's tolerance specifications for pressure fluctuations caused by high-pressure pumps.
- A study must be conducted on installing accumulator buffers to withstand high pressure alongside low fuel volume.
- Addition of High-High Pressure L Alarm (PAHH) and Emergency Shutdown (ESD), downstream of the HP pump skid.

5. Ammonia FSS – Ammonia Return from M/E

- The positioning the catch tank and its support type to limit sloshing effects must be considered.
- The catch tank dimensions must accommodate the BOG return, engine fuel return, and fuel supply.
- Develop a control logic sequence to ensure adequate ammonia levels in the catch tank.
- A study must be conducted on the volume and proper dimensioning abilities of the Vapour Collection Tank (VCT).
- The Vapour Collection Tank must be properly sized to meet toxicity limits at the vent outlet.
- A study needs to be conducted on the engine manufacturer's requirements to maintain the appropriate pressure of the catch tank (CT) when receiving ammonia from the engine.

6. BOG Handling System

Additional research is required on the purging connection of the BOG to ensure compliance with the IGF code.

7. GW System

- A study must be conducted on venting the glycol water expansion tank, considering the option of venting through a tank instead of directly to the open deck.
- A pressure regulating or a pressure relief valve must be installed downstream of the glycol water pumps.
- A High-Pressure Level (L) Alarm (PAH) transmitter (warning) and a High-High Pressure Level (L) Alarm (PAHH) transmitter (safety and control) must be installed downstream of the glycol water pumps and upstream of the HP heater to initiate AFSS shutdown.
- A Low-Pressure Level (L) Alarm (PAL) transmitter (warning) and a Low-Low Pressure Level (L) Alarm (PALL) transmitter (safety and control) must be installed downstream of the HP heater to initiate AFSS shutdown.

8. N2 Supply System

- Install secondary pressure regulating units for the appropriate pressures comprised of a manual valve, a pressure regulating valve and a non-return check valve for redundancy.
- Further study to be done on the filtering capacity of the nitrogen system.

- Gas dispersion analysis to be conducted to evaluate efficiency of the gas detection system and the location for gas detectors inside the space.
- A drying system must be included in the nitrogen generator system.

1.7 Conclusions

The Ammonia Fuel Supply System (FSS), designed by NIKKISO CEIG in accordance with WinGD's engine specifications, was reviewed by a multi-disciplinary HAZOP team during a workshop. This review adhered to the scope of work and methodology detailed in this report.

In total, one hundred and thirty-six (136) scenarios were identified at the HAZOP workshop. Thirty-eight (38) scenarios were purposefully not ranked, fifteen (15) scenarios were categorised as low-risk and thirty-six (36) were categorised as moderate-risk. Forty-seven (47) scenarios were categorised as high-risk, while no scenarios were categorised as extreme risk (shown in Table 6).

Table 6: Risk Ranking (Current Risk)

		Low	**Minor**	**Moderate**	**Major**	**Critical**
		3	**4**	**5**	**6**	**7**
Likelihood	Almost Certain **(0):** Occurs 1 or more times a ship year	**0**	**0**	**0**	**0**	**0**
	Likely **(-1):** Occurs once every 1-10 ship years	**20**	**19**	**13**	**0**	**0**
	Possible **(-2):** Occurs once every 10-100 ship years	**2**	**16**	**10**	**4**	**0**
	Unlikely **(-3):** Occurs once every 100-1000 ship years	**2**	**11**	**0**	**1**	**0**
	Rare **(-4):** Occurs once every 1000-10000 ship years	**0**	**0**	**0**	**0**	**0**

In case that additional safeguard(s)/measure(s) implemented to the design, as per discussions and conclusions for the recommendations, is/are considered to reduce frequency/severity of the accident scenario, the risk ranking for the relevant accident scenario was re-evaluated. As a result, forty-one (41) scenarios were categorised as low-risk and twenty (20) were categorised as moderate-risk. Thirty-seven (37) scenarios were categorised as high-risk, while no scenarios were categorised as extreme risk (shown in Table 7).

Table 7: Re-evaluated Risk Ranking (Residual Risk)

		Low 3	Minor 4	Moderate 5	Major 6	Critical 7
Likelihood	Almost Certain **(0):** Occurs 1 or more times a year	**0**	**0**	**0**	**0**	**0**
	Likely **(-1):** Occurs once every 1-10 years	**6**	**14**	**11**	**0**	**0**
	Possible **(-2):** Occurs once every 10-100 years	**12**	**11**	**7**	**2**	**0**
	Unlikely **(-3):** Occurs once every 100-1000 years	**3**	**12**	**3**	**3**	**0**
	Rare **(-4):** Occurs once every 1000-10000 years	**1**	**12**	**1**	**0**	**0**

One hundred and forty-eight (148) recommendations were made from the HAZOP workshop, and the full results of the HAZOP workshop were documented in the HAZOP Worksheet (see Appendix B).

Thirty-eight (38) scenarios were purposefully not ranked. Thirty-three (33) out of those unranked scenarios were general remarks/considerations that were either not node-specific (thus grouped under the 'General' node) or there was not enough technical information to carry out the risk ranking.

For the remaining five (5) (out of 38) scenarios, the identified deviations/hazards could lead to major consequences with a high likelihood of occurrence. However, since the system's design was still deemed incomplete, with multiple components that had not been finalised yet, the HAZOP team decided not to rank those. An overview of those five (5) hazards is provided in Table 8. The remark column outlines major safety considerations arisen regarding this early design.

Table 8: Major unranked identified hazards

Item	Node	Deviation	Consequence(s)	Remarks
2.11	Fuel Tank Filling	As well as Flow – Nitrogen inside the bunkering line	**2.11.1.** The manufacturer's design philosophy is to return the nitrogen used to purge the bunkering lines into the fuel tank.	Return of the nitrogen used for purging of the bunkering lines to the fuel tank has the potential to cause major operational issues to the compressors of the reliquification/BOG system. Furthermore, there is a lack of temperature control of the fuel tank.
5.2	Ammonia Return from M/E	No Flow - Manual non-return valve CK-F51 closed due to failure or operator's error	**5.2.1.** Main engine NH_3 fuel mode failure/interlock. **5.2.2.** Pressure increases upstream of valve CK-F51, leading to potential damage of equipment and/or NH_3 leakage.	The design of the return line does not align with the engine maker's specifications.
7.29	Glycol Water System	Other than Flow	**7.29.1.** Potential for degraded performance of the glycol water system and off-spec ammonia supply to the main engine.	The installation of the GW Heater HT-11, supplied with M/E Jacket Water is not aligned with the engine maker's specifications.

Item	Node	Deviation	Consequence(s)	Remarks
7.30		Less temperature	**7.30.1.** Potential for degraded performance of the glycol water system and off-spec ammonia supply to the main engine.	The installation of the GW Heater HT-11, supplied with M/E Jacket Water is not aligned with the engine maker's specifications.
8.18	N2 Supply Nitrogen	High Temperature - Loss of cooling in the air compressors	**8.18.1.** Loss of system.	Technical specification of the air compressors system is insufficient.

The following list of requirements, not included in the IGF Code (as the Code designed primarily for LNG as fuel applications), are derived from the "IMO Interim Guidelines for the Safety of Ships Using Ammonia as Fuel, MSC.1/Circ.1687". It highlights key design deviations in the NIKKISO CEIG drawings, which were developed for a generic ship design and are limited within the scope to the ammonia fuel supply system.

 # 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.
 # Ch.6.3.1 - The ammonia fuel should be stored in a refrigerated state at atmospheric pressure.
 # Ch.6.9.1.1 - The temperature of the liquefied ammonia in the fuel tanks should be maintained at a temperature of no more than -30°C at all times by means acceptable to the Administration.
 # Ch. 6.9.1.2 - Venting of fuel vapour for control of the tank pressure is not acceptable, except in emergency situations.
 # Ch.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.

 # Ch.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.
 # Ch.9.5.1 - Fuel pipes should be protected by a secondary enclosure. This enclosure can be a duct or a double wall piping system.
 # 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.
 # 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.
 # Ch.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.
 # Ch.15.Table 1 - Ammonia detection in enclosed spaces at 25 ppm (Local indication at all entrances to the space, no alarm at the alarm system).

The following list of requirements supplements the above and is also based on the "IMO Interim Guidelines for the Safety of Ships Using Ammonia as Fuel, MSC.1/Circ.1687." It highlights requirements not addressed in the IGF Code but that should be considered by NIKKISO CEIG while refining the arrangement drawings and design philosophy for a specific ship, ensuring compliance with the Interim Guidelines.

 # Ch.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.
 # Ch.5.7.1.8 - Fuel preparation room entrances should be arranged with water screens having constantly available water supply.

 # Ch.5.7.2.7 - Tank connection space entrances should be arranged with water screens having constantly available water supply.

 # Ch.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.

 # Ch.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.

 # Ch.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.

 # Ch.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.

 # Ch.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.

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

 # Ch.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.

The NIKKISO CEIG Ammonia FSS design was still under development. In particular:

- Multiple subsystems, in particular, FVU, BOG, engine injector water cooling system and N2 system had not been described yet.
- Multiple subsystems' components, such as HP pump skid, GW pumps and BOG compressors had not been detailed and described so far.
- The HAZOP team proposed additional safety measures to improve the safety level of the system (e.g., the redesign of the system so that re-circulation of N2 to the fuel tanks due to purging is not allowed).
- The design requirements were not fully met as required by the WinGD's X52DF-A engine specifications.

Taking into consideration the HAZOP findings, and provided that the technical system designs are updated accordingly, NIKKISO CEIG will be required to carry out Failure Modes, Effects, and Criticality Analysis (FMECA) of their Ammonia FSS as part of the class approval process. Carrying out a FMECA requires the system to be at late stages of development and is usually facilitated by the system designers. Therefore, the outcomes and findings of an FMECA report are confidential. An overview of the FMECA approach is outlined in Appendix F.

2. Port risk assessment approach - SIMOPS

2.1 Objectives

SIMOPS are defined as “situations where two or more operations or activities occur in close proximity in terms of time and space. These activities may interfere or clash with one another, increasing the risks involved or generating new risks.” In this context, operations encompass a range of activities, including maintenance, construction, commissioning, and facility operations, while it is common for these activities to take place adjacent to one another, potentially jeopardizing the safety of nearby operations. This study focuses on SIMOPS related to vessels during their port stay and conducts a risk analysis of port operations that could be impacted by the use of ammonia as a fuel for vessels. The primary challenges associated with this include safe handling, toxic risks, and environmental impacts, necessitating a meticulous and detailed analysis to ensure the safety and sustainability of port operations.

2.2 Methodology

To effectively assess the risks associated with ammonia use in port activities, it is crucial to develop a structured methodology that addresses safety, health, and environmental factors, alongside operational and technical risks. This methodological approach offers a comprehensive, step-by-step guide to identifying, assessing, controlling, and mitigating the hazards associated with ammonia use in port operations.

2.2.1 Identification of Hazardous Locations

In the context of ammonia storage and handling, several critical areas are essential for safe and efficient operations. First, there are the ammonia tanks, which serve as the primary storage facilities. Adjacent to these tanks, loading and unloading zones facilitate the transfer of ammonia to and from transport vessels or vehicles. Additionally, bunkering facilities are established to manage the fuelling processes for vessels reliant on ammonia as a fuel source. The safety and functionality of these areas depend heavily on well-designed piping systems that ensure the proper flow and containment of ammonia.

Ventilation systems play a vital role, particularly in confined spaces, to maintain air quality and reduce the risk of hazardous accumulations. Maintenance areas and workshops are also crucial, as they provide a dedicated space for the upkeep of equipment and infrastructure associated with ammonia handling.

Furthermore, emergency response zones are strategically designated to prepare for any accidental releases or leaks, ensuring that safety protocols are in place if needed. For vessels equipped with ammonia engines, ship engine rooms are specifically designed to accommodate the unique requirements of ammonia-fuelled operations. Lastly, ammonia production plants located within the port area are critical components of the overall ammonia supply chain, contributing to both storage and transport operations.

2.2.2 SIMOPS Identification

Ammonia bunkering can occur concurrently with cargo operations, facilitating efficient use of time and resources. During this process, ammonia transfer may take place alongside maintenance or repair activities on the vessel. It is also feasible to handle other hazardous materials simultaneously, provided that safety measures are rigorously adhered to. Furthermore, ammonia transfer can align with vessel manoeuvring, allowing for a coordinated operational strategy. This includes the possibility of simultaneous vessel refuelling, creating a comprehensive approach to operations.

In certain scenarios, ammonia bunkering may happen while passengers are boarding, which requires meticulous planning and execution to ensure safety. Additionally, ammonia handling can proceed alongside heavy cargo lifting or crane operations, underscoring the necessity for precise coordination among crew members.

Simultaneous maintenance of ammonia tanks and vessel operations can also be achieved, highlighting the importance of maintaining safety protocols throughout these processes. Safety drills are vital during all ammonia operations to equip crew members with the training necessary to respond effectively in emergencies. Finally, ammonia bunkering can be conducted in conjunction with tugboat operations, further enhancing the logistics of marine activities.

2.2.3 Risk Identification

At this stage, our objective is to identify all potential risks associated with the use of ammonia in port operations. This is a critical step in our risk assessment process, as it enables us to comprehend the potential threats and formulate effective mitigation strategies. The safety risks tied to ammonia include the likelihood of leaks, fires, and explosions, as well as the dangers of accidental exposure. Furthermore, we must consider environmental concerns, such as potential spills on land or in water, alongside air pollution that may result from improper handling. On the health front, personnel are at substantial risk from exposure to toxic concentrations of ammonia. Operationally, risks are varied and include infrastructure failures, supply chain disruptions, and the possibility of accidents during ammonia handling and storage.

2.2.4 Impact Assessment

Once risks have been identified, it is crucial to assess their impact and the probability of their occurrence. This can be achieved using either quantitative or qualitative scales. This assessment phase is vital for prioritizing risks. To define impact, one must consider how an incident related to ammonia could affect human health, port operations, the environment, and infrastructure. High-impact leaks are significant incidents that can severely harm the health of many individuals or result in substantial environmental damage. In contrast, moderate-impact leaks typically involve minor incidents that have localised effects, causing limited disruption. Low-impact leaks, on the other hand, result in minor damage without significantly affecting operations or the environment.

Probability refers to the estimation of how likely specific events or accidents are to occur. A high probability indicates the presence of high or poorly controlled risk factors. Risk assessments can be categorised into various probability levels. Moderate probability suggests that while some risks are effectively managed, others remain unaddressed. Conversely, low probability reflects a strong safety infrastructure and well-established procedures that significantly reduce potential threats. To evaluate these probabilities and their impacts, a variety of tools are utilised, including qualitative analysis, probability and impact matrices, and scenario analysis, which aid in understanding and managing risks more effectively.

2.2.5 Quantitative Analysis

A more comprehensive quantitative analysis can be advantageous when dealing with critical or complex risks. In this context, numerical modelling and simulations can be employed to predict the potential outcomes of an accident. This approach aids in assessing the magnitude of risk in terms of financial implications, human lives, or environmental effects. Some useful tools for this analysis include Monte Carlo simulation, fault tree analysis (FTA), and event tree analysis (ETA).

2.2.6 Consequences Analysis

The next step involves assessing the potential consequences of the identified risks, with careful consideration of various impacts. When evaluating the implications of a possible ammonia release, several critical factors must be taken into account. Primarily, human health is of utmost importance, as it affects both port personnel and the surrounding community. It is crucial to analyse how such an incident might jeopardise their safety and wellbeing.

Equally significant is the environmental impact, particularly regarding how the release would influence local air and water ecosystems. A thorough understanding of these ecological consequences is essential for responsible port operations. Additionally, the incident is likely to lead to operational downtime, resulting in considerable losses in efficiency and delays in cargo handling, which could disrupt overall business operations.

Lastly, there are reputational concerns; any incident involving ammonia could negatively affect the company's image as well as that of the port itself, potentially undermining public trust and investor confidence. Each of these factors warrants careful consideration to ensure safety and uphold operational integrity. The tools utilised for this assessment include gas dispersion modelling, toxicity analysis, and environmental impact studies.

2.2.7 Control and Mitigation Measures

In this phase, strategies are developed to reduce the likelihood of risks occurring and to minimise their impacts should they materialise. When considering ammonia use, several measures may be implemented. To enhance the safety and efficiency of ammonia storage and transport systems, it is vital to improve their design by incorporating advanced features such as leak detection systems and constructing robust containment barriers. In addition to these infrastructural enhancements, clear operational instructions are essential for the safe handling of ammonia, along with established emergency protocols to follow in the event of a leak.

Moreover, specialised training must be provided to dock workers and personnel involved in ammonia handling, equipping them with knowledge of safety hazards and the necessary procedures to mitigate risks. A comprehensive emergency response plan should also be developed, emphasizing continuous monitoring, alarm systems, and clear evacuation procedures in case of an ammonia release. This integrated approach will significantly enhance safety and preparedness in ammonia management. Tools such as regulatory review, barrier analysis, Job Safety Analysis (JSA), and Preliminary Hazard Analysis (PHA) can support these efforts.

2.3 Continuous Monitoring and Review

Risks and control measures must be monitored continuously to ensure that operational and safety conditions are consistently upheld. It is recommended that periodic audits be conducted to ensure compliance with procedures and assess the effectiveness of mitigation measures. Furthermore, as new factors emerge or operational circumstances change, it is crucial to update the risk analysis accordingly. This ongoing process is essential for maintaining strong risk management practices. Recommended tools include internal audits, safety management systems, and regular inspections.

2.4 Final Report

Upon completion of the risk analysis, it is crucial to document all stages of the process. The risk management process begins with the identification of potential risks that may impact the project or organisation. After identifying these risks, a comprehensive assessment of their impact and likelihood is conducted to gauge their significance. Next, a consequence analysis is carried out to evaluate the potential outcomes associated with the identified risks.

In response to these risks, suitable control and mitigation measures are developed and implemented, ensuring that the organisation is adequately prepared to address any adverse effects. Finally, proposals for monitoring the effectiveness of these measures, along with strategies for continuous improvement, are established, thereby creating a framework for ongoing risk management and process enhancement. This report will serve as a valuable reference for risk management and for formulating future policies and regulations at the port. An overview of the risk assessment approach is provided in Appendix E.

The analysis identifies the main risks associated with these concurrent operations and proposes a series of mitigation measures to ensure the safety of the personnel and vessel and its facilities. These measures include the delimitation of exclusion zones, coordination of equipment through dedicated communication systems, implementation of emergency shutdown (ESD) protocols and restriction of certain activities during ammonia transfer. Finally, proposals for monitoring the effectiveness of these measures, along with strategies for continuous improvement, are established, thereby creating a framework for ongoing risk management and process enhancement. This report will serve as a valuable reference for risk management and for formulating future policies and regulations at the port.

The specific recommendations and detailed risk analysis are developed in Appendix E.

3. Consequence Modelling

Gas dispersion modelling has been a long-standing component of consequence analysis, driven by the continuous need for accurate air quality predictions. While Computational Fluid Dynamics (CFD) has emerged as a viable tool, its application to multiphase releases (i.e., gaseous and liquid) of ammonia is still developing. Consequently, current analyses, including those presented here, have predominantly modelled ammonia releases as purely gaseous. However, real-world scenarios, such as bunkering operations or incidents in engine rooms, typically involve two-phase flows of both liquid and gaseous ammonia. Significant efforts are underway to advance CFD methods and techniques to more accurately simulate these complex multiphase flows. Despite this simplification, the pure-gas assumption adopted in this analysis is considered plausible for most industrial applications. This approach provides a more conservative assessment of the release impact, as the liquid component of a release would likely rain out and evaporate slowly. This slower dispersion would afford vessel crews sufficient time to implement appropriate response measures.

A detailed introduction to the CFD methodology as applied here can be found in a companion report to EMSA[9]. Briefly, Siemens Star-CCM+, was utilised for the study cases presented in the present report. The CFD model solves the conservation equations of mass, momentum, gas species, energy, and turbulent quantities throughout the entire domain. The model was based on the 3D Navier-Stokes equations supplemented by proper multi-component gas representations, a proper turbulence model (such as the k-ε, k-ω, the Detached Eddy Simulation family, or the Large Eddy Simulation), and the equation of state. For simplicity, it was considered reasonable to apply the ideal gas law for gaseous ammonia. In the present work, phase change and chemical reactions were also ignored.

The ammonia plume pattern can be displayed for any specified concentration level. The impact of various ammonia concentration levels can be inspected from different perspectives. For all study cases as follows, the concentration of 25 ppm was selected as a critical concentration level to be highlighted. The concentration of 160 ppm was selected as a second critical level mainly to represent Acute Exposure Guideline Level (AEGL-2, 1-hour exposure) above which the general population could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape. A third level at 1,000 ppm was selected as a critical level to approximately match the AEGL-3 (1,100 PPM, 1-hour exposure) level. For the case of fuel leakage in the engine room, a fourth concentration level at 15,000 ppm was highlighted, which is 10% of the Lower Explosive Limits (LEL) of ammonia. The 10% of LEL level is a common threshold for ammonia gas detectors to trigger a warning of fire and explosion hazards and thus is informative for the planning of gas detector placement in a future phase of vessel design.

For all study cases presented in this section, the ammonia releases concerned started in a steady ambient air flow. That means the CFD model with air only and no ammonia should be run for a period of time to establish such a steady-state ambient air flow. The time duration required for this pre-release phase varied from case to case and was influenced by the air flow speed, direction, and any structures surrounding the release point.

Based on the HAZOP W/S that was carried out, the scenarios that were deemed more credible for carrying out the ammonia gas dispersion modelling, are the following:

1. Ship-to-Ship Bunkering of Ammonia at a Port
2. Ammonia Release from a Vent Mast
3. Ammonia Accidental Releases in the Engine Room

[9] Section 2.3.4, Safety of Ammonia for Use in Ships: Part 1 – Ammonia: Properties, Regulations and Accidents Review, Rev. 1.1, EMSA, 24/06/2024.

3.1 Ship-to-Ship Bunkering of Ammonia at a Port

This scenario aims to evaluate the potential impact of the ammonia dispersion from accidental releases during ship-to-ship bunkering operations. The CFD simulation results provide ammonia concentration distributions around the release area, which are used as the basis for designation of hazardous and toxic zones for the bunkering operations.

3.1.1 Case Conditions and CFD Model Setup

In the study cases presented here, the ammonia bunkering vessel (ABV) was a 33,000 m^3 gas carrier. A crude oil tanker of 320,500 deadweight tonnage was taken as the receiving vessel. Two conditions were investigated in this section: one with wind blowing from the ABV to the tanker with a speed of 3 m/s and the other with wind blowing from the tanker to the ABV with a speed of 2 m/s. These two conditions represented the daytime and nighttime weather conditions at the port, respectively. Water vapour contents were considered in the CFD model to reflect the relative humidity of the environment. In this case, the ambient air would consist of dry air and water vapour. The relative humidities were set to 70% for the daytime condition and to 90% for the nighttime condition, respectively. The corresponding air temperatures were 33°C and 24°C for the daytime and the nighttime conditions, respectively. These ambient air conditions targeted a Pasquil stability class between D (neutral conditions) and E (slightly stable conditions).

The bunkering was normally done via an 8-in hose with a flow rate of 1,000 m^3/hr and a gauge pressure of 4 barg. The leak point was assumed to be 1 m above the starboard bunkering station of the tanker. This leakage position was to represent a leakage from the manifold of the bunkering station. **The leakage was assumed to be caused by a pin-hole rupture represented by a circular hole with a diameter of 12 mm. The ammonia release rate through this pinhole was estimated as 0.203 kg/s. The leakage direction was assumed to be horizontally toward the port (i.e., landward). The leakage duration was set to 60 s before the leakage was stopped.**

Figure 3 shows the setting of the boundary condition types for the CFD model. For both wind conditions, the air flow entered the computational domain from the inlet boundary (red colour) and exit the domain at the outlet boundary (brown colour). The remaining two vertical sides and the top side of the computational domain were symmetry-plane boundaries. The solid surfaces, such as those of the vessels, the ground of the port and the water surface, were set as the solid wall type of boundaries. A coordinate system was set to have its X axis pointing towards the vessel bow, its Y axis pointing towards the port and its Z axis pointing vertically upwards. The domain had dimensions of 900m × 1200m × 300m in the X, Y, and Z directions, respectively. The total number of Finite Volume cells generated for the computational domain was about 18 million.

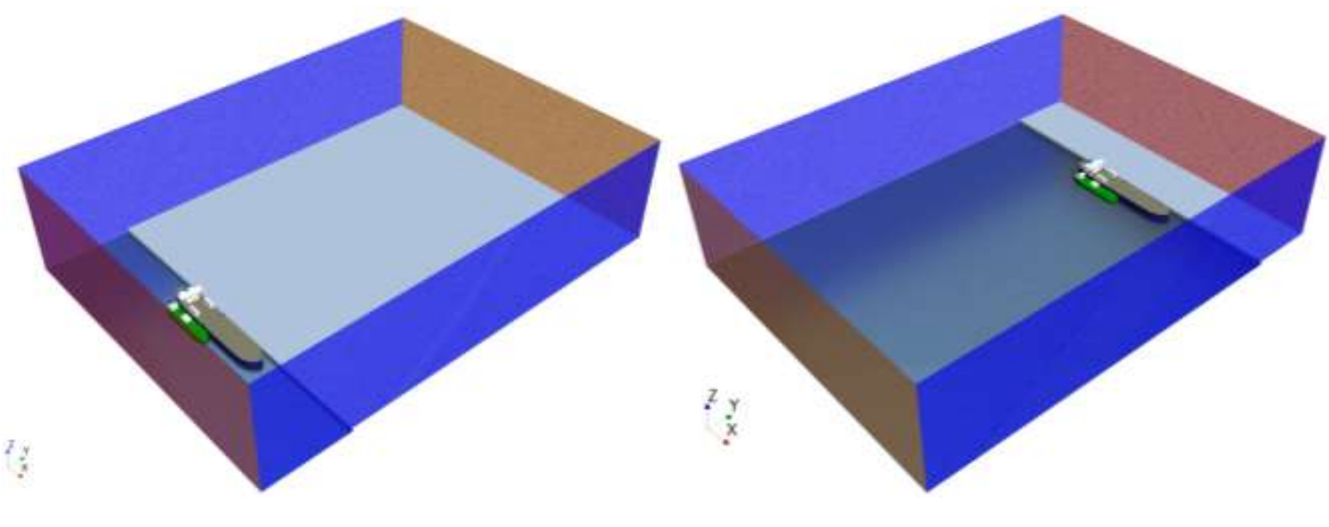


Figure 3: CFD computational domain for the ammonia dispersion study cases for the ship-to-ship bunkering scenario. Left: with wind direction from the ABV to the tanker; the inlet boundary is the face with the smallest Y value. Right: with wind direction from the tanker to the ABV; the inlet boundary is the face with the largest Y value.

Figure 4 shows the computational mesh of the CFD domain. The spatial resolution of the mesh was made fine enough to capture physical phenomena of interest. Due to the small size of the leakage hole and the high speed of the ammonia jet out of it, the mesh dimensions in the near field were refined in order to attain a reasonable Courant number. As the plume was anticipated to slow down significantly in the far field, the mesh there was coarsened accordingly.

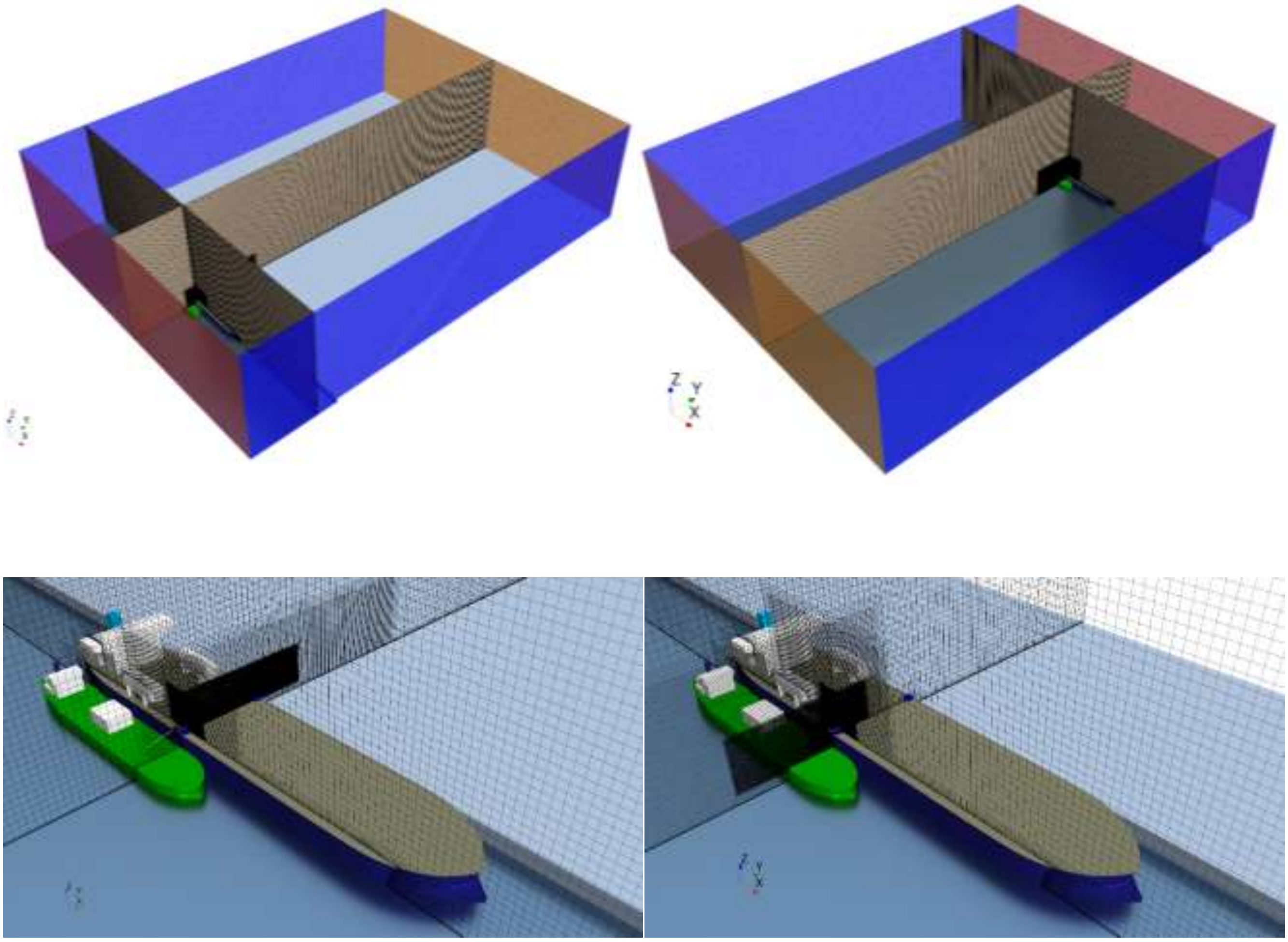


Figure 4: CFD computational mesh for the ammonia dispersion study cases for the ship-to-ship bunkering scenario as shown on different sections. Left column: with wind direction from the ABV to the tanker. Right column: with wind direction from the tanker to the ABV.

3.1.2 Simulation Results for the Case with a landward Wind

The steady-state air flow field surrounding the tanker and ABV was first obtained, as depicted in Figure 5. Apparently, the streamlines were displaced upwards due to the obstruction of the ABV and the tanker. In the downstream of the vessels, the flow became more turbulent. The ammonia plume would definitely be affected by such an ambient flow pattern.

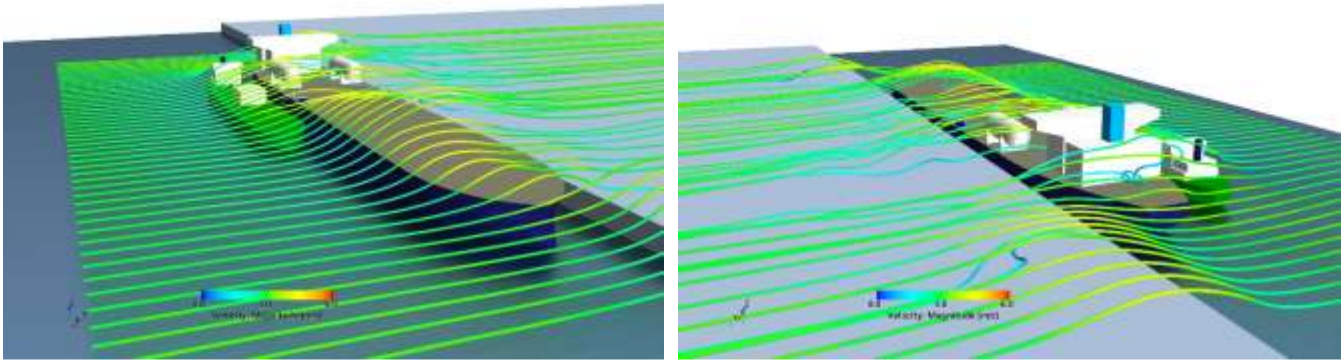
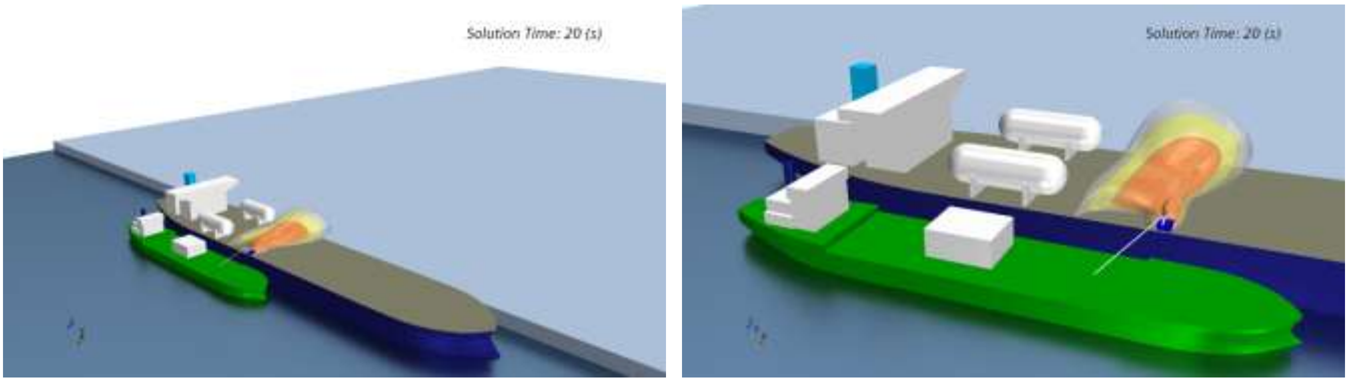
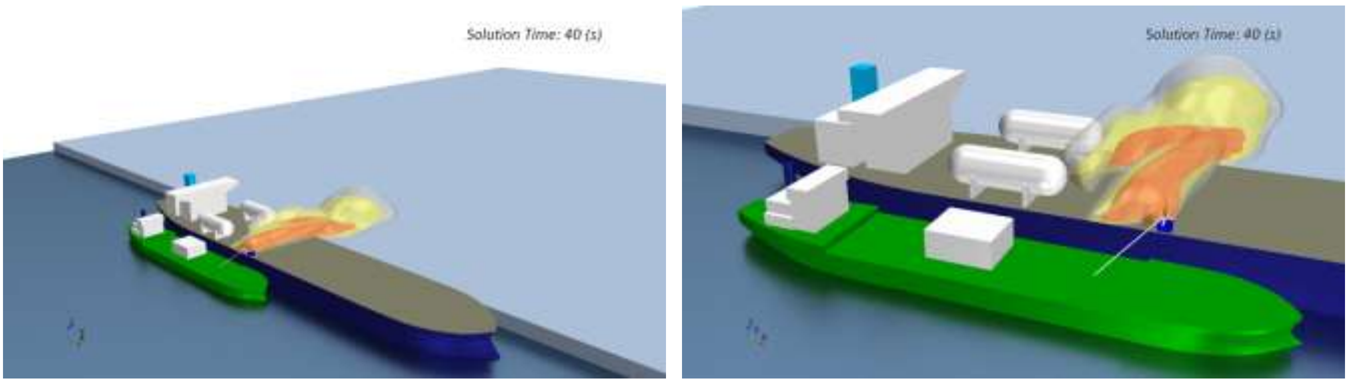


Figure 5: The steady-state air flow field around the ABV and the tanker for the landward wind condition for the ship-to-ship bunkering scenario. The left and the right subfigures show the streamlines as viewed from two different angles. The colours along the streamlines represent the velocity magnitude.

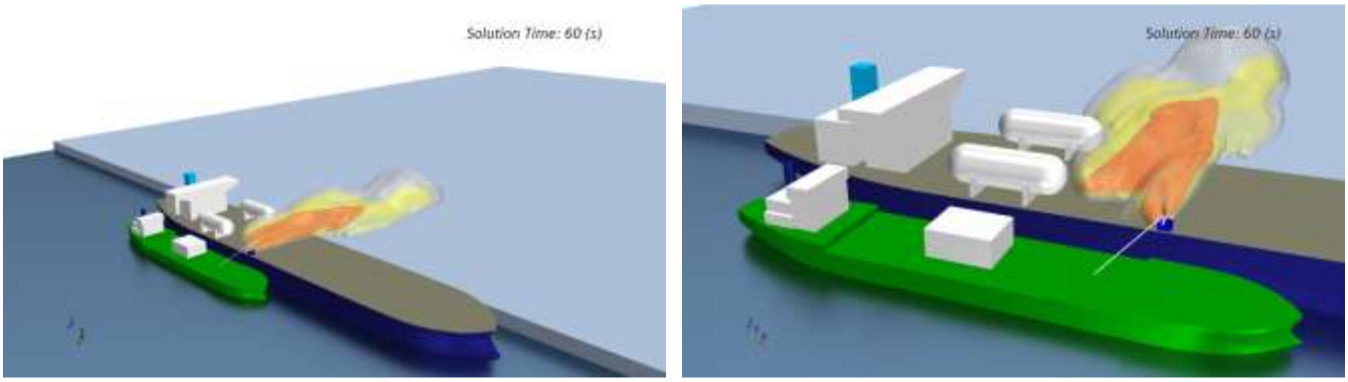
Figure 6 shows the snapshots of the evolution of the ammonia plume for the case with a landward wind. The contour surfaces coloured in grey, yellow and red represent ammonia concentrations of 25 ppm, 160 ppm and 1,000 ppm, respectively. As observed from the evolution history, the ammonia plume created by the accidental leakage spread out in both transverse and longitudinal directions. The high concentration level of 1,000 ppm nearly reached the fuel tank on the port side. **After the leakage was closed at 60 s, the plume was advected away from the tanker and diluted over time. The concentration level of 25 ppm eventually vanished throughout the entire domain after 400 s (i.e., about 7 min).**



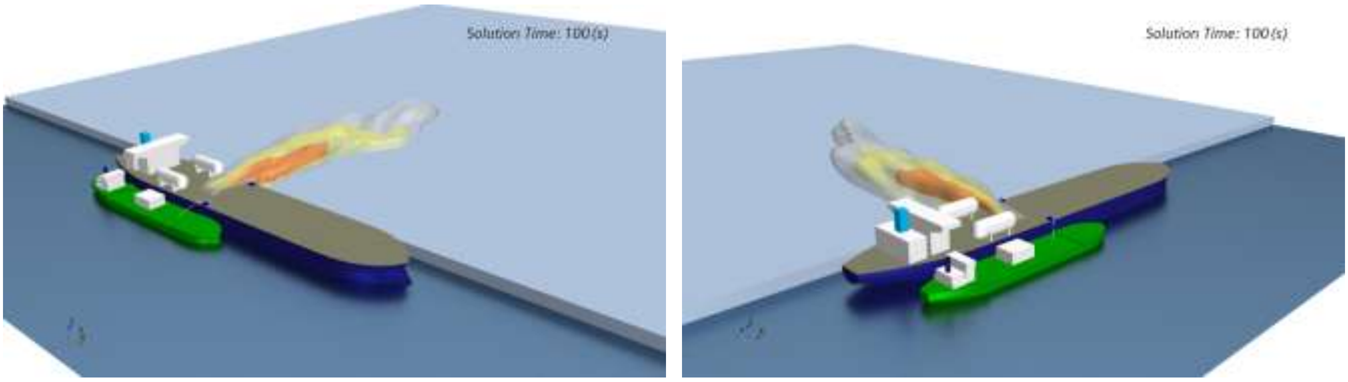
(a) time = 20 s



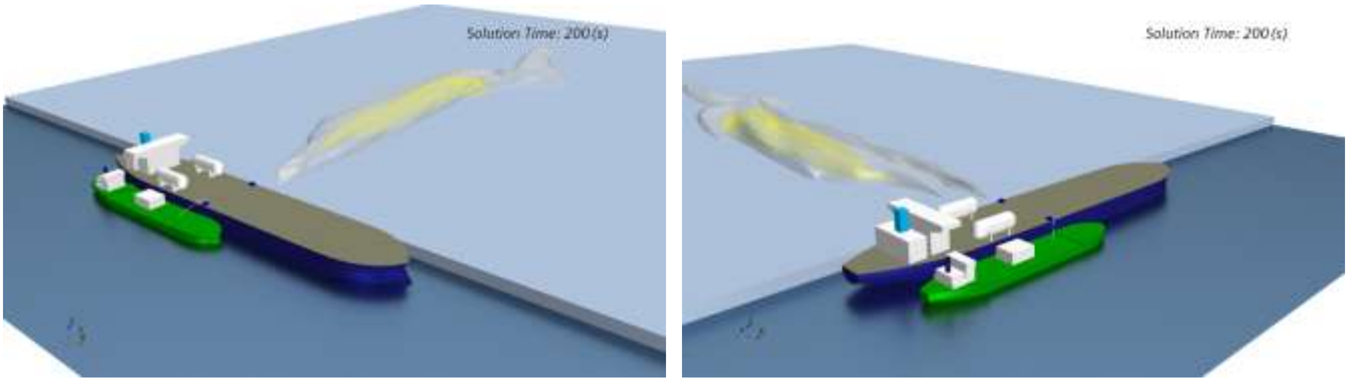
(b) time = 40 s



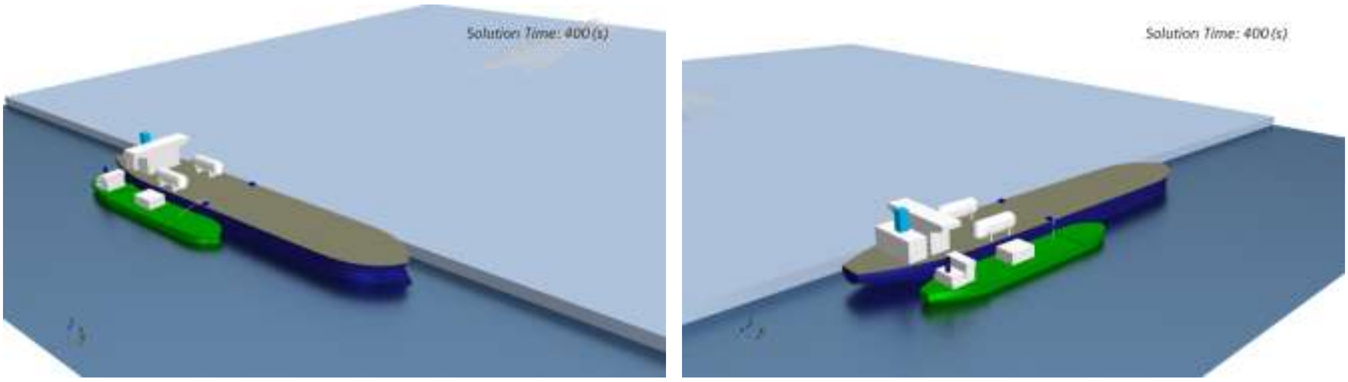
(c) time = 60 s; the leakage was closed at this moment.



(d) time = 100 s



(e) time = 200 s



(f) time = 400 s

Figure 6: Evolution of the ammonia plume for the case with a landward wind (from the ABV to the tanker) of the ship-to-ship bunkering scenario. The leakage duration was 60 s. The contour colours: grey for 25 ppm, yellow for 160 ppm, and red for 1,000 ppm. Left and right columns show the same flow field and time from two different angles.

Five numerical probes were placed 2 m above the tanker deck to capture the ammonia concentrations in the working area over time. The probe positions are shown in Figure 7. The distance between any two adjacent probes was 20 m. The durations of exposure for different concentration levels were calculated and displayed in Figure 8 as an indicator of the actual exposure of a person to ammonia. The durations shown in the present report are accumulated duration at a certain location throughout the simulation time, which could include a number of time segments, not necessarily a continuous time interval. Figure 8 shows that the “Middle” probe, which was directly in way of the ammonia plume, had the highest concentration. At the “Aft1” and “Aft2” probes, the highest concentrations were 3,751 and 1 ppm, respectively. This indicates that the ammonia plume hardly spread past the “Aft2” probe. Figure 8 also shows the duration time was less than one minute for all concentrations higher than 1,000 ppm at those probe locations. In this case, the risk of the bridge and the accommodation being impacted by the leakage would be negligible.

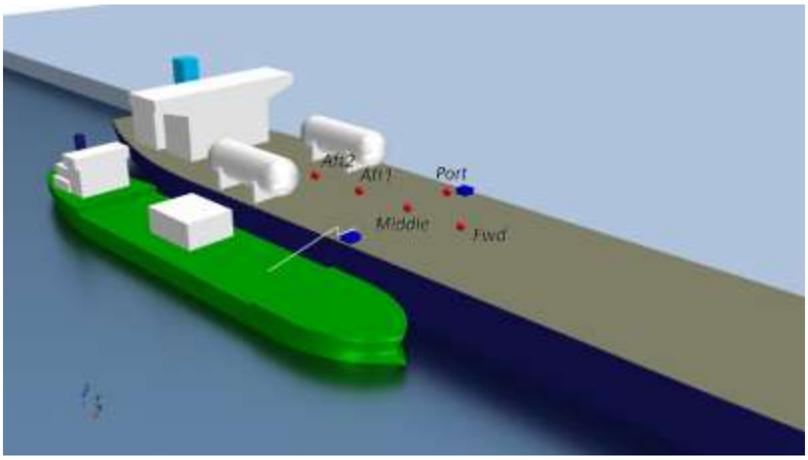


Figure 7: The probe locations on the tanker deck for the case with a landward wind for the ship-to-ship bunkering scenario. The probes were used to monitor the ammonia concentrations during the dispersion process.

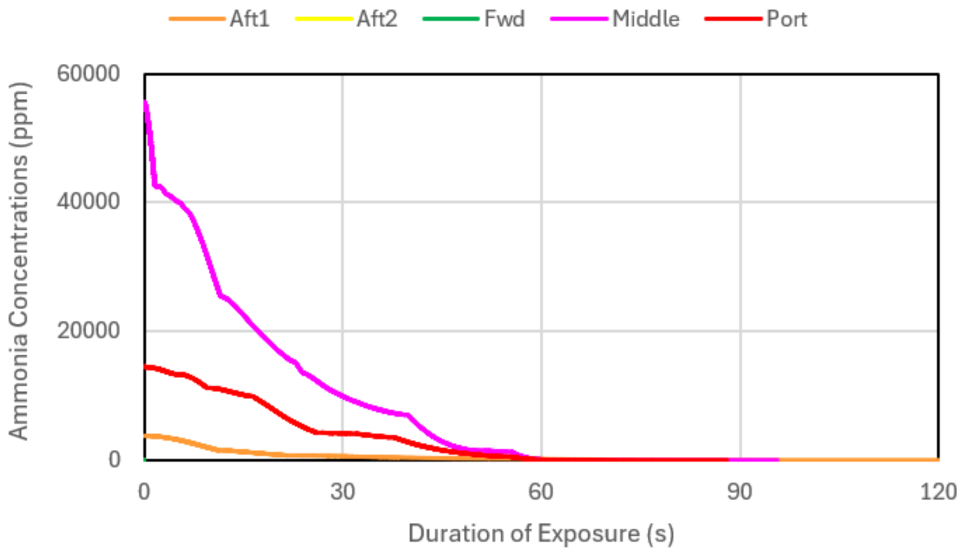


Figure 8: The duration of exposure for different ammonia concentration levels as captured at the five probe locations for the case with a landward wind for the ship-to-ship bunkering scenario

3.1.3 Simulation Results for the Case with a seaward Wind

Figure 9 shows the steady-state air flow field around the tanker and the ABV when the wind was blowing from the land (port) to the ABV. Because the ABV hull is substantially smaller than the tanker hull, the ABV primarily fills in the recirculation zone downwind from the tanker and does not cause further obstruction to the air flow.

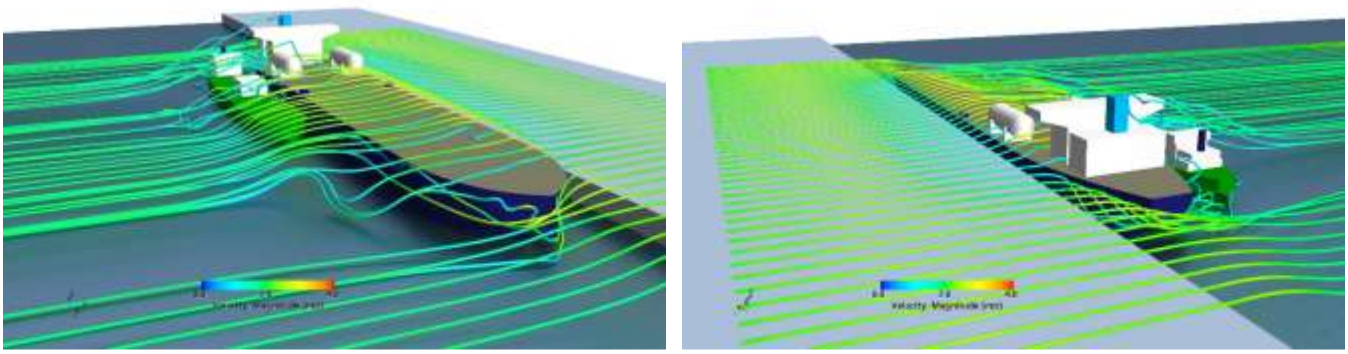
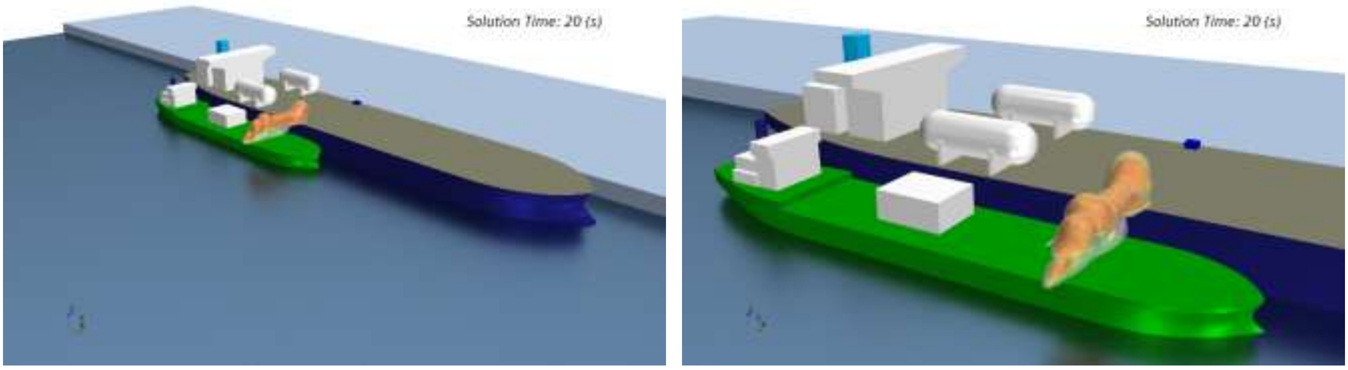
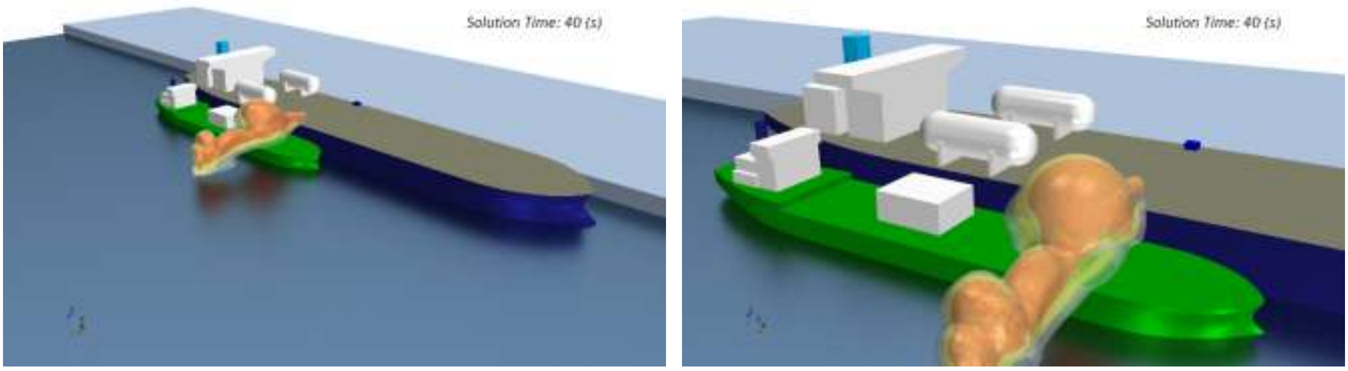


Figure 9: The steady-state air flow field around the ABV and the tanker for the seaward wind condition for the ship-to-ship bunkering scenario. The left and the right subfigures show the streamlines as viewed from two different angles. The colours along the streamlines represent the velocity magnitude.

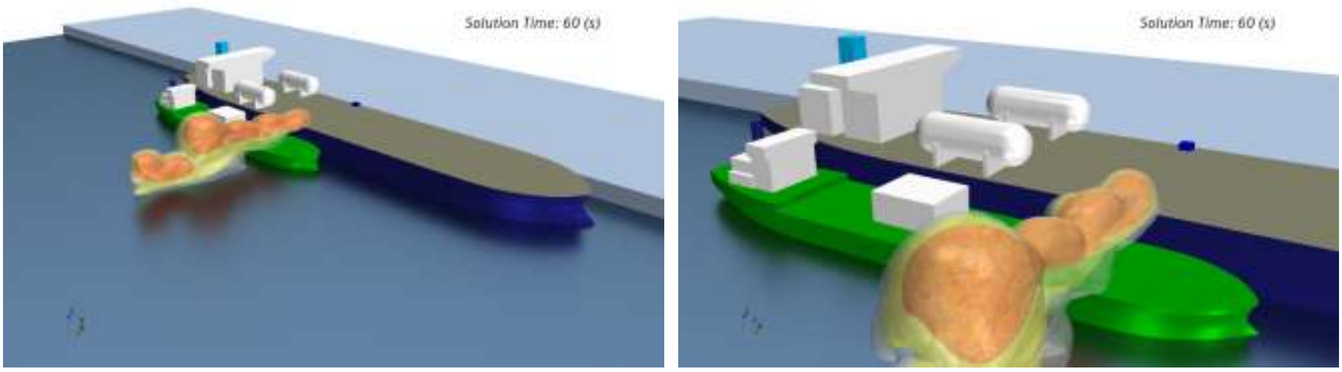
The evolution history of the ammonia plume is shown in Figure 10. While the leakage direction was landward, the plume direction was countered and reversed by the wind and eventually moved into the sea. After the leakage was closed at 60 s, the ammonia concentration level of 25 ppm was diluted within about 300 s (i.e., 5 min), to a concentration lower than 25 ppm across the entire domain.



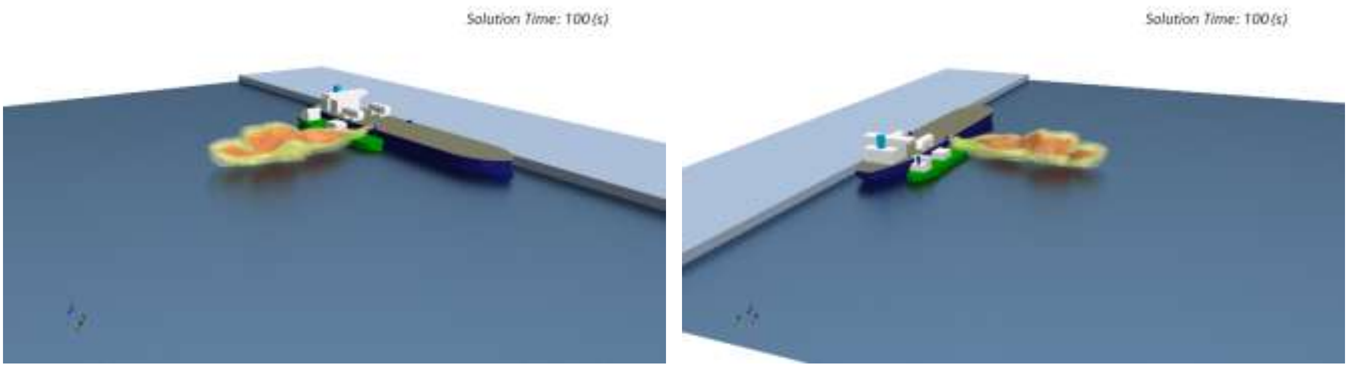
(a) time = 20 s



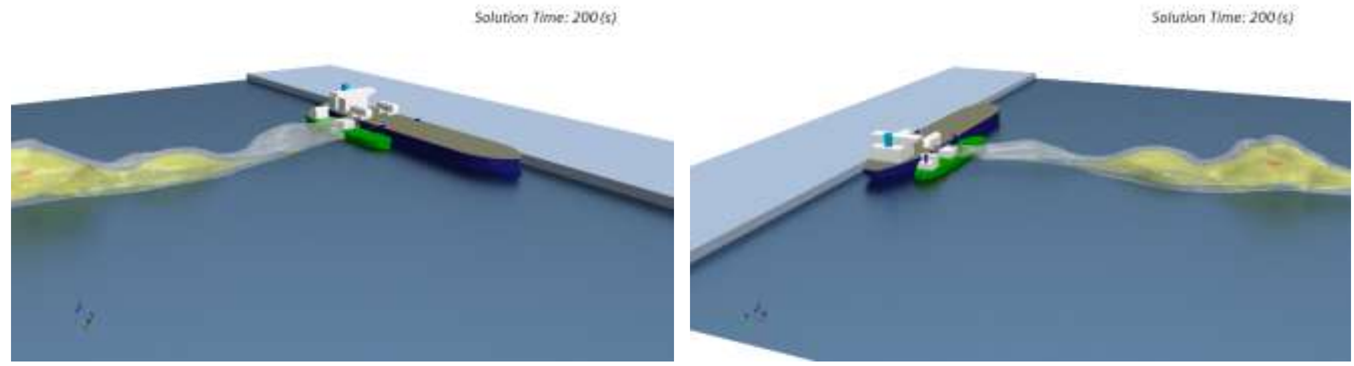
(b) time = 40 s



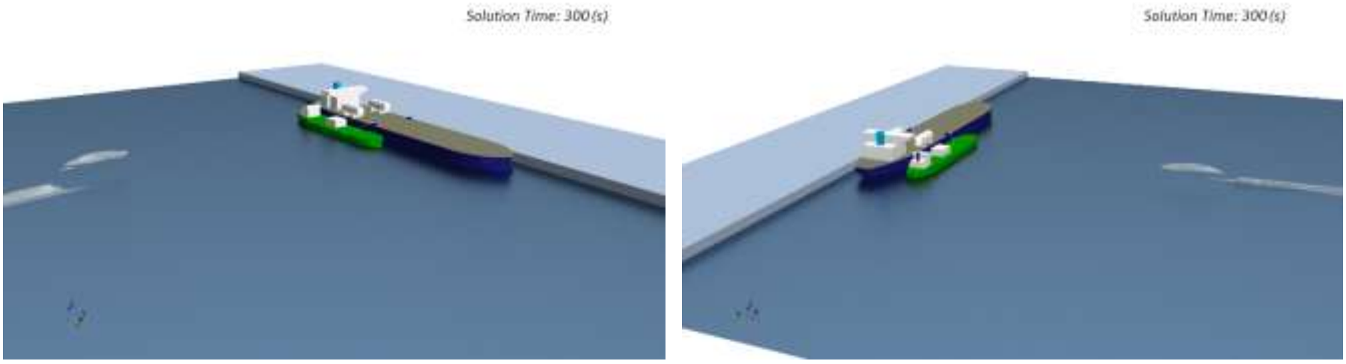
(c) time = 60 s; the leakage was closed at this moment.



(d) time = 100 s



(e) time = 200 s



(f) time = 300 s

Figure 10: Evolution of the ammonia plume for the case with a seaward wind (from the tanker to the ABV) of the ship-to-ship bunkering scenario. The leakage duration was 60 s. The contour colours: grey for 25 ppm, yellow for 160 ppm, and red for 1,000 ppm. Left and right columns show the same flow field and time from two different angles.

Five numerical probes were placed 2 m above the ABV deck to track the ammonia concentration levels over time. Figure 11 displays the layout of the probes. The distance between any two adjacent probes was 20 m longitudinally and 9 m transversely. The durations of exposure for different concentration levels were calculated and displayed in Figure 12 as an indicator of the actual exposure of a person to ammonia. Figure 12 demonstrates that for all concentrations above 25 ppm, the duration of exposure was less than one and a half minutes at those probe locations. Additionally, the highest concentration was observed on the starboard side of the ABV (at the probe “Stbd”) which is higher than the port side (at the probe “Port”). This is because the tank deck is higher than the ABV deck.

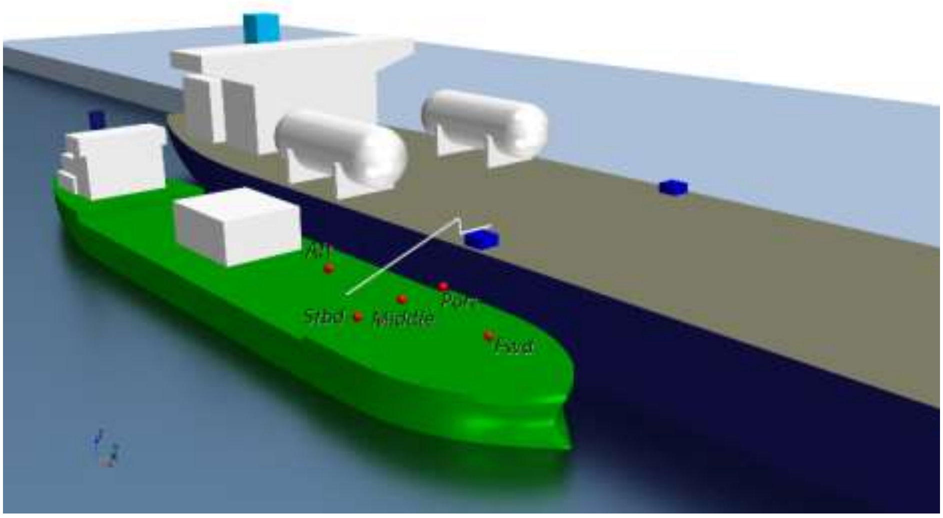


Figure 11: The probe locations on the ABV deck for the case of seaward wind for the ship-to-ship bunkering scenario. The probes were used to monitor the ammonia concentrations during the dispersion process.

There is a vortex near the port probe, functioning like a slope. The majority of ammonia vapour is pushed to the starboard side along the slope. However, the ammonia concentrations at all five probes over the ABV for the seaward wind condition were mostly lower than those for the landward wind condition as shown in Figure 12. This difference resulted from the extra dilution caused by the reversal of the plume when its landward momentum was exhausted by the seaward wind.

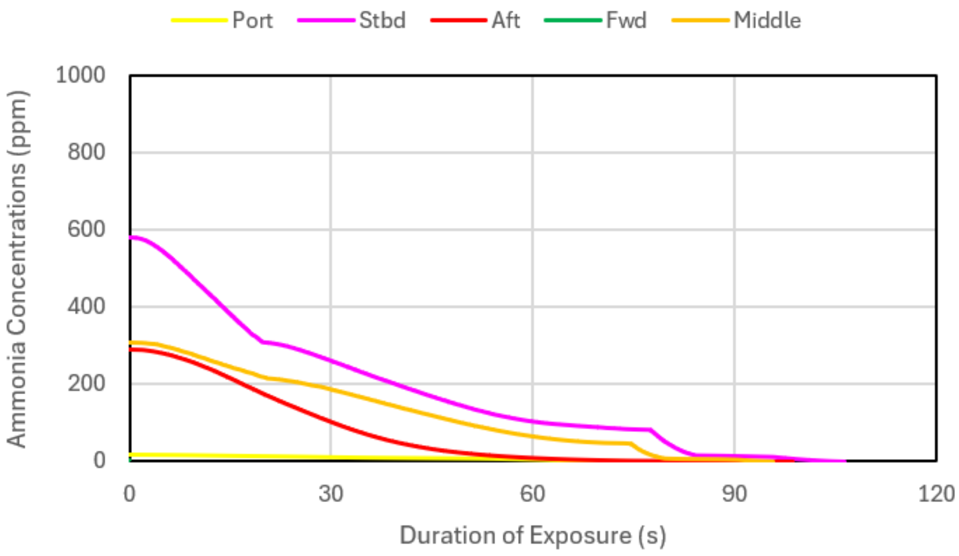


Figure 12: The duration of exposure for different ammonia concentration levels as captured at the five probe locations as shown in Figure 11 for the case with a seaward wind of the ship-to-ship bunkering scenario.

3.2 Ammonia Release from a Vent Mast

While ammonia releases from a vent mast can be well controlled, those still pose safety risks if high concentrations of ammonia can either directly impact any crew members or reach the air intake ports toward any manned spaces. In the present section, study cases are presented to demonstrate the possible impact on the vessel of the ammonia plume release from a vent mast under certain conditions.

3.2.1 Case Conditions and CFD Model Setup

For this scenario, study cases were created for the vessel as described in Section 3.1. The layout of the vessel deck including the vent mast used for the ammonia leakage can be found in Figure 17. The vent mast had a nominal diameter of 1 m and a height of 20 m above the deck. It was located 10 m forward of the starboard fuel tank. The release nozzle of the vent mast had a diameter of 0.219 m. The ammonia release rate from the vent mast was estimated as 2.479 kg/s. The temperature of the ammonia released was taken as -25°C. Based on the release conditions, the vertical release velocity out of the nozzle could be estimated to be 71.61 m/s. The release duration was assumed to be 300 s before the release was stopped. The development of ammonia plumes was also demonstrated in this simulation.

The wind direction was set to be parallel to the vessel centreline, i.e., from the bow toward the stern. This wind direction would have the bridge and the accommodations directly downwind from the resulting plume. The plume could also impact the two fuel tanks on deck. The wind speed was set to 5 knots or about 2.57 m/s. This condition was considered to be the worst for gas safety. The ambient temperature was set to 33°C uniformly. In general, the ambient air conditions reflected a Pasquill stability class between D (neutral conditions) and E (slightly stable conditions).

Figure 13 shows the computational domain of the CFD model. The domain measured 1,600 m in the longitudinal direction of the vessel, 500 m transversely, and 300 m vertically. With the assumed wind direction, the inlet boundary of the computational domain is the side at the vessel bow and the outlet boundary is the opposite face to the inlet. The coordinate system used is also shown in Figure 13.

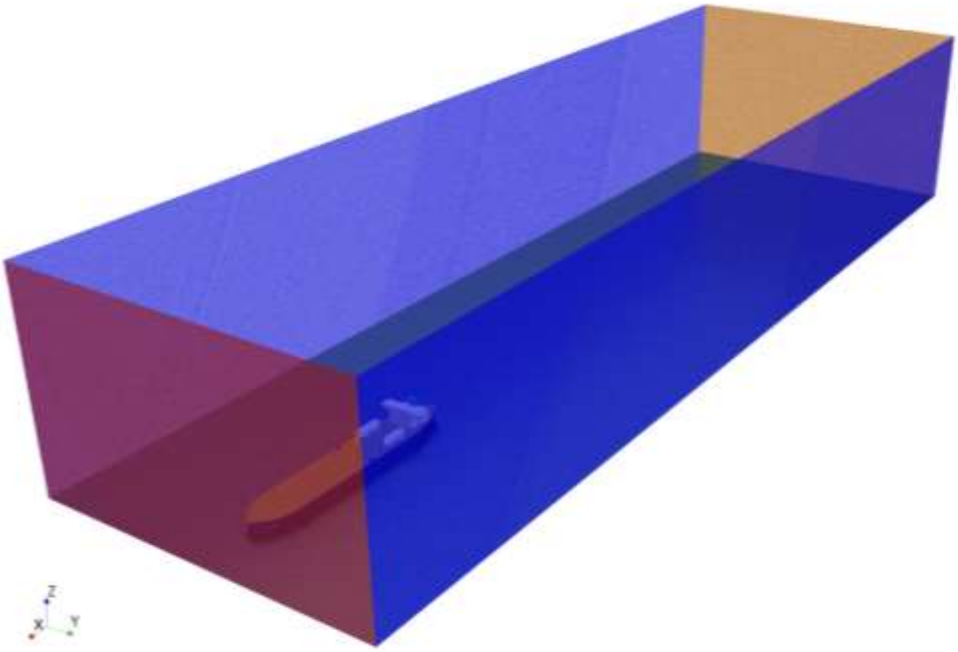


Figure 13: CFD computational domain for the scenario of ammonia released from a vent mast of the vessel.

Figure 14 shows the computational mesh of the CFD model. The mesh was refined near the vent mast and the downstream from it, where the plume was expected be in its near and medium fields. The mesh was gradually coarsened away from the vessel and toward the far field of the plume. The total number of cells was about 15 million.

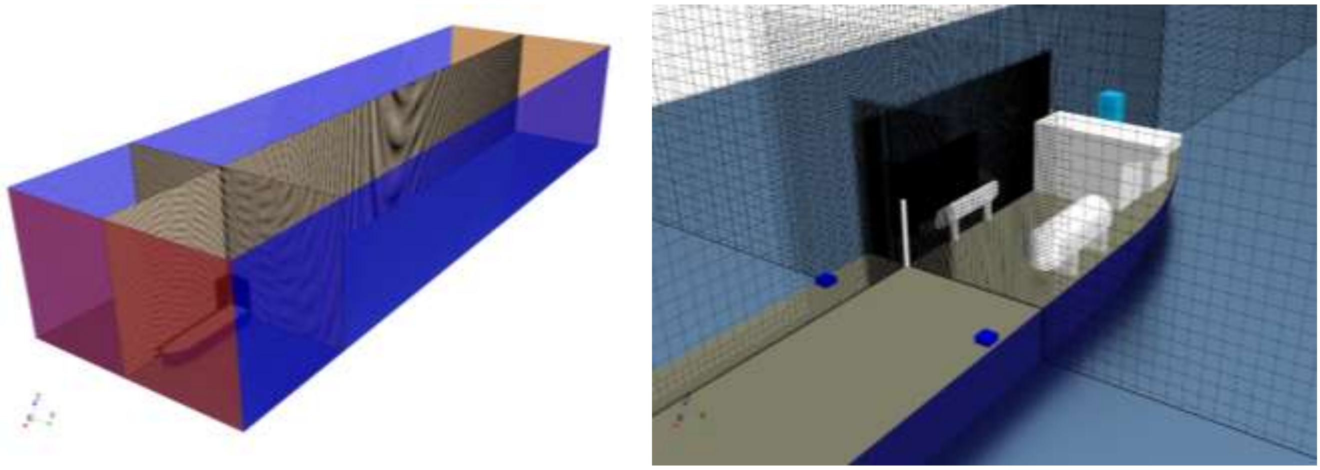


Figure 14: Computational mesh of the CFD model for the scenario of ammonia released from a vent mast of the vessel, as shown in various sectional cuts of the computational domain.

3.2.2 Simulation Results

Figure 15 demonstrates the steady-state air flow field where the ammonia plume would be released next. Due to the blunt obstruction of the vessel, the streamlines of the air flow were displaced around the vessel, causing vortices and high turbulence downwind of the obstructions.

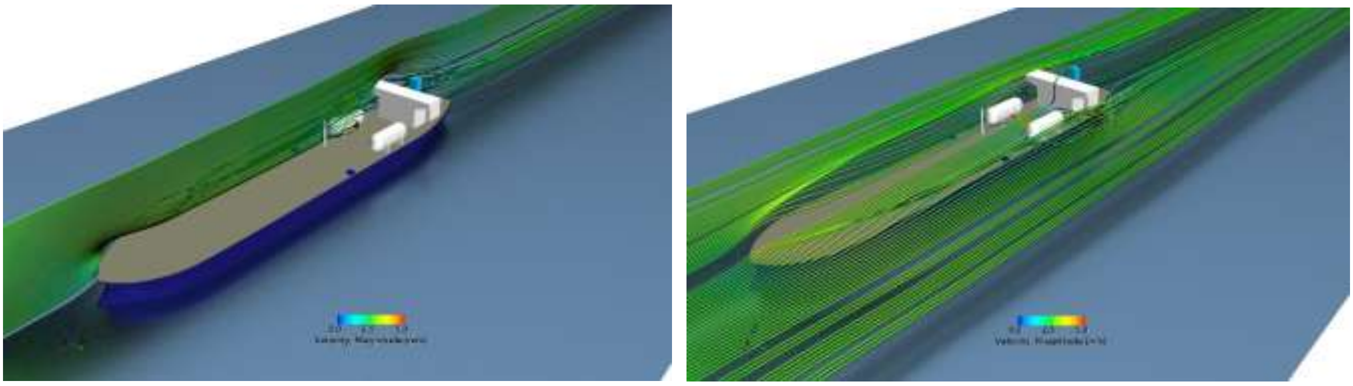


Figure 15: Streamlines of the steady-state air flow field around the vessel for the scenario of ammonia released from a vent mast, as shown in a vertical (left) and a horizontal (right) sections.

Figure 16 shows the evolution of the ammonia plume over time at selected key moments. Because the released ammonia had an upward momentum, the gas plume had a clear tendency of rising toward the bridge. The ambient flow pattern, however, became complex passing the bridge. The low pressure in the wake of the bridge tended to draw the plume down. Overall, the ammonia plume remained clear of the bridge and the accommodations throughout the entire duration of the release. As a result, the release from the vent mast did not pose a safety risk for the crew members working there. In the end, the ammonia concentration was diluted to lower than 25 ppm behind the vessel after 400 s (i.e. about 7 min) from the release start time.

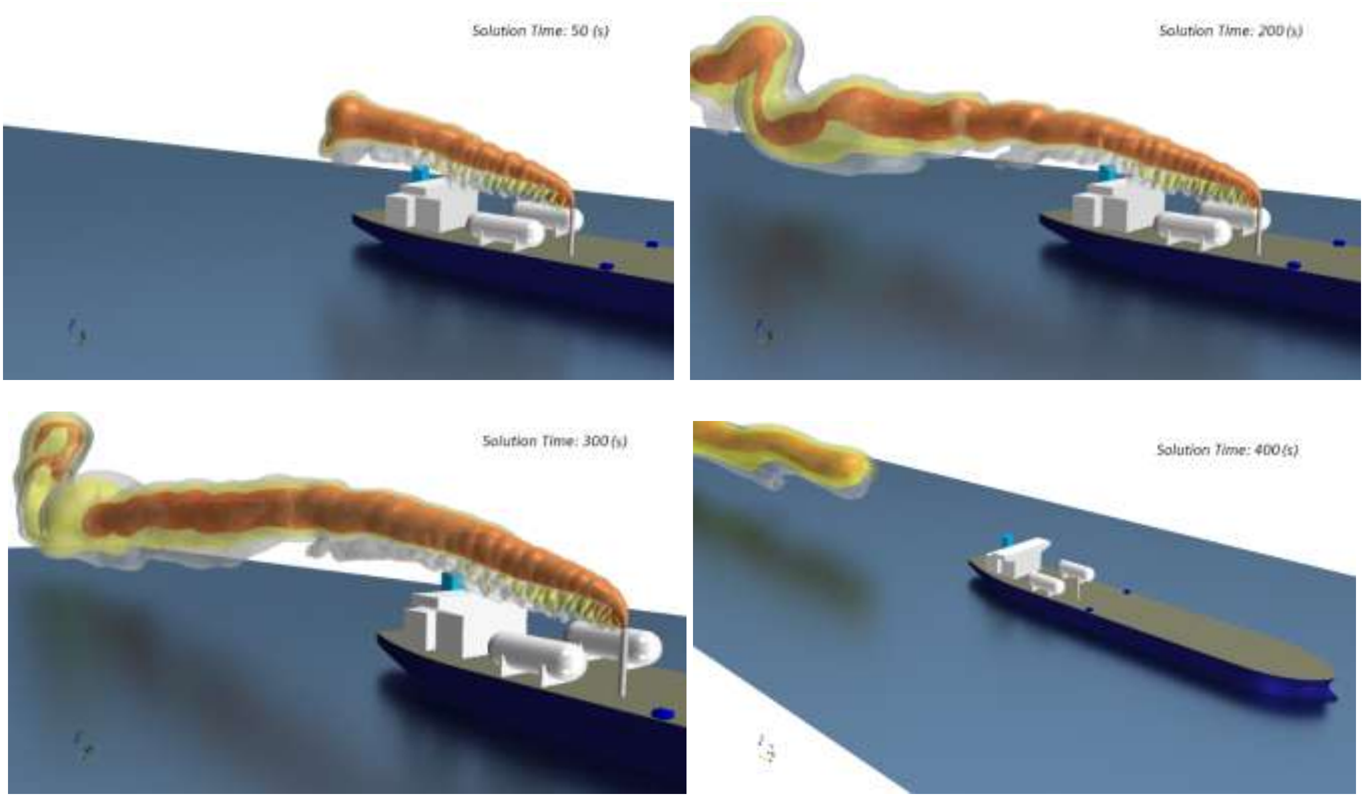


Figure 16: The evolution of the ammonia plume over time as shown at four selected moments following the initial release from the vent mast. The release duration was 300 s. Contour colours: grey for 25 ppm, yellow for 160 ppm, and red for 1,000 ppm.

Two numerical probes, referred to as “Probe1” and “Probe2”, were placed over the vessel deck to capture the local ammonia concentration over time, as shown in Figure 17. Transversely, they share the same Y position as the vent mast. Probe1 was 35 m above the deck and 40 m aft from the vent mast. Probe2 was at the same height as the release point of the vent mast (i.e., the centre of the nozzle) and 20 m downstream from the vent mast. While for this case the ammonia concentration at the deck level was negligibly low (Figure 16), it is recommended in general that point probes be placed close to the deck level or at the human nose height in the common working areas on deck, in order to capture the gas impact on vessel crew.

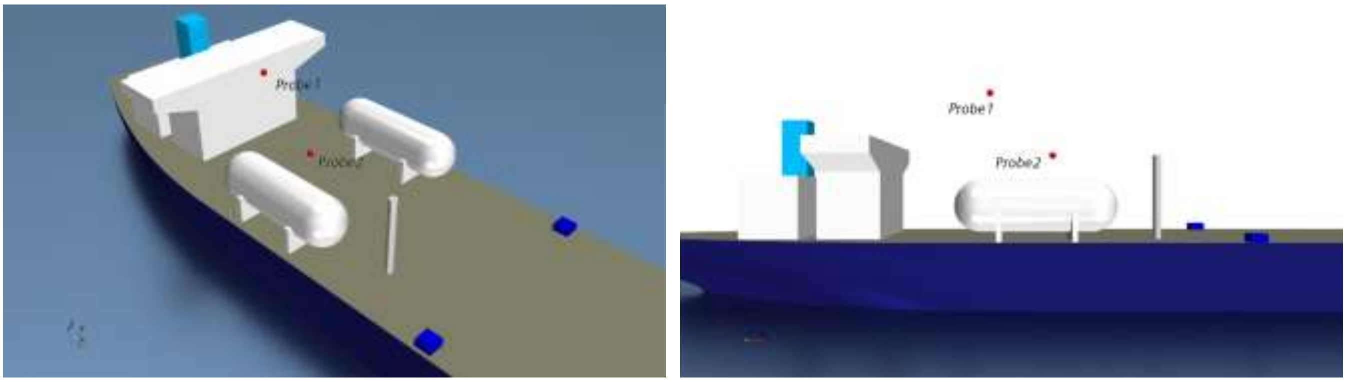


Figure 17: The numerical probe locations for capturing ammonia concentrations over time for the scenario of ammonia release from a vent mast, as shown from different perspectives.

Figure 18 shows the ammonia concentration time histories as captured from Probe1 and Probe2. Probe1 captured an ammonia concentration as high as 15,000 ppm. This high concentration could be taken as a pre-warning for fire and explosion. Such high concentration occurred also because Probe1 happened to be close to the centreline of the plume. On the other hand, Probe2 registered quite low concentrations, invariably below 100 ppm. Those levels of ammonia concentration do not signify risks of fire and explosion but would certainly raise safety or health concerns. Shortly after the termination of the release, which was at 300 s, the ammonia concentrations at Probe1 and Probe2 dropped to zero.

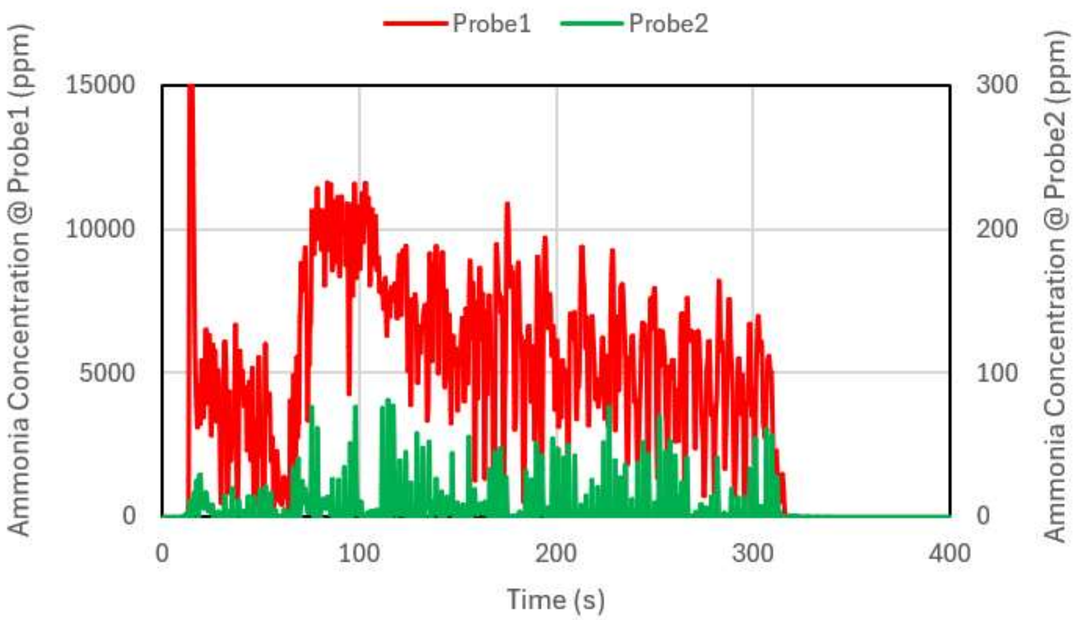


Figure 18: The ammonia concentration time histories as captured at Probe1 and Probe2 for the scenario of ammonia released from a vent mast on the vessel.

3.3 Ammonia Accidental Releases in the Engine Room

Due to the complex setting and the variety of equipment in the engine room (referred to as E/R hereinafter), the risks caused by an accidental leakage of ammonia, such as one in a fuel line, can be high. The present section aims to show study cases that could demonstrate the potential range of ammonia dispersion and the associated concentration distributions in the E/R in case of such incidents. The CFD model and results can be expanded to investigate the consequence of a broader variety of leakage conditions.

3.3.1 Case Conditions and CFD Model Setup

To make this scenario general, a generic E/R layout from a generic vessel, which could be a bulk carrier, tanker, or container carrier, was modelled using CFD. The modelled space of the E/R extended four deck levels from the bottom of the main engine to a virtual top surface where ventilated air continued to move up. In the actual setting of the E/R, there is a wide variety of details, such as the main engine, pumps, piping, boiler, genset and auxiliary engines. For simplicity, the CFD model only included the main pieces that would interfere with the ammonia plume. Figure 19 shows an illustration of the main geometrical parts including the deck floors considered in the CFD model.

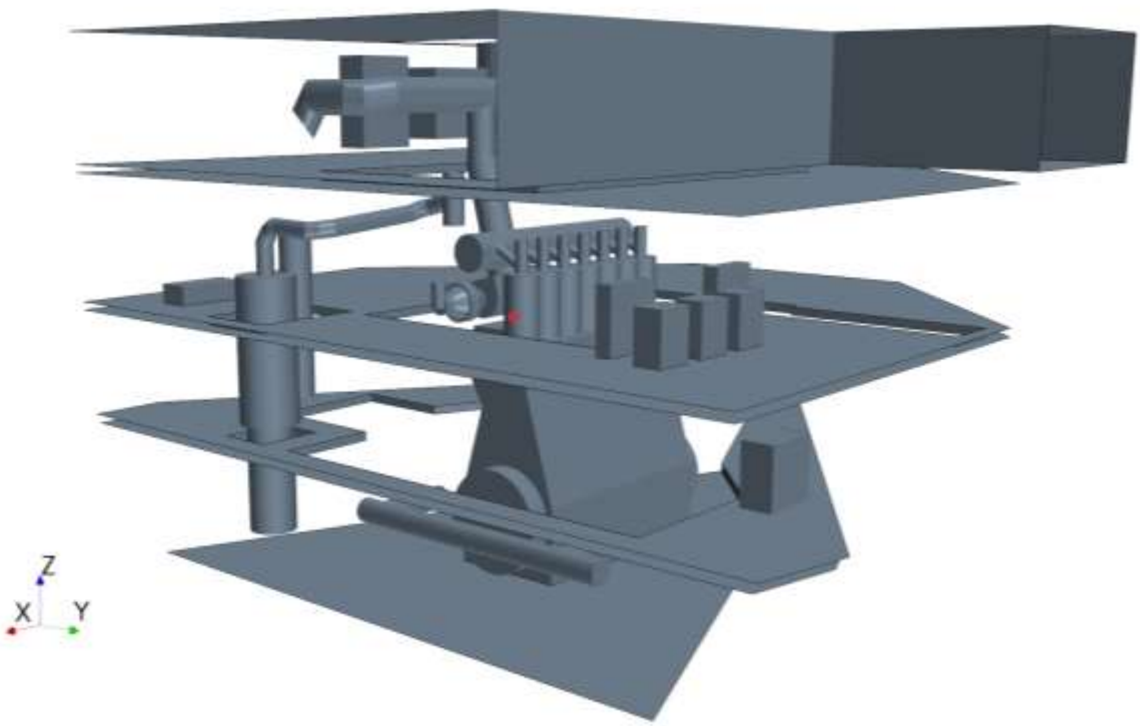


Figure 19: The illustration of the main geometrical parts of the E/R.

The accidental leakage of ammonia fuel was assumed to occur from a fuel supply line on the third deck, about 1 m away from the main engine (the red dot in Figure 19), due to a rupture. The rupture caused a circular hole with a diameter of 2 mm in the fuel line. The liquid ammonia fuel in the fuel line had a pressure of 80 barg and a temperature of 40°C before the leakage occurred. As soon as the rupture hole formed, the ammonia, assumed to be fully gaseous and at the temperature of -33°C, would be released through the small hole at a local sonic speed. The CFD simulation starts at the leakage behind the rupture hole. The resulting mass flux rate of the gaseous ammonia through the rupture hole was estimated to be 0.2313 kg/s. This mass flow rate was assumed to be constant during the time of leakage. The leakage direction was assumed to be horizontal and obliquely toward the main engine, making an angle of 45 degrees with the latter, to create one of the worst cases for gas safety in the E/R. The leakage duration was assumed to last for 150 s[10] before any emergency measure was taken. The ventilation of the four-deck E/R space was set to be a normal value of 30 Air Changes per Hour (ACH) before and after the leakage occurred. The main direction of ventilation was from all lower decks to the top of the fourth deck. Moreover, the air intake through the turbocharger of the main engine was also considered. The volumetric flow rate through the turbocharger was assumed to be 17.8 m^3/s, corresponding to a 25% engine load. More detail about the air flow patterns driven by the ventilation is shown in Figure 22. The ambient air flow had a constant and uniform temperature of 25°C prior to the ammonia leakage.

[10] 150 s is the normal reaction time in the engine room after the leakage, which is critical for human safety.

The CFD computational domain as well as the boundary condition types for each face represented by different colours is shown in Figure 20.

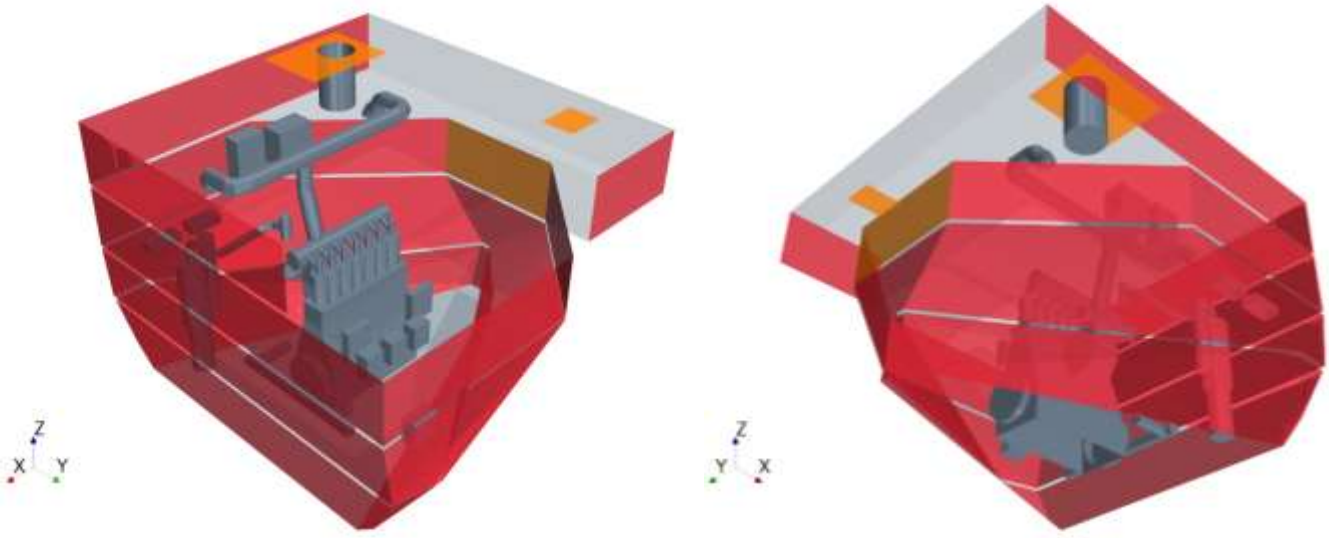


Figure 20: The computational domain for the scenario of ammonia leakage in an E/R. The boundary colours: red for the inlet boundary condition; orange for the outlet boundary condition; grey for solid walls (light grey for deck floors; dark grey for machinery and equipment).

Figure 21 shows the computational mesh of this CFD model on various virtual sections. The mesh was refined near the leakage point and the near field of the plume to capture the initial development of the plume. Prism layers were used around solid surfaces to capture the detailed near-wall flow. The total mesh number of the entire computational mesh is about 12 million.

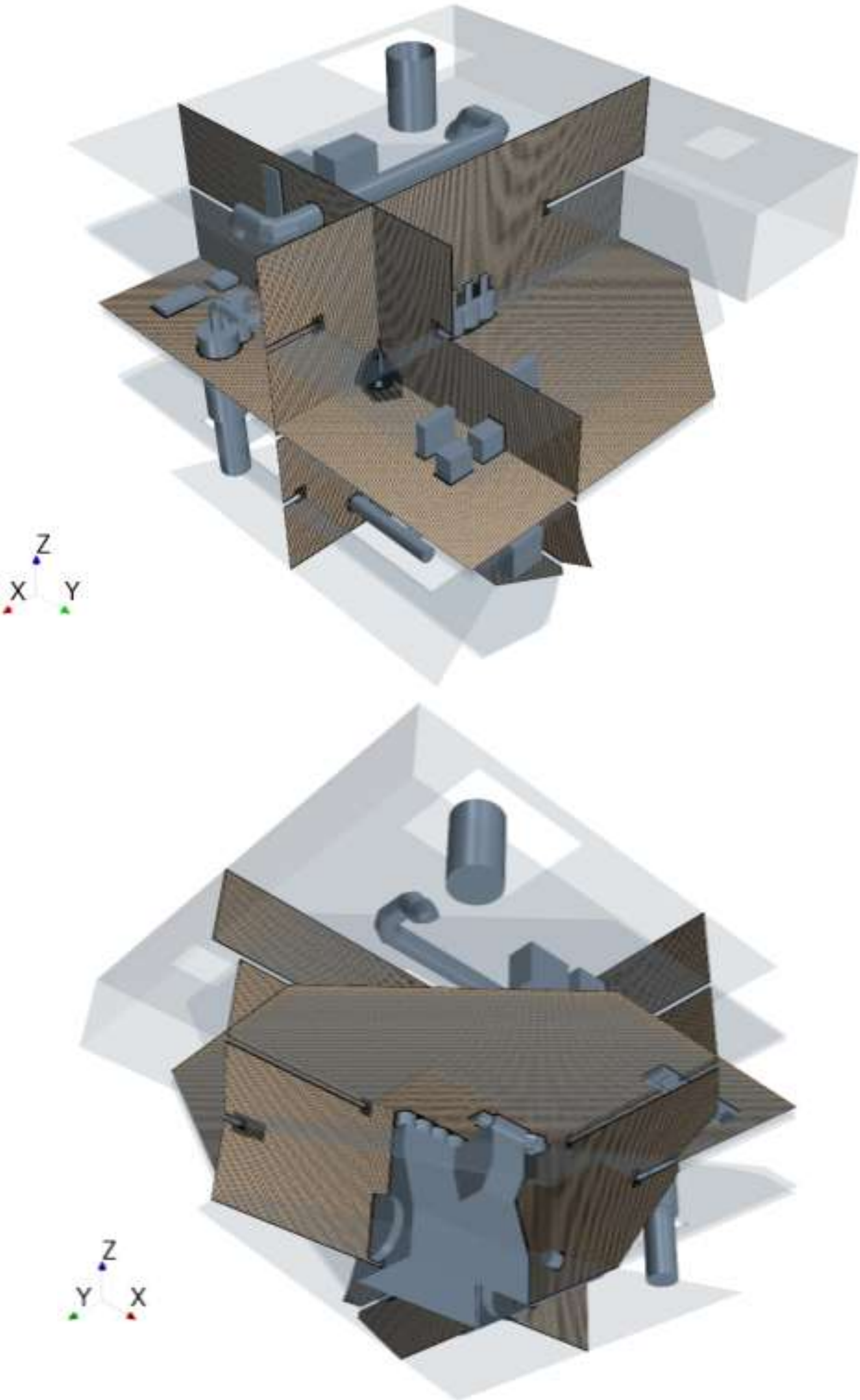
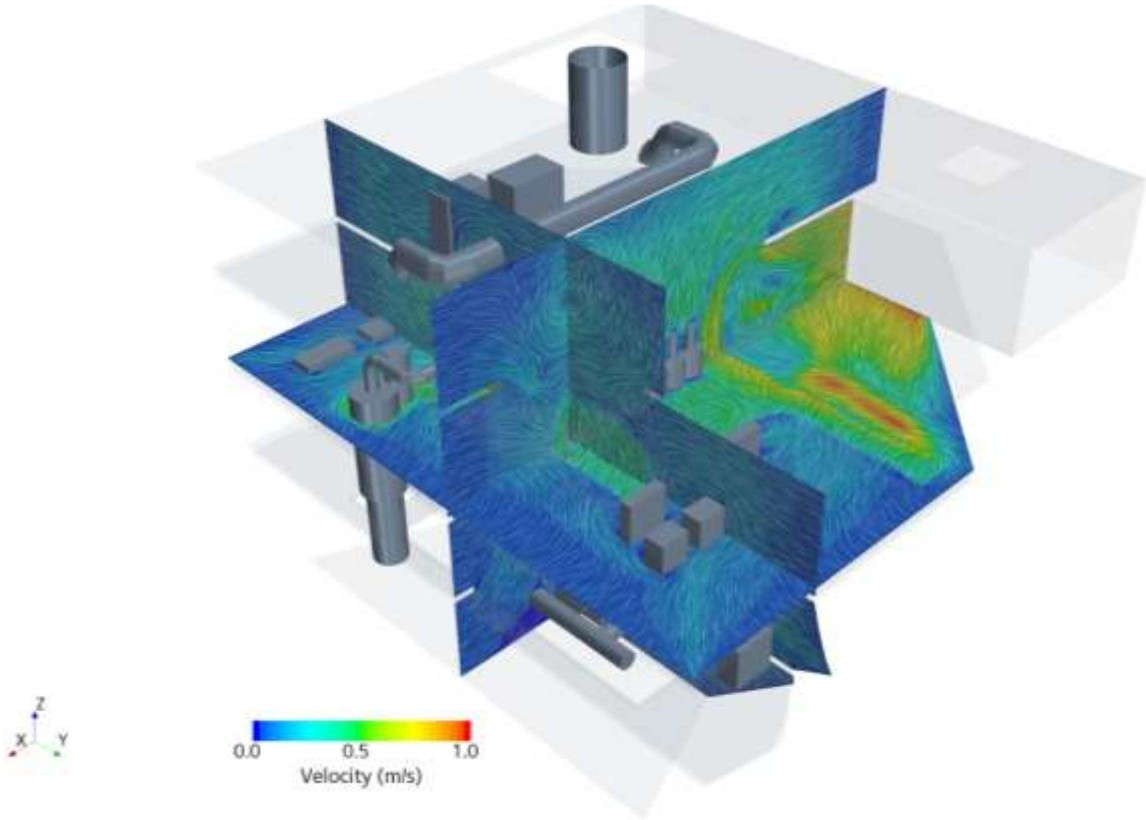
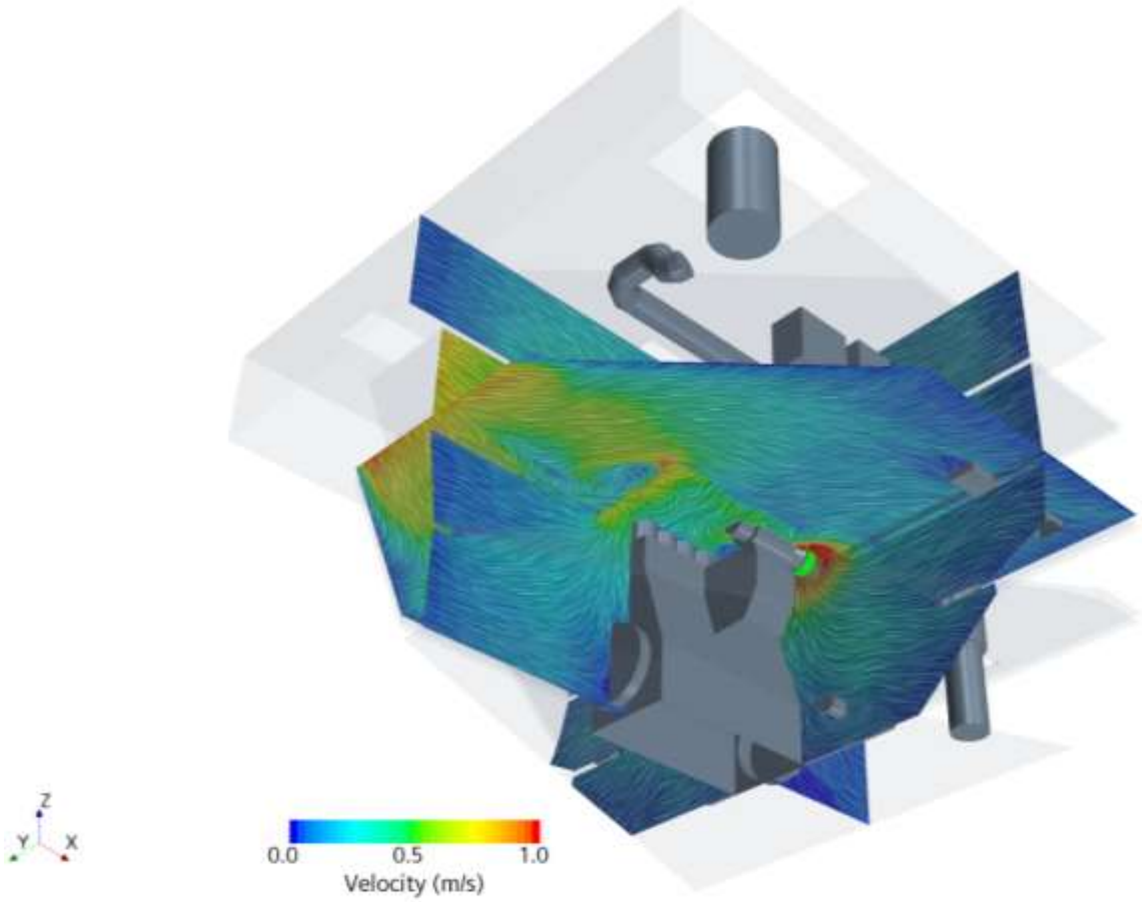


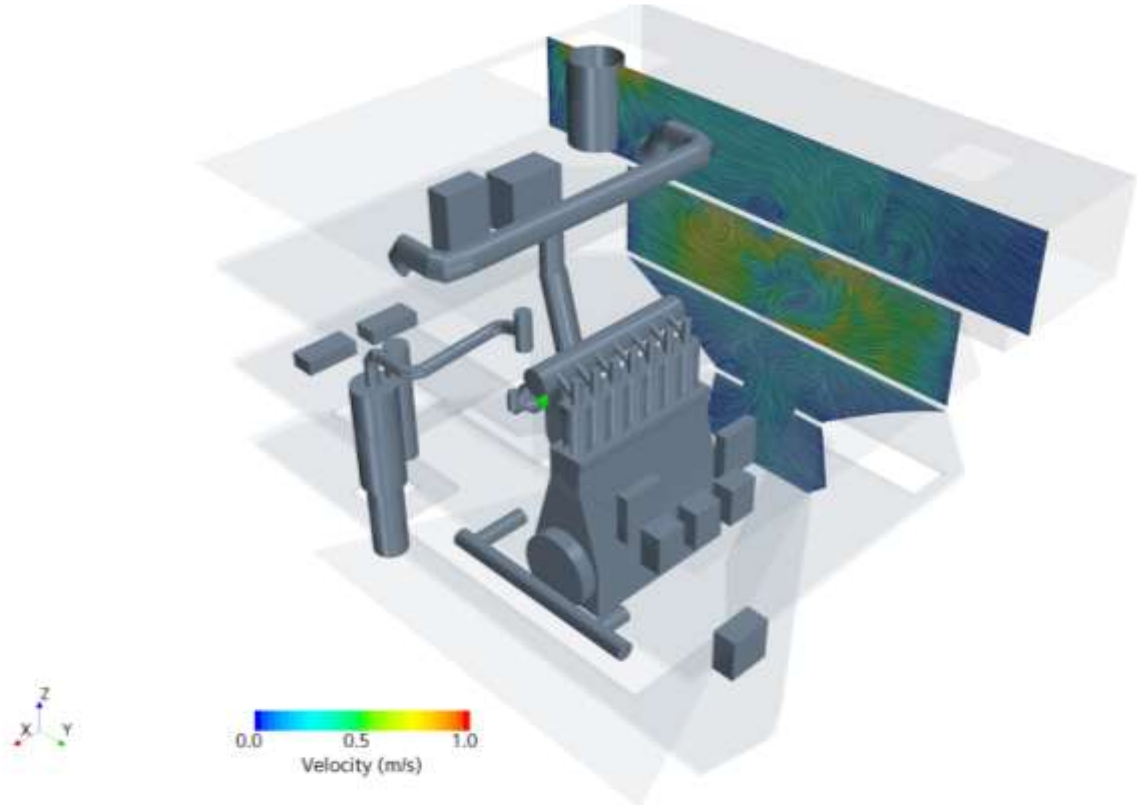
Figure 21: Computational mesh for the scenario of ammonia leakage in a vessel E/R.

3.3.2 Simulation Results

A steady-state air flow field with no ammonia release was first obtained based on the ventilation pattern and rate. The steady-state air velocity field (both magnitude and direction) is shown on various virtual sections and from various angles in Figure 22. The sectional planes in the first two subfigures go through the leakage point. The sectional planes in the next two subfigures go through the centre of the pressure outlet boundary on the top face of the computaional domain. It can be clearly seen that the air flow tended to accelerate in multiple parts of the E/R.




Z
Y
X
0.0
0.5
1.0
Velocity (m/s)


Z
X
Y
0.0
0.5
1.0
Velocity (m/s)

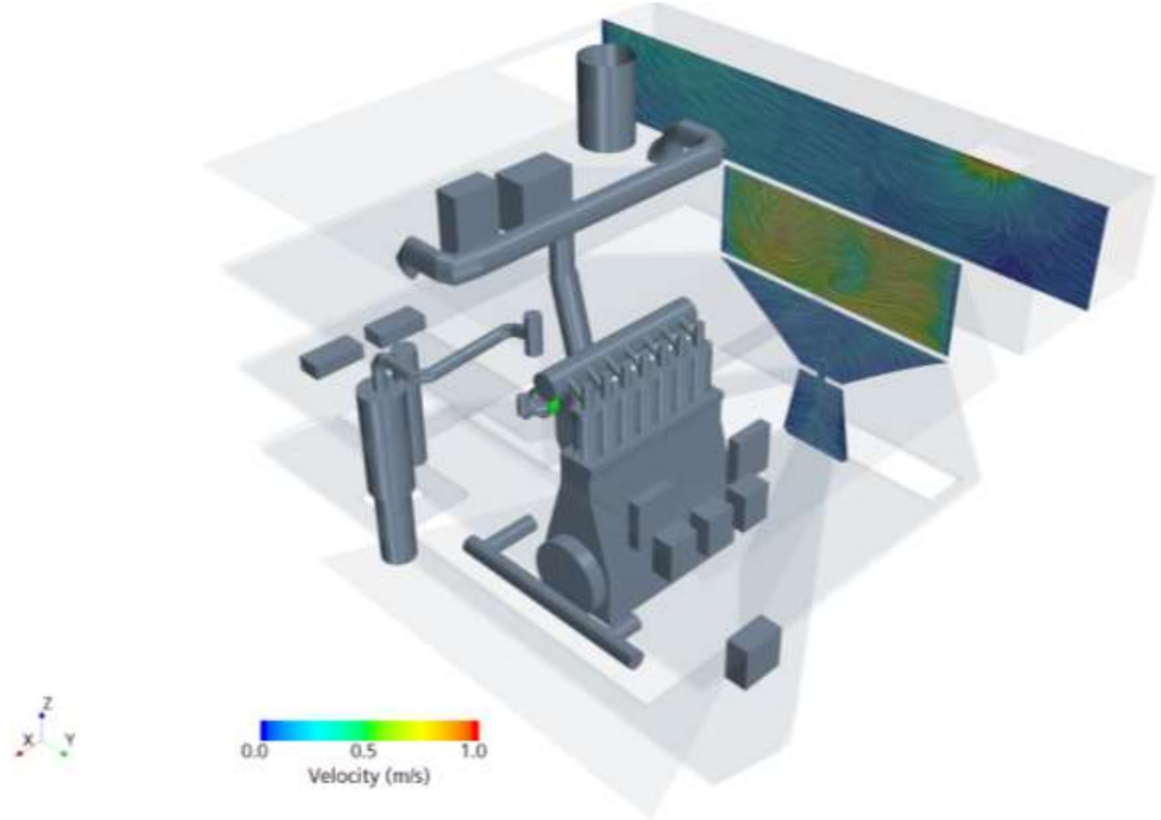
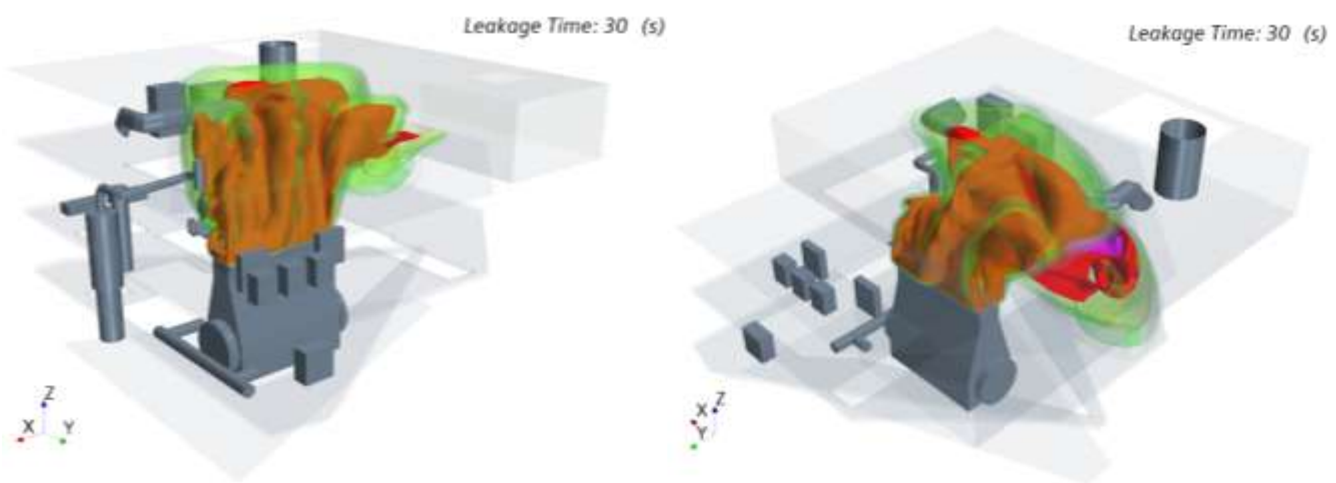
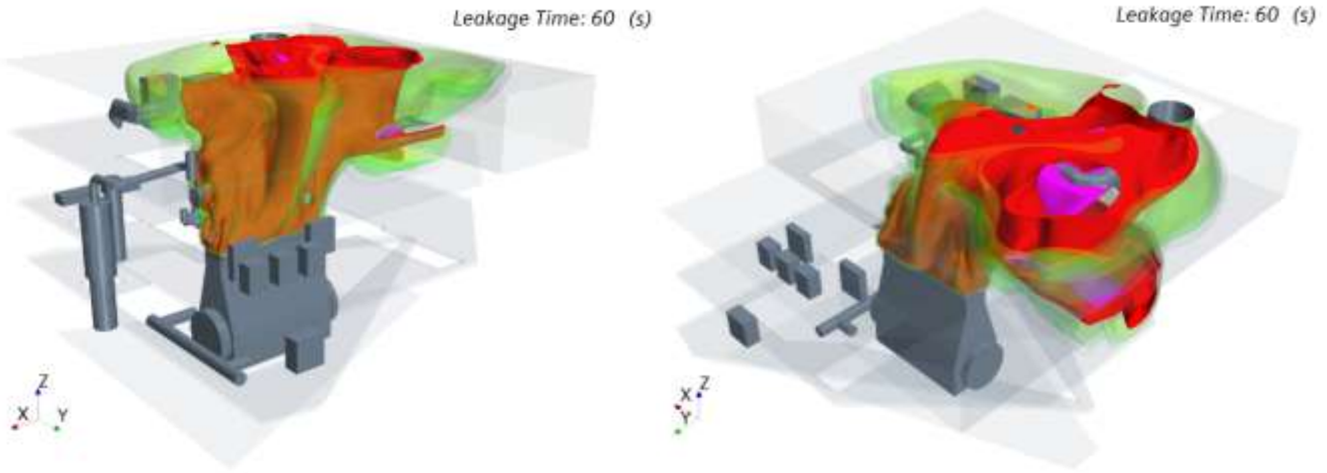


Figure 22: The steady-state air flow field in the E/R as shown on various virtual sections and from various angles for the scenario of ammonia leakage in a vessel E/R. The light green ring on the marine engine indicates the air inlet of the turbocharger.

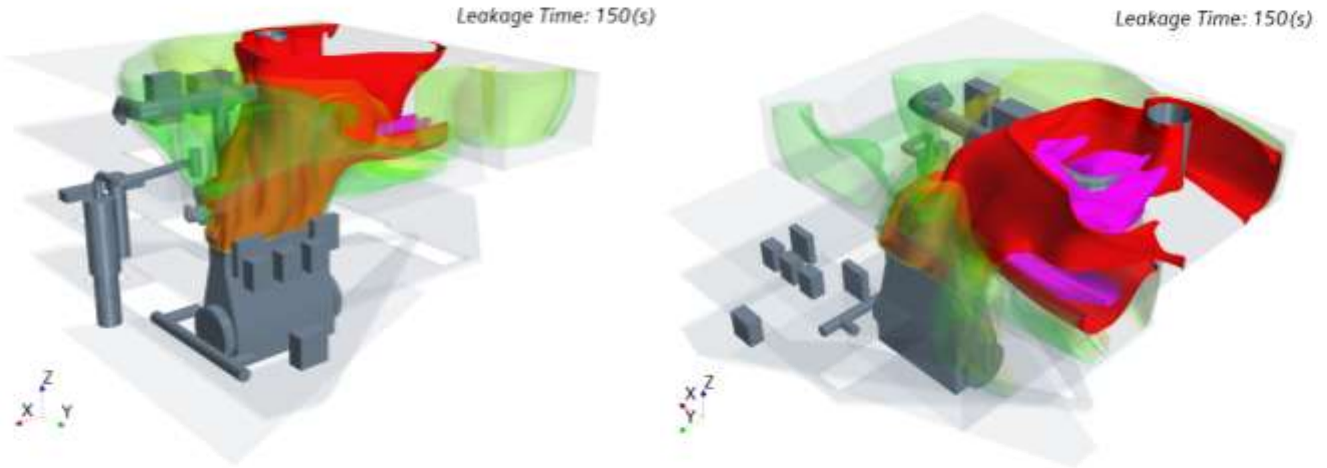
Figure 23 shows the evolution of ammonia plume over time in the E/R. The grey, green, yellow, red and magenta colours represent the ammonia concentrations of 25, 160, 1,000, 15,000, and 75,000 ppm, respectively. This colour scheme is also mentioned in the caption under the pictures. After the ammonia was released, the plume carried its initial momentum but was also advected upward by the ambient air flow. The consequence of this release included 1) negligible ammonia reaching the lowest two deck levels and 2) high ammonia concentrations could appear underneath the deck floors or at corners where ventilation was not effective. The latter is most evident between 60 and 200 s from the initial release (Figure 23(b-d)). The accumulated ammonia in those dead zones (i.e., spaces underneath deck floors or near corners) was gradually diluted and dispersed after the shut-off of the leakage at 150 s. It took an extra 250 – 300 s (i.e., until time = 400 – 450 s) for the lowest concentration level, 25 ppm, to fully disappear in the entire E/R.



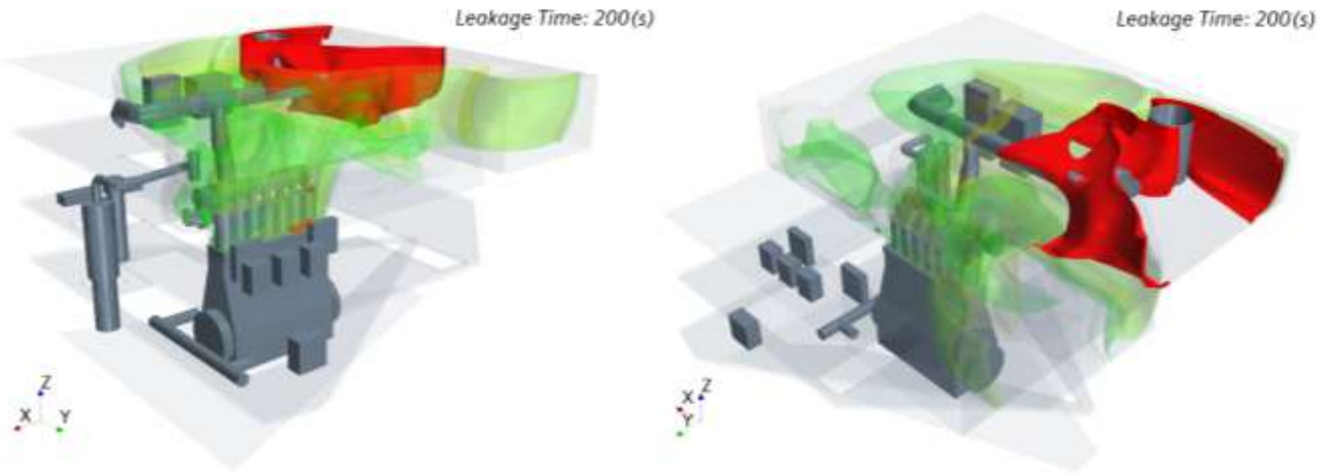
(a) time = 30 s



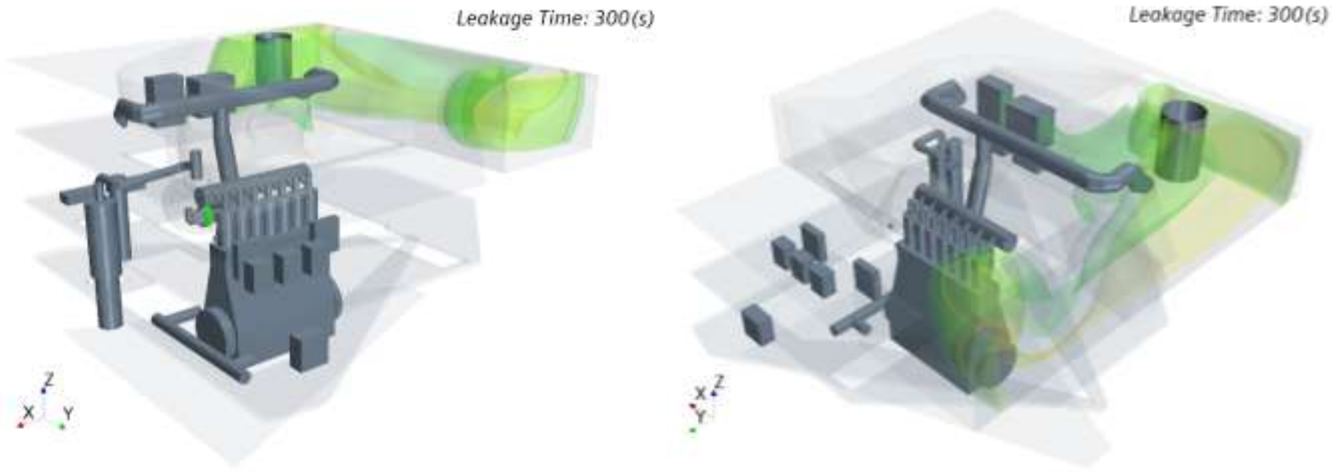
(b) time = 60 s



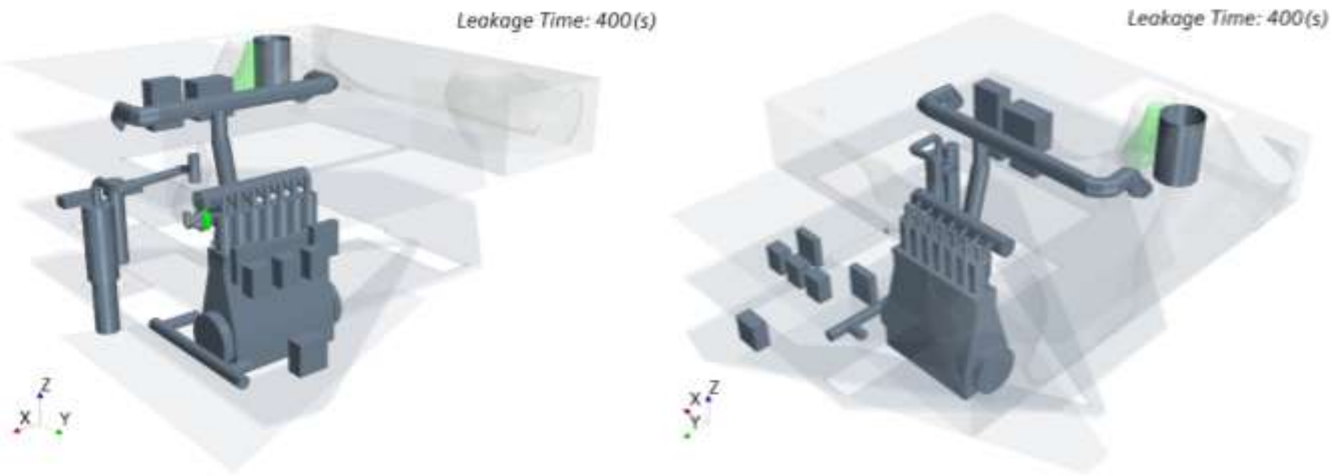
(c) time = 150 s; the leakage was closed at this moment



(d) time = 200 s



(e) time = 300 s



(f) time = 400 s

Figure 23: The evolution of the ammonia plume over time following the initial release of the ammonia in the vessel E/R. The contour colours: grey for 25 ppm, green for 160 ppm, yellow for 1,000 ppm, red for 15,000 ppm, and magenta for 75,000 ppm.

Figure 24.Evidently, the entire event was comprised of three different phases. The first phase is the first 30 s, where the ammonia mass increased almost linearly because the ammonia input from the leakage point was at a constant rate and there had been no ammonia exiting the E/R. The second phase started as the ammonia plume reached the outlets. The total ammonia mass retained in the E/R levelled off and remained at nearly a constant value (between 70 and 150 s) because the input and output rates were close to one another. The third phase started after the leakage was closed at 150 s, during which the total mass of ammonia in the E/R experienced a rapid decay toward zero (between 150 and 500 s).

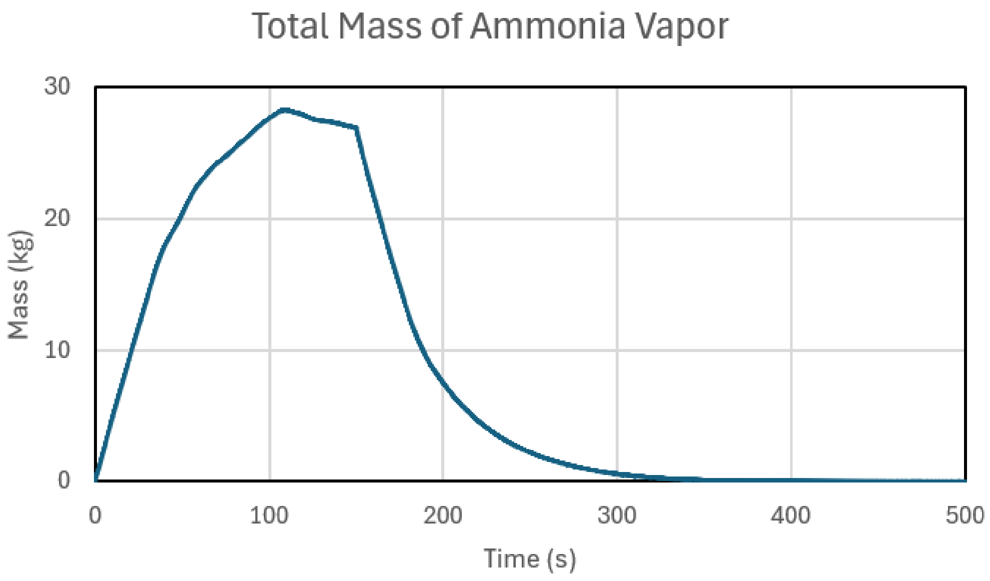


Figure 24: The time history of total mass of ammonia vapour retained in the E/R.

To evaluate the ammonia concentration at fixed locations, six numerical probes were placed at selected locations in this four-decked E/R. Because the main direction of dispersion was upward, four probes were placed on the fourth deck and the remaining two probes were placed on the third deck, respectively. Table 9 lists the coordinates of the probe locations, where x is the longitudinal direction, y is the offset in the transverse direction and z denotes the vertical direction. Figure 25 illustrates those locations. The probe "P-L4-2" can't been seen in the second picture because it locates between two structures on the 4th deck. The green point in Figure 25 is the origin of the Cartesian coordinate system which is the intersection of the centre line longitudinal plane, the transverse plane at midship and the horizontal plane at the base line. Instantaneous ammonia concentrations were recorded at each probe throughout the simulation time.

The durations of exposure for different concentration levels were calculated and shown in Figure 26 as an indicator of the actual exposure of a person to ammonia. For example, at the location "P-L4-1" and "P-L4-2", the actual, total exposure times for the concentration level of 1,000 ppm were 150 and 205 s, respectively. The probe "P-L3-1" was able to capture ammonia concentrations up to 20,000 ppm, as it was positioned directly downstream of the ammonia jet. On the other hand, the probe "P-L3-2" recorded a near-zero ammonia concentration level. For the probes on the fourth deck, the highest ammonia concentration captured was about 9,000 ppm, which was at "P-L4-2".Compared to the wide range of the concentration contour of 15,000 ppm on the fourth deck, as shown in Figure 23, the concentrations captured by the four point probes (or, in practice, point gas detectors) could significantly underestimate the impact of an ammonia release. Since the LFL of 160,000 ppm was not achieved throughout the simulation, there was no ignition in this E/R space.

Table 9: Probe positions in a cartesian coordinate system for the scenario of ammonia accidental releases in the E/R

Probe	x (m)	y (m)	z (m)
P-L3-1	27.75	-0.13	14.39
P-L3-2	17.75	2.37	12.89
P-L4-1	11.02	7.45	18.80
P-L4-2	16.68	-11.51	18.01
P-L4-3	26.43	4.73	17.80
P-L4-4	18.43	4.73	17.80

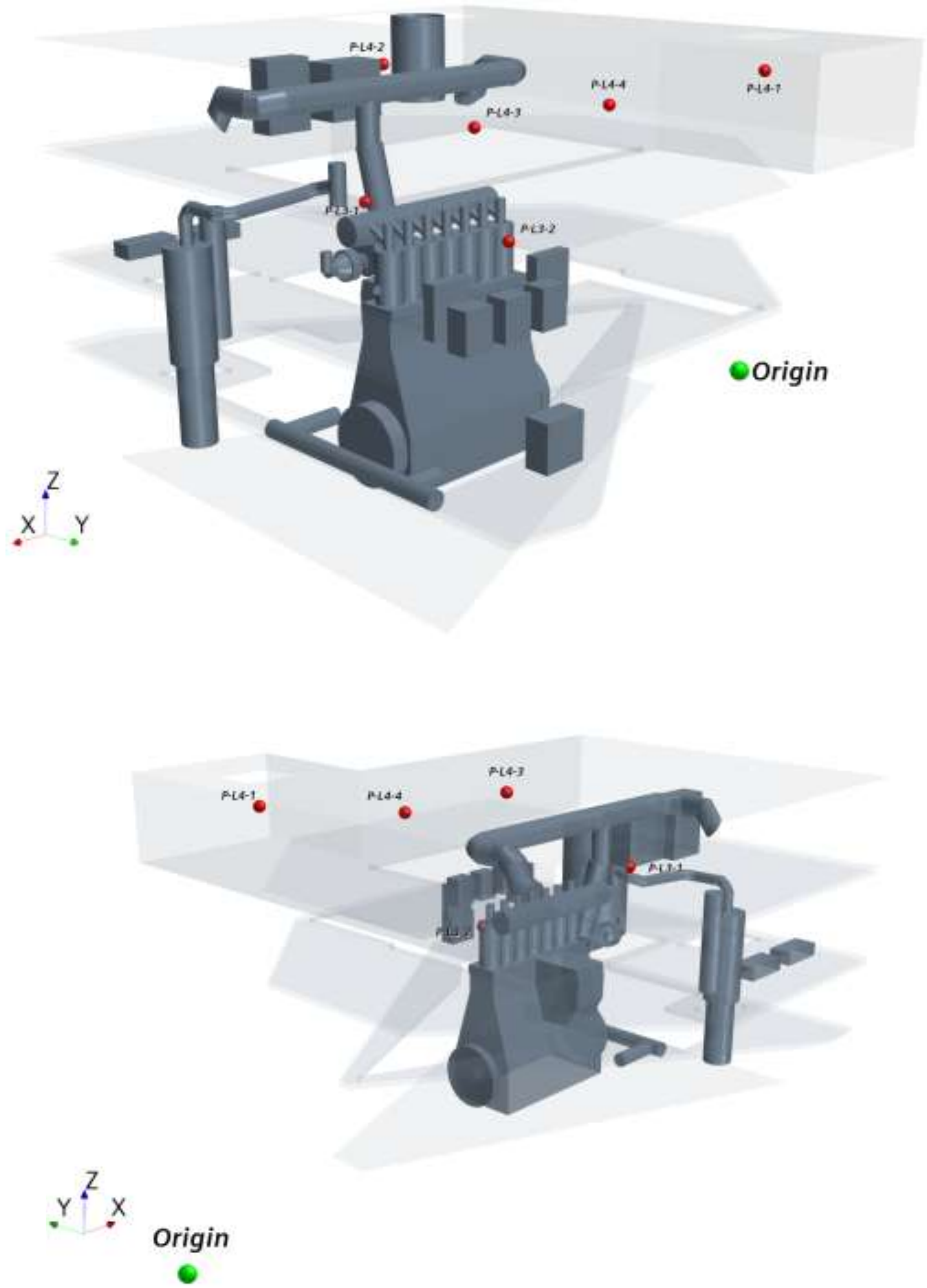


Figure 25: Numerical probe layout for capturing local ammonia concentrations in the E/R.

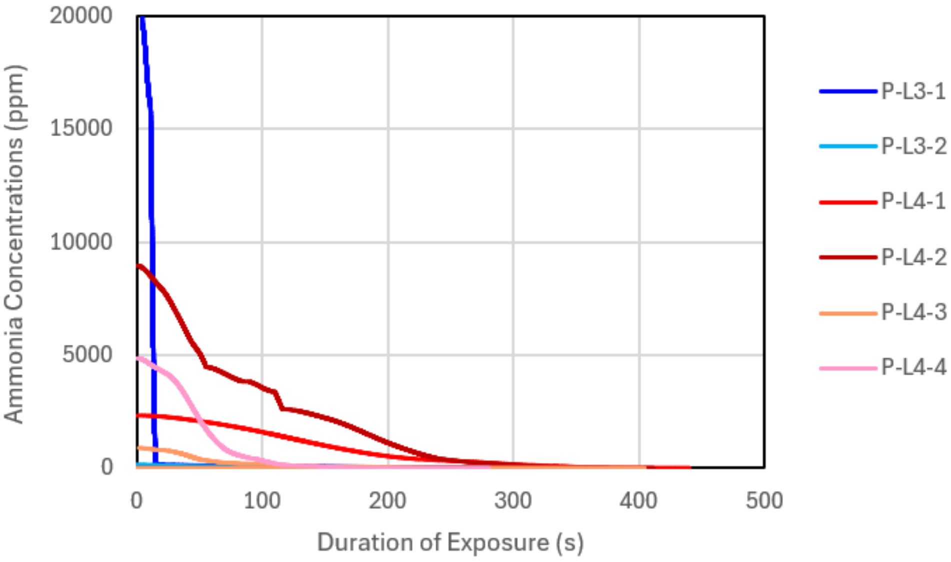
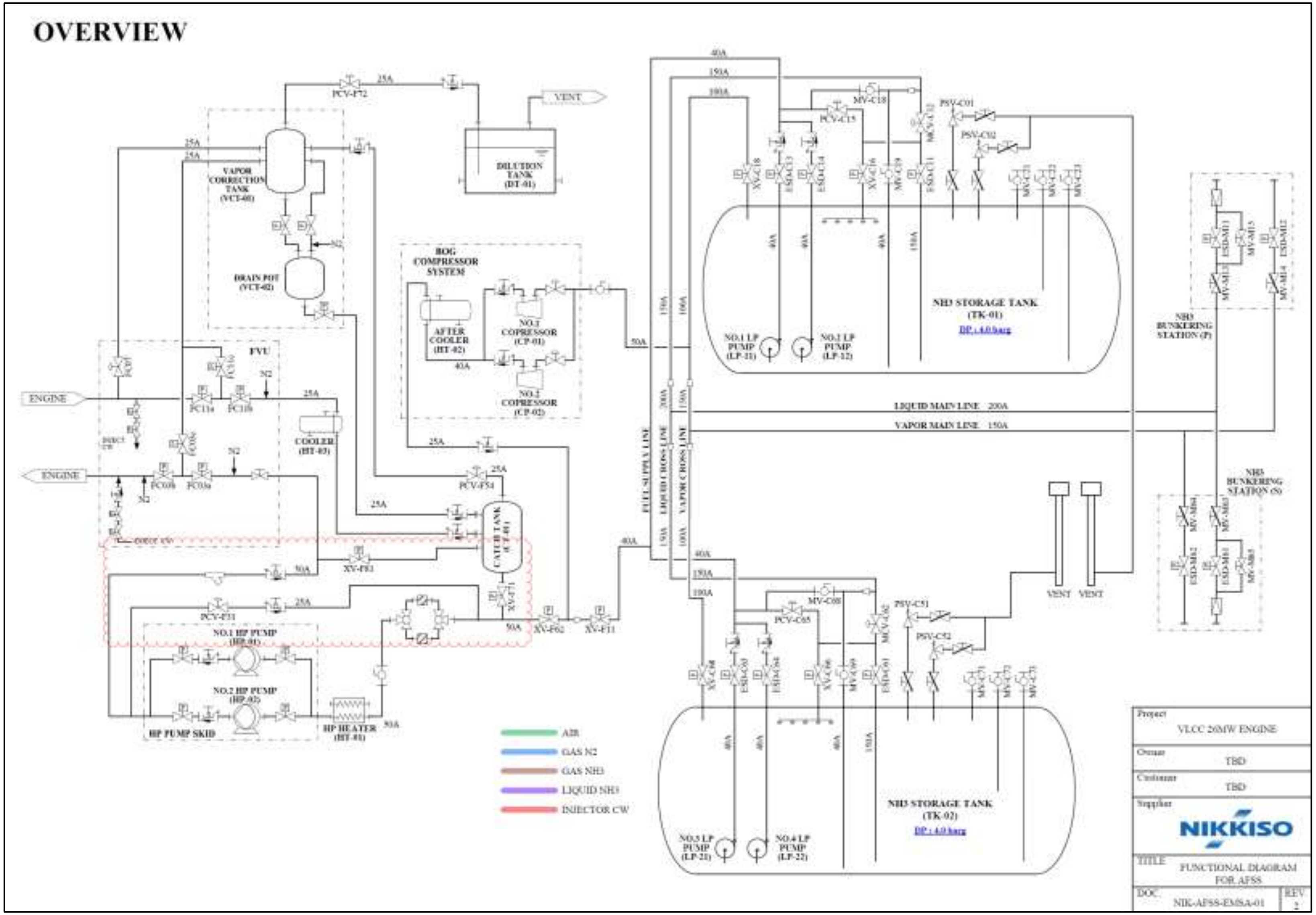
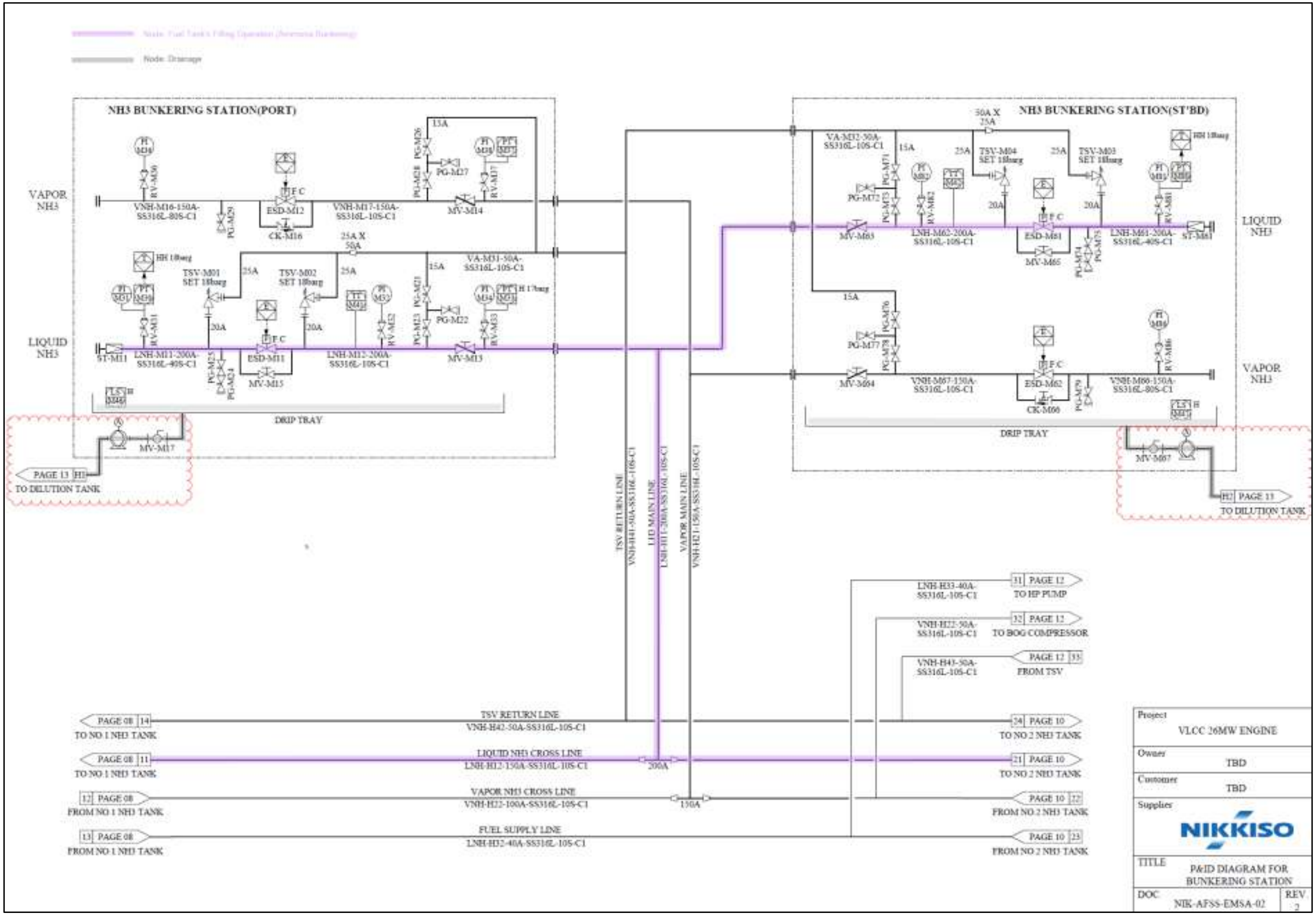
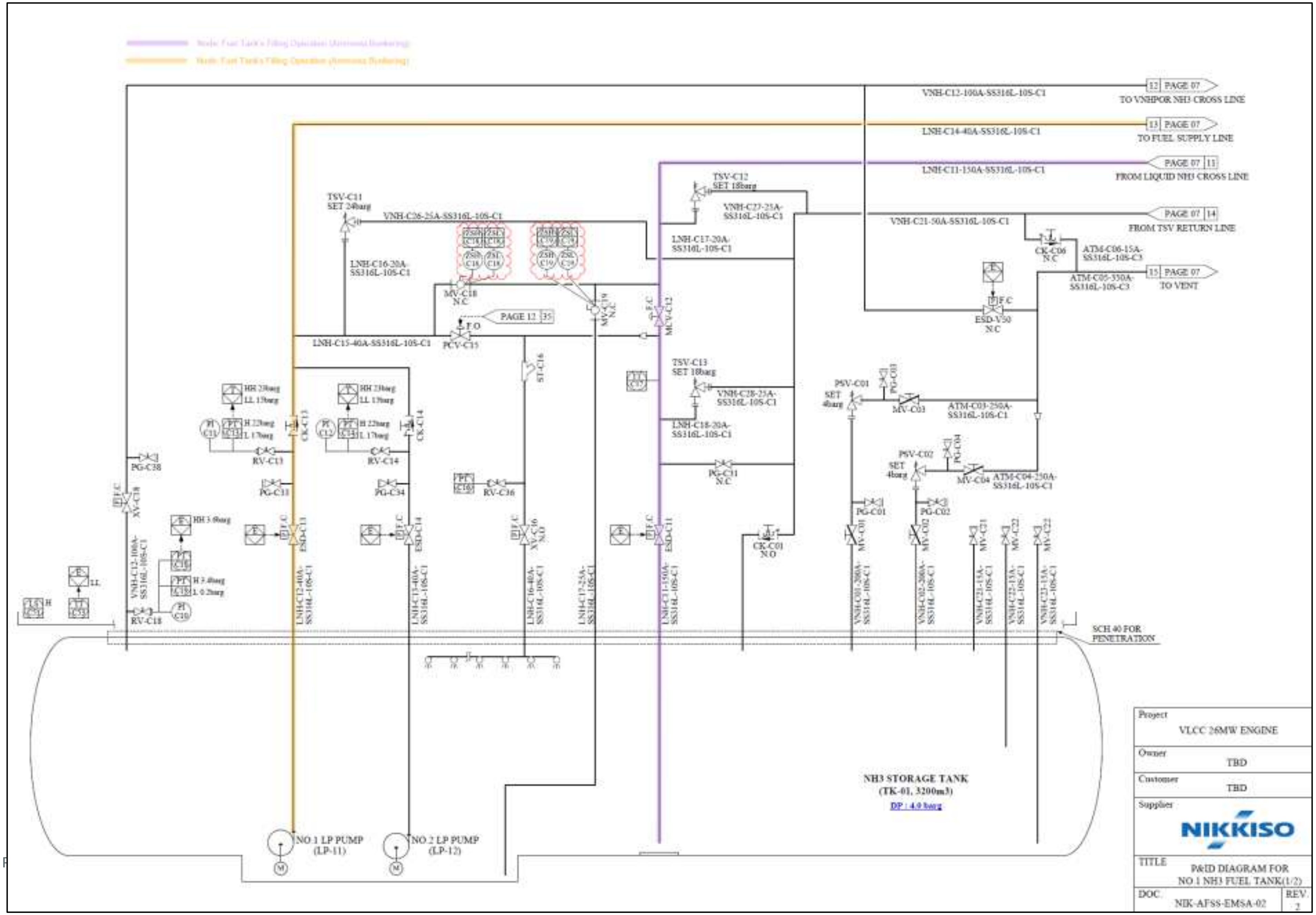


Figure 26: The duration of exposure for different ammonia concentration levels as captured by the six numerical probes positioned at various locations in the E/R.

Appendix A Process Flow Diagram and Marked-up P&IDs




Node: Drainage
NH3 BUNKERING STATION(PORT)
NH3 BUNKERING STATION(ST'BD)
VAPOR NH3
LIQUID NH3
VNH-M16-150A-SS316L-80S-C1
VNH-M17-150A-SS316L-10S-C1
ESD-M12
CK-M16
MV-M14
PG-M27
VA-M31-50A-SS316L-10S-C1
TSV-M01 SET 18barg
TSV-M02 SET 18barg
LNH-M11-200A-SS316L-40S-C1
LNH-M12-200A-SS316L-10S-C1
ESD-M11
MV-M15
MV-M13
PG-M22
ST-M11
DRIP TRAY
MV-M17
PAGE 13
TO DILUTION TANK
VA-M32-50A-SS316L-10S-C1
TSV-M04 SET 18barg
TSV-M03 SET 18barg
MV-M03
LNH-M62-200A-SS316L-10S-C1
ESD-M01
MV-M65
LNH-M61-200A-SS316L-40S-C1
ST-M61
PG-M72
PG-M77
MV-M64
VNH-M67-150A-SS316L-10S-C1
ESD-M62
CK-M66
VNH-M66-150A-SS316L-80S-C1
MV-M07
TSV RETURN LINE
LIQ MAIN LINE
VAPOR MAIN LINE
LNH-H33-40A-SS316L-10S-C1
PAGE 12
TO HP PUMP
VNH-H22-50A-SS316L-10S-C1
TO BOG COMPRESSOR
VNH-H43-50A-SS316L-10S-C1
FROM TSV
TSV RETURN LINE
VNH-H42-50A-SS316L-10S-C1
LIQUID NH3 CROSS LINE
LNH-H12-150A-SS316L-10S-C1
VAPOR NH3 CROSS LINE
VNH-H22-100A-SS316L-10S-C1
FUEL SUPPLY LINE
LNH-H32-40A-SS316L-10S-C1
PAGE 08
TO NO 1 NH3 TANK
FROM NO 1 NH3 TANK
PAGE 10
TO NO 2 NH3 TANK
FROM NO 2 NH3 TANK
200A
150A
Project
VLCC 26MW ENGINE
Owner
TBD
Customer
TBD
Supplier
NIKKISO
TITLE
P&ID DIAGRAM FOR BUNKERING STATION
DOC
NIK-AFSS-EMSA-02
REV


VNH-C12-100A-SS316L-10S-C1
PAGE 07
TO VNHPOR NH3 CROSS LINE
LNH-C14-40A-SS316L-10S-C1
TO FUEL SUPPLY LINE
LNH-C11-150A-SS316L-10S-C1
FROM LIQUID NH3 CROSS LINE
TSV-C12
SET 18barg
VNH-C27-25A-SS316L-10S-C1
VNH-C21-50A-SS316L-10S-C1
FROM TSV RETURN LINE
TSV-C11
SET 24barg
VNH-C26-25A-SS316L-10S-C1
LNH-C17-20A-SS316L-10S-C1
CK-C06
N.C
ATM-C06-15A-SS316L-10S-C3
LNH-C16-20A-SS316L-10S-C1
ATM-C05-350A-SS316L-10S-C3
TO VENT
MV-C18
N.C
PAGE 12
F.O
ESD-V50
N.C
LNH-C15-40A-SS316L-10S-C1
PCV-C15
ST-C16
TSV-C13
SET 18barg
VNH-C28-25A-SS316L-10S-C1
LNH-C18-20A-SS316L-10S-C1
PSV-C01
SET 4barg
MV-C03
ATM-C03-250A-SS316L-10S-C1
PSV-C02
SET 4barg
MV-C04
ATM-C04-250A-SS316L-10S-C1
HH 23barg
LL 13barg
H 22barg
L 17barg
RV-C13
RV-C14
PG-C38
PG-C13
PG-C34
RV-C36
PG-C11
N.C
PG-C01
PG-C02
HH 3.4barg
H 3.4barg
L 0.2barg
RV-C18
CK-C01
N.O
SCH 40 FOR PENETRATION
NH3 STORAGE TANK
(TK-01, 3200m3)
DP : 4.0 barg
NO.1 LP PUMP
(LP-11)
NO.2 LP PUMP
(LP-12)
Project
VLCC 26MW ENGINE
Owner
TBD
Customer
TBD
Supplier
NIKKISO
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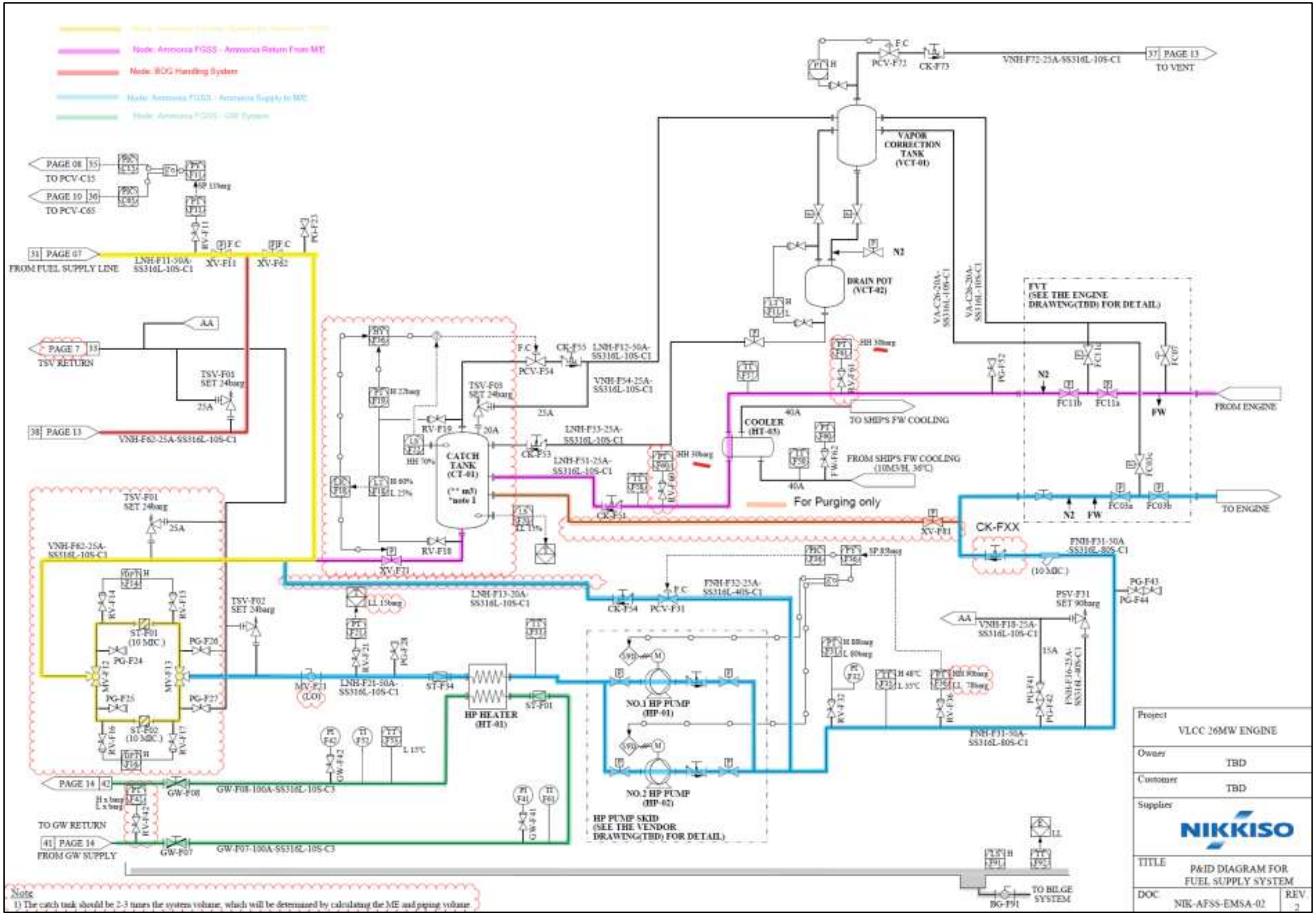
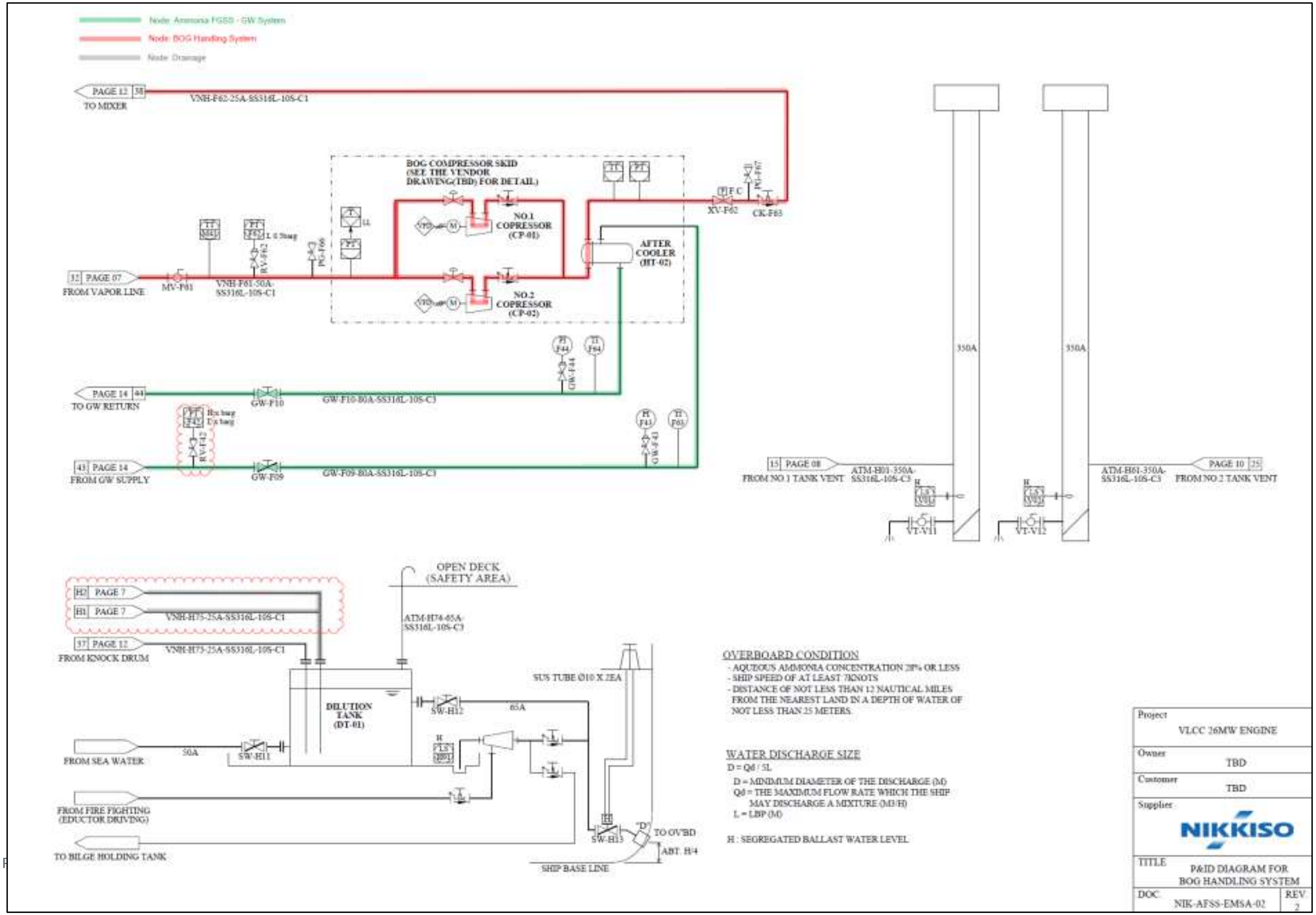
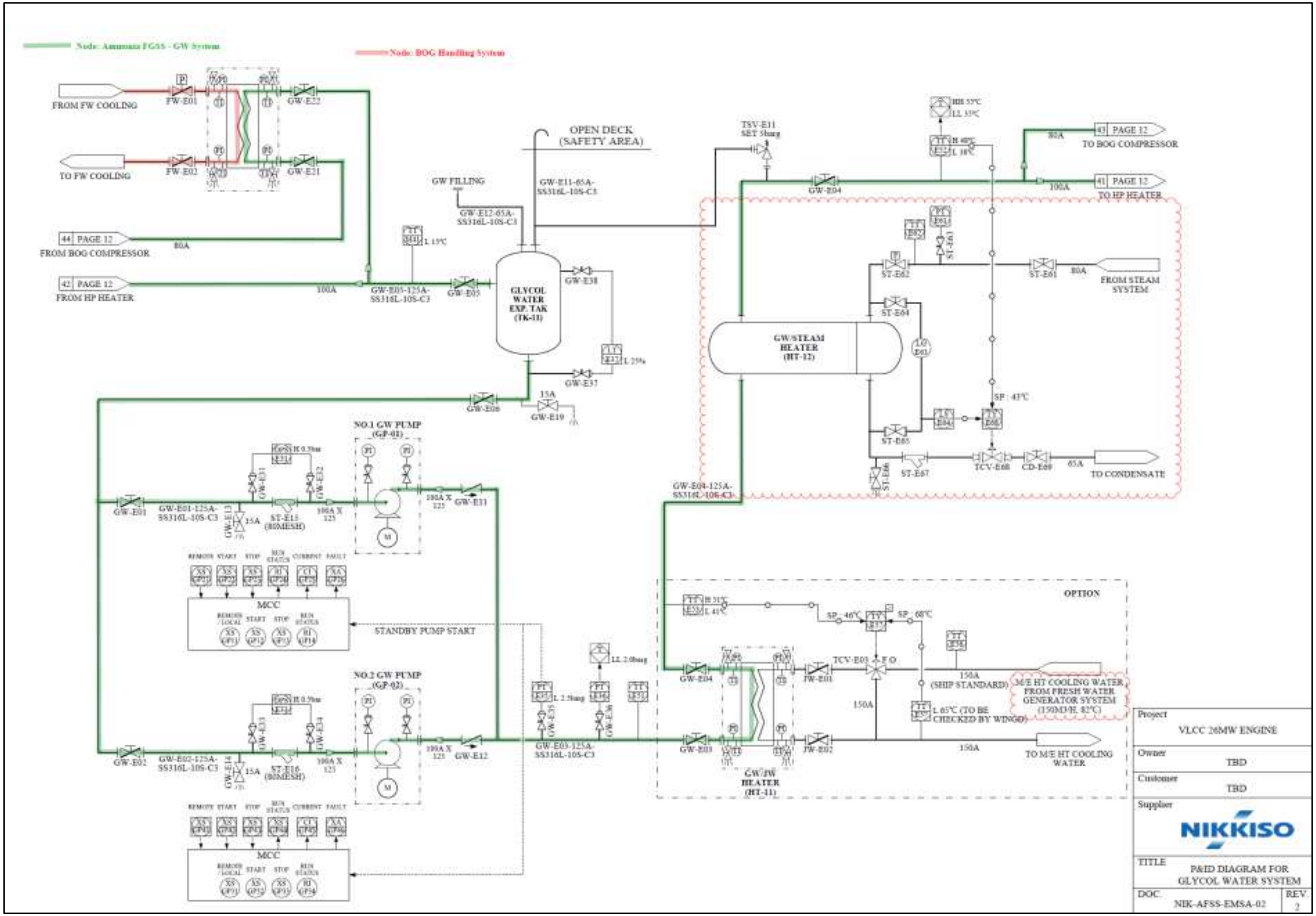
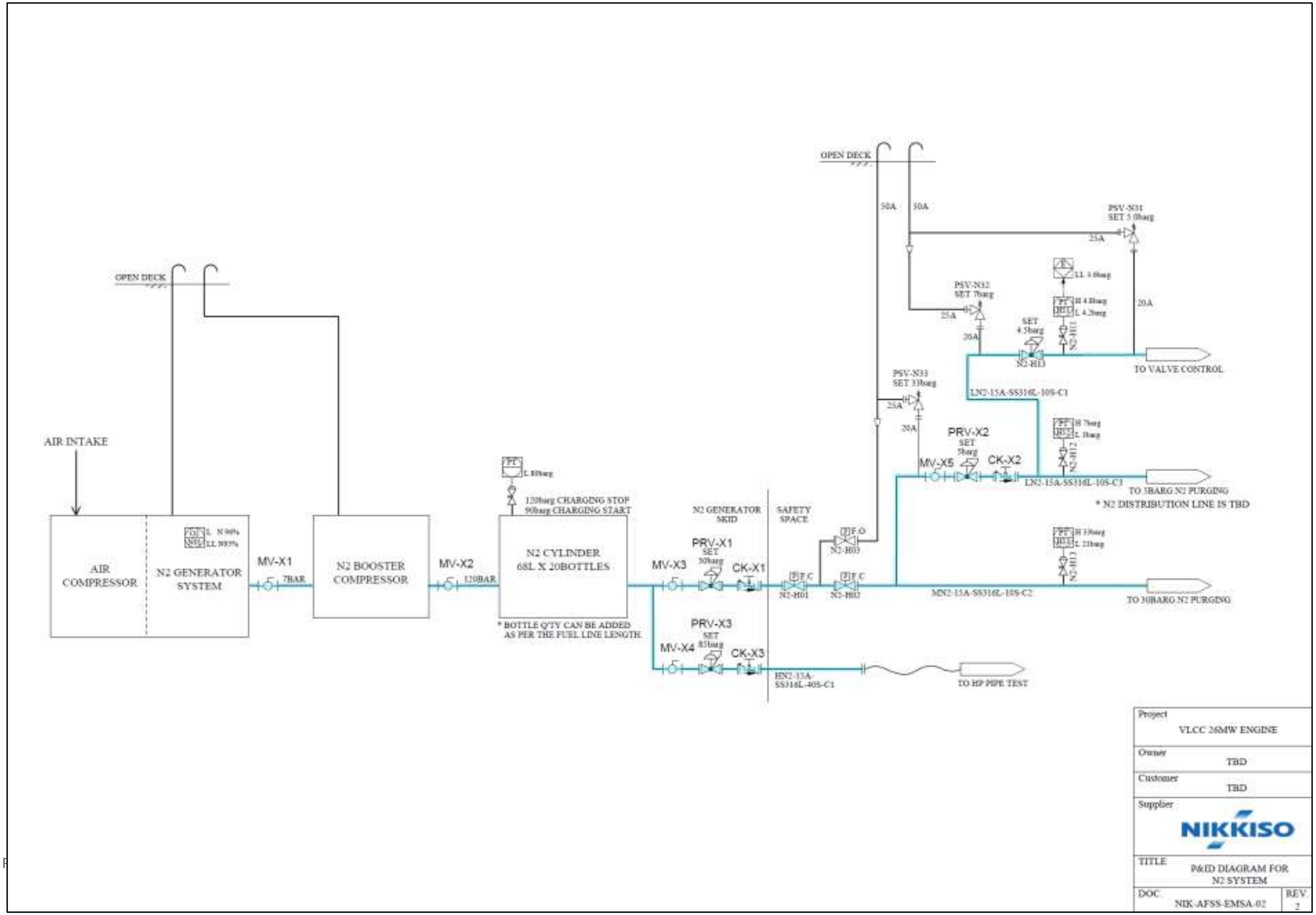
NIK-AFSS-EMSA-02
REV.
2


VAPOR CORRECTION TANK (VCT-01)
DRAIN POT (VCT-02)
CATCH TANK (CT-01)
COOLER (HT-03)
HP HEATER (HT-01)
NO.1 HP PUMP (HP-01)
NO.2 HP PUMP (HP-02)
HP PUMP SKID (SEE THE VENDOR DRAWING(TBD) FOR DETAIL)
FVT (SEE THE ENGINE DRAWING(TBD) FOR DETAIL)
PAGE 13 TO VENT
PAGE 07 FROM FUEL SUPPLY LINE
PAGE 08 TO PCV-C15
PAGE 10 TO PCV-C65
PAGE 7 TSV RETURN
PAGE 13
PAGE 14 TO GW RETURN
PAGE 14 FROM GW SUPPLY
FROM ENGINE
TO ENGINE
TO SHIP'S FW COOLING
FROM SHIP'S FW COOLING
For Purging only
CK-FXX
TO BILGE SYSTEM
Project VLCC 26MW ENGINE
Owner TBD
Customer TBD
Supplier NIKKISO
TITLE P&ID DIAGRAM FOR FUEL SUPPLY SYSTEM
DOC NIK-AFSS-EMSA-02
REV 2
Note
1) The catch tank should be 2-3 times the system volume, which will be determined by calculating the ME and piping volume


Node: Ammonia FGSS - GW System
Node: BOG Handling System
Node: Drainage
PAGE 12 38
TO MIXER
VNH-F62-25A-SS316L-10S-C1
BOG COMPRESSOR SKID
(SEE THE VENDOR
DRAWING(TBD) FOR DETAIL)
NO.1
COPRESSOR
(CP-01)
NO.2
COPRESSOR
(CP-02)
AFTER
COOLER
(HT-02)
XV-F62
CK-F63
32 PAGE 07
FROM VAPOR LINE
MV-F01
VNH-F61-50A-
SS316L-10S-C1
PAGE 14 44
TO GW RETURN
GW-F10
GW-F10-80A-SS316L-10S-C3
43 PAGE 14
FROM GW SUPPLY
GW-F09
GW-F09-80A-SS316L-10S-C3
350A
350A
15 PAGE 08
FROM NO.1 TANK VENT
ATM-H01-350A-
SS316L-10S-C3
ATM-H61-350A-
SS316L-10S-C3
PAGE 10 25
FROM NO.2 TANK VENT
VT-V11
VT-V12
OPEN DECK
(SAFETY AREA)
H7 PAGE 7
H1 PAGE 7
VNH-H75-25A-SS316L-10S-C1
37 PAGE 12
FROM KNOCK DRUM
VNH-H73-25A-SS316L-10S-C1
ATM-H74-65A-
SS316L-10S-C3
DILUTION
TANK
(DT-01)
SW-H12
65A
SUS TUBE Ø10 X 2EA
FROM SEA WATER
50A
SW-H11
FROM FIRE FIGHTING
(EDUCTOR DRIVING)
TO BILGE HOLDING TANK
SW-H13
TO OV'BD
ABT. H/4
SHIP BASE LINE
OVERBOARD CONDITION
- AQUEOUS AMMONIA CONCENTRATION 28% OR LESS
- SHIP SPEED OF AT LEAST 7KNOTS
- DISTANCE OF NOT LESS THAN 12 NAUTICAL MILES
FROM THE NEAREST LAND IN A DEPTH OF WATER OF
NOT LESS THAN 25 METERS.
WATER DISCHARGE SIZE
D = Qd / 5L
D = MINIMUM DIAMETER OF THE DISCHARGE (M)
Qd = THE MAXIMUM FLOW RATE WHICH THE SHIP
MAY DISCHARGE A MIXTURE (M3/H)
L = LBP (M)
H : SEGREGATED BALLAST WATER LEVEL
Project
VLCC 26MW ENGINE
Owner
TBD
Customer
TBD
Supplier
TITLE
P&ID DIAGRAM FOR
BOG HANDLING SYSTEM
DOC
NIK-AFSS-EMSA-02
REV
2


Node: BOG Handling System
FROM FW COOLING
TO FW COOLING
FW-E01
FW-E02
GW-E22
GW-E21
OPEN DECK
(SAFETY AREA)
GW FILLING
PAGE 12
FROM BOG COMPRESSOR
80A
PAGE 12
FROM HP HEATER
100A
GW-E05
GW-E38
GW-E37
GW-E06
GW-E19
15A
GLYCOL WATER EXP. TAK (TK-11)
TSV-E11
GW-E04
PAGE 12
TO BOG COMPRESSOR
PAGE 12
TO HP HEATER
GW/STEAM HEATER (HT-12)
ST-E61
ST-E62
ST-E64
ST-E65
ST-E67
TCV-E68
CD-E69
FROM STEAM SYSTEM
TO CONDENSATE
65A
SP : 43℃
NO.1 GW PUMP (GP-01)
NO.2 GW PUMP (GP-02)
GW-E01
GW-E02
GW-E11
GW-E12
15A
MCC
STANDBY PUMP START
OPTION
SP : 46℃
SP : 68℃
TCV-E03
150A
(SHIP STANDARD)
M/E HT COOLING WATER FROM FRESH WATER GENERATOR SYSTEM
TO M/E HT COOLING WATER
GW-E03
JW-E01
JW-E02
GW/JW HEATER (HT-11)
Project
VLCC 26MW ENGINE
Owner
TBD
Customer
TBD
Supplier
NIKKISO
TITLE
P&ID DIAGRAM FOR GLYCOL WATER SYSTEM
DOC.
NIK-AFSS-EMSA-02
REV.


OPEN DECK
AIR INTAKE
AIR COMPRESSOR
N2 GENERATOR SYSTEM
MV-X1
7BAR
N2 BOOSTER COMPRESSOR
MV-X2
120BAR
N2 CYLINDER 68L X 20BOTTLES
120barg CHARGING STOP
90barg CHARGING START
* BOTTLE QTY CAN BE ADDED AS PER THE FUEL LINE LENGTH
N2 GENERATOR SKID
SAFETY SPACE
MV-X3
PRV-X1
CK-X1
MV-X4
PRV-X3
CK-X3
N2-H01
N2-H02
N2-H03
MN2-15A-SS316L-10S-C2
TO 30BARG N2 PURGING
HN2-15A-SS316L-40S-C1
TO HP PIPE TEST
MV-X5
PRV-X2
CK-X2
LN2-15A-SS316L-10S-C3
TO 5BARG N2 PURGING
* N2 DISTRIBUTION LINE IS TBD
LN2-15A-SS316L-10S-C1
TO VALVE CONTROL
PSV-N31
PSV-N32
PSV-N33
50A
25A
20A
Project
VLCC 26MW ENGINE
Owner
TBD
Customer
TBD
Supplier
NIKKISO
TITLE
P&ID DIAGRAM FOR N2 SYSTEM
DOC
NIK-AFSS-EMSA-02
REV.

Appendix B HAZOP Worksheet

Company: EMSA, YCA, WinGD, Nikkiso, NTUA, ABS		
Title: EMSA NH3		
Description:		
Method: HAZOP	**Type:** Other	General
Design Intent:		
Comment:		

No.: 1	**Description:** General

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
1.1	General			1.1.1. General.					1.1.1. Provide position indicator for valve MV-C18, MV-C19 **Comment:** Converted from Rec 35 (1/24/2025 2:02:35 PM)			33. Operational procedures to include the position of valve MV-C18 131. Pressure transmitter PT-F42 is being used in two locations of the P&ID. Update. 132. Tag numbers of P&ID diagram are to be checked and revised. 133. All drainage valves are to be blank flanged.
1.2	High flow			1.2.1. No additional hazards identified								

No.: 1 | **Description:** General

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
1.3	Low/no flow			1.3.1. High level upstream					1.3.1. Flow indication 1.3.2. Low flow alarm 1.3.3. Differential pressure indication to detect plugging 1.3.4. High differential pressure alarm			
				1.3.2. Blocked pump discharge, resulting in high pressure								
				1.3.3. Low level downstream								
1.4	Reverse flow			1.4.1. Contamination of upstream system					1.4.1. Check valve			
				1.4.2. High level upstream								
				1.4.3. High pressure upstream								
				1.4.4. Low level downstream								
1.5	Misdirected flow			1.5.1. Contamination of a product stream					1.5.1. Checklist that specifies valve alignment 1.5.2. Startup testing			

No.: 1 | **Description:** General

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
				1.5.2. Reaction with incompatible material at destination								
				1.5.3. Unexpected presence of hazardous material in a system								
1.6	High level			1.6.1. Overflow and release of hazardous material					1.6.1. Level indication 1.6.2. High level alarm			
				1.6.2. Overflow of liquid to vent line								
				1.6.3. Overflow into utility line, resulting in contamination of utility system								
				1.6.4. High pressure								
1.7	Low level			1.7.1. Gas blow by to downstream equipment, resulting in high pressure downstream					1.7.1. Level indication 1.7.2. Low level alarm			
				1.7.2. Low/no flow downstream								

No.: 1	**Description:** General

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
1.8	High interface level			1.8.1. Carryover of heavier liquid to lighter liquid stream					1.8.1. Interface level indication 1.8.2. High interface level alarm			
1.9	Low interface level			1.9.1. Contamination of heavier liquid stream with lighter liquid					1.9.1. Interface level indication 1.9.2. Low interface level alarm			
1.10	High temperature			1.10.1. High pressure					1.10.1. Temperature indication 1.10.2. High temperature alarm			
1.11	Low temperature			1.11.1. Freezing of liquid					1.11.1. Temperature indication 1.11.2. Low temperature alarm 1.11.3. Heat tracing and insulation			
				1.11.2. Low pressure								
1.12	High pressure			1.12.1. Relief device opens, discharging hazardous material					1.12.1. Pressure indication 1.12.2. High pressure alarm 1.12.3. Relief device to help prevent rupture			

No.: 1	**Description:** General											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				1.12.2. Potential loss of containment if pressure exceeds the rating of equipment								
1.13	Low pressure			1.13.1. Air intrusion					1.13.1. Pressure indication 1.13.2. Low pressure alarm 1.13.3. Vacuum breaker			
				1.13.2. Vacuum damage and potential loss of containment if vacuum exceeds the rating of equipment								
1.14	High concentration of contaminants			1.14.1. Reaction with incompatible material					1.14.1. Material delivery procedures 1.14.2. Material testing before unloading/use 1.14.3. Checklist that specifies valve alignment			
				1.14.2. Corrosion of incompatible material of construction								
1.15	Loss of containment			1.15.1. Release of hazardous material					1.15.1. Corrosion probes 1.15.2. Non-destructive inspection			

No.: 1	**Description:** General											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									1.15.3. Plugs in vent and drain valves 1.15.4. Capability to isolate the tank/vessel remotely or manually 1.15.5. Operation/maintenance response as required, including isolation if needed			
1.16	Deviation during startup			1.16.1. No additional hazards identified								
1.17	Deviation during shutdown			1.17.1. No additional hazards identified								
1.18	Deviation during maintenance			1.18.1. No additional hazards identified								
1.19	Deviation during sampling			1.19.1. No sampling is routinely performed								

Company: EMSA, YCA, WinGD, Nikkiso, NTUA, ABS		
Title: EMSA NH3		
Description:		
Method: HAZOP	**Type:** Tank/Vessel	Fuel Tank Filling
Design Intent:		
Comment:		

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
2.1	General			2.1.1. General Comment								1. Consider the installation of a Tank Connection Space 2. Further study to be done on the control of temperature in the Tank. Nikkiso is considering of providing thermal insulation to protect from solar radiation. 3. Further study to be done on the maximum allowable filling level in the tank (95% instead of 98%) 4. Further study to be done on continuous temperature control

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
2.2	No Flow		Remotely controlled valve ESD-M11 closed due to failure or operator's error.	2.2.1. Unable to transfer ammonia from the bunkering vessel or terminal to the ship	General	4	-2	Moderate (2)	2.2.1. Manual Check 2.2.2. Manual valve (bypass) **Comment:** MV-M15 2.2.3. Thermal Relief Valve **Comment:** TSV M01 @18barg 2.2.4. High-pressure indication. **Comment:** PI-M31 2.2.5. High Pressure L Alarm **Comment:** PT-M30 (HH-18barg) 2.2.6. High-High Pressure L Alarm and Emergency Shut Down **Comment:** 5 sec	-3	Low (1)	5. Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered 6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2 **Description:** Fuel Tank Filling

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
				2.2.2. Pressure increases in the ammonia bunkering hose/loading arm and ship's fuel line, upstream of ESD-M11	General	4	-2	Moderate (2)	2.2.1. Manual Check 2.2.2. Manual valve (bypass) **Comment:** MV-M15 2.2.3. Thermal Relief Valve **Comment:** TSV M01 @18barg 2.2.4. High-pressure indication. **Comment:** PI-M31 2.2.5. High Pressure L Alarm **Comment:** PT-M30 (HH-18barg) 2.2.6. High-High Pressure L Alarm and Emergency Shut Down **Comment:** 5 sec	-3	Low (1)	5. Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered 6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				2.2.3. Potential for ammonia leakage from bunkering hose/loading arm	Environmental	4	-2	Moderate (2)	2.2.1. Manual Check 2.2.2. Manual valve (bypass) **Comment:** MV-M15 2.2.3. Thermal Relief Valve **Comment:** TSV M01 @18barg 2.2.4. High-pressure indication. **Comment:** PI-M31 2.2.5. High Pressure L Alarm **Comment:** PT-M30 (HH-18barg) 2.2.6. High-High Pressure L Alarm and Emergency Shut Down **Comment:** 5 sec	-3	Low (1)	5. Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered 6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				2.2.4. Potential for fire, explosion and/or accident escalation leading to injuries/fatalities and/or asset damage	Injury	4	-2	Moderate (2)	2.2.1. Manual Check 2.2.2. Manual valve (bypass) **Comment:** MV-M15 2.2.3. Thermal Relief Valve **Comment:** TSV M01 @18barg 2.2.4. High-pressure indication. **Comment:** PI-M31 2.2.5. High Pressure L Alarm **Comment:** PT-M30 (HH-18barg) 2.2.6. High-High Pressure L Alarm and Emergency Shut Down **Comment:** 5 sec	-3	Low (1)	5. Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered 6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
2.3	No Flow		Manual valve MV-M13 closed due to failure or operator's error.	2.3.1. Unable to transfer ammonia from the bunkering vessel or terminal to the ship	General	4	-1	High (3)	2.3.1. Manual Check. 2.3.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 2.3.3. High-pressure indication. **Comment:** PI-M34 2.3.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)	-2	Moderate (2)	5. Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered 6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				2.3.2. Pressure increases in the ammonia bunkering hose/loading arm and ship's fuel line, upstream of MV-M13 resulting in halt of operations	Asset	4	-1	High (3)	2.3.1. Manual Check. 2.3.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 2.3.3. High-pressure indication. **Comment:** PI-M34 2.3.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)	-2	Moderate (2)	5. Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered 6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.
				2.3.3. Potential for ammonia leakage from bunkering hose/loading arm	Environmental	4	-1	High (3)	2.3.1. Manual Check. 2.3.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02	-2	Moderate (2)	5. Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered

No.: 2 **Description:** Fuel Tank Filling

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
									2.3.3. High-pressure indication. **Comment:** PI-M34 2.3.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)			6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.
				2.3.4. Potential for fire, explosion and/or accident escalation leading to injuries/fatalities and/or asset damage	Injury	4	-1	High (3)	2.3.1. Manual Check. 2.3.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 2.3.3. High-pressure indication. **Comment:** PI-M34 2.3.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)	-2	Moderate (2)	5. Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.
				2.3.5. Potential damage to the pumps	Asset	4	-1	High (3)	2.3.1. Manual Check. 2.3.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 2.3.3. High-pressure indication. **Comment:** PI-M34 2.3.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)	-2	Moderate (2)	5. Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.
2.4	No Flow		Manual valve MV-M14 closed due to failure or operator's error.	2.4.1. Unable to transfer ammonia from the bunkering vessel or terminal to the ship	General	4	-1	High (3)	2.4.1. Manual Check. 2.4.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 2.4.3. High-pressure indication. **Comment:** PI-M34 2.4.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)	-2	Moderate (2)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2 | **Description:** Fuel Tank Filling

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
				2.4.2. Pressure increases in the ammonia bunkering hose/loading arm and ship's fuel line, upstream of MV-M13	Asset	4	-1	High (3)	2.4.1. Manual Check. 2.4.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 2.4.3. High-pressure indication. **Comment:** PI-M34 2.4.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)	-2	Moderate (2)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.
				2.4.3. Potential for ammonia leakage from bunkering hose/loading arm	Environmental	5	-1	High (4)	2.4.1. Manual Check. 2.4.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 2.4.3. High-pressure indication. **Comment:** PI-M34	-2	High (3)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									2.4.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)			
				2.4.4. Potential for fire, explosion and/or accident escalation leading to injuries/fatalities and/or asset damage	Injury	4	-1	High (3)	2.4.1. Manual Check. 2.4.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 2.4.3. High-pressure indication. **Comment:** PI-M34 2.4.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)	-2	Moderate (2)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				2.4.5. Potential damage to the pumps	Asset	4	-1	High (3)	2.4.1. Manual Check. 2.4.2. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 2.4.3. High-pressure indication. **Comment:** PI-M34 2.4.4. High Pressure Transmitter. **Comment:** PT-M33 (H-17barg)	-2	Moderate (2)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.
2.5	No Flow		Remotely controlled valve ESD-M12 closed due to failure or operator's error.	2.5.1. Unable to transfer ammonia from the bunkering vessel or terminal to the ship	General	4	-2	Moderate (2)	2.5.1. Manual Check. 2.5.2. Low-pressure indication. **Comment:** PI-M36	-3	Low (1)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2 | **Description:** Fuel Tank Filling

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
				2.5.2. Pressure increases in the ammonia bunkering hose/loading arm and ship's fuel line, upstream of MV-M13	Asset	4	-2	Moderate (2)	2.5.1. Manual Check. 2.5.2. Low-pressure indication. **Comment:** PI-M36	-3	Low (1)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.
				2.5.3. Potential for ammonia leakage from bunkering hose/loading arm	Environmental	5	-2	High (3)	2.5.1. Manual Check. 2.5.2. Low-pressure indication. **Comment:** PI-M36 2.5.3. Pressure relief through Thermal Safety Valve. **Comment:** TSV-M02 (TBC)	-3	Moderate (2)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.

No.: 2	**Description:** Fuel Tank Filling

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
				2.5.4. Potential for fire, explosion and/or accident escalation leading to injuries/fatalities and/or asset damage	Injury	4	-2	Moderate (2)	2.5.1. Manual Check. 2.5.2. Low-pressure indication. **Comment:** PI-M36	-3	Low (1)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.
				2.5.5. Potential damage to the pumps	Asset	4	-2	Moderate (2)	2.5.1. Manual Check. 2.5.2. Low-pressure indication. **Comment:** PI-M36	-3	Low (1)	6. Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during the bunkering process, the only method available to control pressure is through the vapour return line.
2.6	Less flow	As with No Flow	Same as no Flow	2.6.1. Unable to transfer ammonia from the bunkering vessel or terminal to the ship.	General	4	-2	Moderate (2)		-2	Moderate (2)	

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				2.6.2. Pressure increases in the ammonia bunkering hose/loading arm and ship's fuel line, upstream of MV-M13.	Asset	4	-2	Moderate (2)		-2	Moderate (2)	
				2.6.3. Potential for ammonia leakage from bunkering hose/loading arm.	Environmental	5	-2	High (3)		-2	High (3)	
				2.6.4. Potential for fire, explosion and/or accident escalation leading to injuries/fatalities and/or asset damage.	Injury	4	-2	Moderate (2)		-2	Moderate (2)	
				2.6.5. Potential damage to the pumps.	Asset	4	-2	Moderate (2)		-2	Moderate (2)	
2.7	More flow		Running of more than one bunkering pumps	2.7.1. Built up pressure in the main supply line and the vapour return line. Leakage to the environment	Environmental	5	-2	High (3)		-2	High (3)	7. Development of appropriate bunkering procedures.

No.: 2	**Description:** Fuel Tank Filling

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												102. System design is to be developed according to the IGF codes.
				2.7.2. Built up pressure in the main supply line and the vapour return line. Fire, human injury	Injury	5	-2	High (3)		-2	High (3)	7. Development of appropriate bunkering procedures. 102. System design is to be developed according to the /IGF codes.
2.8	More Flow		Manually controlled bypass valve MV-M15 open due to failure or operator's error.	2.8.1. No concerns were identified.								
2.9	Part of Flow		Thermal safety valve TSV-M01 stuck open.	2.9.1. Release of ammonia to the environment	Environmental	5	-2	High (3)	2.9.1. Use of hot welded connections. 2.9.2. Gas detector at both port and star board sides.	-3	Moderate (2)	8. Mechanical Spray Shielding is to be provided around flanges if not hot welded (in the case of bolted connections).

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												9. Liquid detection at bunkering station. Low temperature leading to Emergency Shut Down (ESD). A study to be made on the sensor calibration for the case of extremely low ambient temperature. 10. Drip tray to be directed to the dilution tank instead of being discharged overboard. 103. Critical spare parts, e.g., Thermal Relief Valves, heat exchangers list is to be evaluated and provided/suggested.
2.10	Part of Flow		Leakage from the Valve Stem	2.10.1. Release of ammonia to the environment	Environmental	5	-2	High (3)	2.10.1. Use of hot welded connections. 2.10.2. Gas detector at both port and star board sides.	-3	Moderate (2)	8. Mechanical Spray Shielding is to be provided around flanges if not hot welded (in the case of bolted connections).

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												9. Liquid detection at bunkering station. Low temperature leading to Emergency Shut Down (ESD). A study to be made on the sensor calibration for the case of extremely low ambient temperature. 10. Drip tray to be directed to the dilution tank instead of being discharged overboard.
2.11	As well as Flow		Nitrogen inside the bunkering line which may cause severe problems with the BOG system which in turn can have a plethora of cascading consequences for safety, assets, and the environment	2.11.1. The manufacturer's design philosophy is to return the nitrogen used to purge the bunkering lines, into the fuel tank.	General	6	0		2.11.1. Disconnection from the system	-1		104. Further study to be done on the nitrogen return line from the BOG.
2.12	Reverse Flow		Emergency Shut Down (ESD) of bunkering ship pumps	2.12.1. No concerns were identified.								

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
2.13	Misdirected Flow		Remotely controlled valve ESD-C61 open due to failure or operator's error	2.13.1. Ammonia recirculating. Unable to fill the fuel tank or delay in the fuel tank filling.	General	3	-2	Low (1)	2.13.1. Operational Procedures **Comment:** Isolation of Valves MV63, M13, MVM16, M65	-3	Low (0)	11. Identification of all valves that need to be monitored (position) and controlled remotely during bunkering operation.
2.14	Misdirected Flow		Manually controlled valve MCV-C62 open due to failure or operator's error	2.14.1. Ammonia recirculating. Unable to fill the fuel tank or delay in the fuel tank filling.	General	3	-3	Low (0)	2.14.1. Operational Procedures	-4	Low (-1)	
2.15	High Level		Level Indicator LI-C11 malfunction	2.15.1. Tank overfilling, buildup of pressure.	General	4	-3	Low (1)	2.15.1. Secondary High-High L Alarm (operator)	-4	Low (0)	
2.16	High Temperature		High ambient temperature during bunkering operations	2.16.1. Buildup of pressure inside the fuel tank due to the increase of vapour inside the tank.	General	4	-1	High (3)		-1	High (3)	13. Given that the fuel tank will be uninsulated and the Reliquefication Plant system is disconnected in the current design, further study to be done on heat transfer analysis and monitoring of heat ingress to the tank.

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												14. Given that the fuel tank will be uninsulated and the Reliquefication Plant system is disconnected in the current design, temperature monitoring and Emergency Shut Down (ESD) is to be provided upstream of the tank. 15. Further study to be done on the heat transfer from ammonia returning to the tank following a triggering of the Pressure Safety Valve PSV-F31.
2.17	High Pressure		External fire close to the tank	2.17.1. Release of ammonia in the environment	Environmental	5	-1	High (4)	2.17.1. Pressure Transmitter **Comment:** PT-C18/C19 (> 3,6 barg) 2.17.2. Pressure Safety Valve (PSV) **Comment:** PSV-C01/C02 (4barg) 2.17.3. Adequate vent mast height	-4	Low (1)	16. Further study to be done to determine an appropriate safety margin of the Pressure Safety Valve (PSV) setting, so that its activation pressure will be lower than the maximum design pressure of the tank.

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									2.17.4. Water suppression system on the tank			
2.18	Contaminants in the Process Line		Ammonia impurities	2.18.1. Premature clogging of filters/strainers	Asset	4	-2	Moderate (2)	2.18.1. Filters/strainers **Comment:** ST-M11, ST-M61 2.18.2. Certification with composition of delivered ammonia 2.18.3. Build in filter of Low-pressure pumps. **Comment:** LP-11/12	-2	Moderate (2)	
2.19	Contaminants in the Process Line		Excessive water concentration in ammonia bunkered.	2.19.1. Potential for hydrate formation	Asset	3	-2	Low (1)	2.19.1. Filters/strainers (redundant) **Comment:** ST-M11, ST-M61 2.19.2. Certification with composition of delivered ammonia	-3	Low (0)	

No.: 2 **Description:** Fuel Tank Filling

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
									2.19.3. Build in filter of Low-pressure pump low pressure 11/12 **Comment:** Nikisso can provide their own pumps. 2.19.4. Sampling			
2.20	Contaminants in the Process Line		Particles from the pipe due to corrosion/erosion	2.20.1. Premature clogging of filters/strainers. Potential for damage to equipment of the ammonia FGSS and the main engine.	Asset	4	-2	Moderate (2)	2.20.1. Filters/strainers **Comment:** ST-M11, ST-M61 2.20.2. Certification with composition of delivered ammonia **Comment:** LP11/12. Nikisso can provide their own pumps. Sampling to verify ammonia composition	-4	Low (0)	17. Further study to be done on the tolerance of the engine to ammonia contaminants 18. Clarification on the function of the Nikkiso pump filters, i.e. whether they are designed to protect system up to the tank or they also protect the system components downstream of the tank.

No.: 2	**Description:** Fuel Tank Filling											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
2.21	Hazards During Maintenance		One or more of the Purging Valves PG-M22, PG-M24, PG-M25, PG-M29 open due to failure or operator's error	2.21.1. Release of ammonia in the environment	Environmental	4	-1	High (3)	2.21.1. Operating Procedures 2.21.2. Pressure Test after purging process	-2	Moderate (2)	

Company: EMSA, YCA, WinGD, Nikkiso, NTUA, ABS		
Title: EMSA NH3		
Description:		
Method: HAZOP	**Type:**	Ammonia transfer system for Ammonia FGSS
Design Intent:		
Comment:		

No.: 3 | **Description:** Ammonia transfer system for Ammonia FGSS

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
3.1	General			3.1.1. General								21. TSV-F03 to be corrected to 24 barg. 22. Consider the re positioning of the catch tank (CT-01). Capacity of the tank is also to be evaluated. 23. Further study to be done on all return discharges from Pressure Safety Valves (PSVs) to the tank.
3.2	No Flow		Failure of Low-pressure pump LP-11.	3.2.1. No supply of ammonia to engine. Main engine damage.	General	4	-3	Low (1)	3.2.1. Redundancy Pump **Comment:** LP-12 (2x100%) 3.2.2. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11	-4	Low (0)	24. Evaluate procedures for cleaning low pressure pump filters.

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									3.2.3. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PTC13 /PTC14@22 barg 3.2.4. Adjustment of pressure setting for PT-F21 **Comment:** Converted from Rec 28 (1/24/2025 2:01:50 PM)			25. Control logic procedure is to be provided/updated for the engagement of the redundancy pump. Secondary pump should start immediately in case of a failure of the first pump. 26. An additional pressure transducer is to be installed downstream as PCV-C15 does not transmit a signal to the pumps.
3.3	No Flow	Loss of air supply	Failure of remotely operated valve ESD-C13.	3.3.1. Pressure build up upstream of ESD-C13 or downstream of low-pressure pumps LP-11, LP-12	Asset	4	-2	Moderate (2)	3.3.1. Redundancy Pump. ESD-C13 and ESD-C14 do not operate under the same control function. **Comment:** LP12 (2x100%) 3.3.2. Change over to diesel mode	-3	Low (1)	105. Further study to be done on the shutoff pressure and the safety pressure limit of the low-pressure pump.

No.: 3 **Description:** Ammonia transfer system for Ammonia FGSS

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
									3.3.3. Redundancy Pump (2x100%) - Provided ESD-C13 and ESD-C14 do not operate under the same control function **Comment:** LP11/LP12 3.3.4. Manual operation of valves with position indicator 3.3.5. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11 3.3.6. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PT-C13 /PT-C14@22 barg 3.3.7. LS-F20 3.3.8. PT-F21			

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				3.3.2. No NH3 supply to the Main Engine leading to M/E NH3 fuel mode failure	General	4	-2	Moderate (2)	3.3.1. Redundancy Pump. ESD-C13 and ESD-C14 do not operate under the same control function. **Comment:** LP12 (2x100%) 3.3.2. Change over to diesel mode 3.3.3. Redundancy Pump (2x100%) - Provided ESD-C13 and ESD-C14 do not operate under the same control function **Comment:** LP11/LP12 3.3.4. Manual operation of valves with position indicator 3.3.5. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11	-4	Low (0)	

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									3.3.6. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PT-C13 /PT-C14@22 barg 3.3.7. LS-F20 3.3.8. PT-F21			
				3.3.3. Potential damage to the LP-11/12 pumps due to blocked discharge	Asset	4	-2	Moderate (2)	3.3.1. Redundancy Pump. ESD-C13 and ESD-C14 do not operate under the same control function. **Comment:** LP12 (2x100%) 3.3.2. Change over to diesel mode 3.3.3. Redundancy Pump (2x100%) - Provided ESD-C13 and ESD-C14 do not operate under the same control function **Comment:** LP11/LP12	-4	Low (0)	

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									3.3.4. Manual operation of valves with position indicator 3.3.5. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11 3.3.6. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PT-C13 /PT-C14@22 barg 3.3.7. LS-F20 3.3.8. PT-F21			
3.4	No flow		Non return valves CK-13/CK-14, CK-63/CK-64 inadvertently closed due to failure or operator's error	3.4.1. Pressure Build Up upstream C13 or downstream of LP11, LP12	Asset	4	-2	Moderate (2)	3.4.1. Redundancy Pump. ESD-C13 and ESD-C14 do not operate under the same control function. **Comment:** LP12 (2x100%) 3.4.2. Manual operation of valves with position indicator	-3	Low (1)	26. An additional pressure transducer is to be installed downstream as PCV-C15 does not transmit a signal to the pumps. 28. Position indicator is to be provided.

No.: 3 **Description:** Ammonia transfer system for Ammonia FGSS

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
									3.4.3. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11 3.4.4. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PT-C13 /PT-C14@22 barg			
				3.4.2. No NH3 supply to the Main Engine leading to M/E NH3 fuel mode failure	General	4	-2	Moderate (2)	3.4.1. Redundancy Pump. ESD-C13 and ESD-C14 do not operate under the same control function. **Comment:** LP12 (2x100%) 3.4.2. Manual operation of valves with position indicator 3.4.3. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11	-4	Low (0)	26. An additional pressure transducer is to be installed downstream as PCV-C15 does not transmit a signal to the pumps. 28. Position indicator is to be provided.

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									3.4.4. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PT-C13 /PT-C14@22 barg			
				3.4.3. Potential damage to the LP-11/12 pumps due to blocked discharge	Asset	4	-2	Moderate (2)	3.4.1. Redundancy Pump. ESD-C13 and ESD-C14 do not operate under the same control function. **Comment:** LP12 (2x100%) 3.4.2. Manual operation of valves with position indicator 3.4.3. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11 3.4.4. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PT-C13 /PT-C14@22 barg	-4	Low (0)	26. An additional pressure transducer is to be installed downstream as PCV-C15 does not transmit a signal to the pumps. 28. Position indicator is to be provided.

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
3.5	No Flow		Pneumatic valve XV-F11 closed due to failure or operator's error.	3.5.1. Pressure Build Up upstream C13 or downstream of LP11, LP12	Asset	4	-2	Moderate (2)	3.5.1. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11 3.5.2. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PT-C13 /PT-C14@22 barg	-3	Low (1)	
				3.5.2. No NH3 supply to the Main Engine leading to M/E NH3 fuel mode failure	General	4	-2	Moderate (2)	3.5.1. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11 3.5.2. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PT-C13 /PT-C14@22 barg	-3	Low (1)	
				3.5.3. Potential damage to the LP-11/12 pumps due to blocked discharge	Asset	4	-2	Moderate (2)	3.5.1. Low Pressure L Alarm (PAL) **Comment:** PT-C13/PI-C11 3.5.2. Low-Low Pressure L Alarm and Emergency Shut Down **Comment:** PT-C13 /PT-C14@22 barg	-3	Low (1)	

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
3.6	No Flow		Clogged Filter ST-F01/ST-F02	3.6.1. Pressure Build Up upstream C13 or downstream of LP11, LP12	Asset	4	-2	Moderate (2)	3.6.1. Follow the planned maintenance system protocol and clean filter at predetermined intervals 3.6.3. Double filter configuration **Comment:** Do not operate both filters simultaneously. The configuration can act as redundancy.	-4	Low (0)	
				3.6.2. No NH3 supply to the Main Engine leading to M/E NH3 fuel mode failure	General	4	-3	Low (1)	3.6.1. Follow the planned maintenance system protocol and clean filter at predetermined intervals	-4	Low (0)	29. Considering the possibility of a filter rupture further study to done on the type of filters chosen. 30. Further study to be done on the automatic changeover from one filter to the other

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												31. Consider the installation of an additional strainer filter located further downstream after the catch tank 32. Procedures are to be developed for the maintenance of the filters and/or strainers.
				3.6.3. Potential damage to the LP-11/12 pumps due to blocked discharge	Asset	4	-3	Low (1)	3.6.1. Follow the planned maintenance system protocol and clean filter at predetermined intervals	-4	Low (0)	29. Considering the possibility of a filter rupture further study to done on the type of filters chosen. 30. Further study to be done on the automatic changeover from one filter to the other 31. Consider the installation of an additional strainer filter located further downstream after the catch tank 32. Procedures are to be developed for the maintenance of the filters and/or strainers.

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				3.6.4. Potential Damage of the high-pressure pumps	Asset	4	-3	Low (1)	3.6.2. Low-Low Pressure L Alarm (PAL) **Comment:** 15 barg 3.6.3. Double filter configuration **Comment:** Do not operate both filters simultaneously. The configuration can act as redundancy.	-4	Low (0)	
3.7	Blocked flow		Clogging of Low-pressure pump LP-11 filters.	3.7.1. Low pressure conditions	Asset	4	-3	Low (1)	3.7.1. Follow planned maintenance system protocol and clean filter at predetermined intervals. 3.7.2. LP pump redundancy LP-12. 3.7.3. Low-Low Pressure L Alarm (PAL) **Comment:** PT-C13 (15 barg)	-4	Low (0)	24. Evaluate procedures for cleaning low pressure pump filters.

No.: 3 **Description:** Ammonia transfer system for Ammonia FGSS

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
				3.7.2. No NH3 supply to the Main Engine leading to M/E NH3 fuel mode failure	General	4	-3	Low (1)	3.7.1. Follow planned maintenance system protocol and clean filter at predetermined intervals. 3.7.2. LP pump redundancy LP-12.	-4	Low (0)	24. Evaluate procedures for cleaning low pressure pump filters.
				3.7.3. Potential damage to the LP-11/12 pumps due to blocked discharge	Asset	4	-3	Low (1)	3.7.1. Follow planned maintenance system protocol and clean filter at predetermined intervals. 3.7.2. LP pump redundancy LP-12.	-4	Low (0)	24. Evaluate procedures for cleaning low pressure pump filters.
3.8	Reverse Flow		MV-C18, MV-C19 left open	3.8.1. Heat ingress due to the recirculation of ammonia.	General	4	-2	Moderate (2)	3.8.1. Provide position indicator for Valve MV-C18, MV-C19 **Comment:** Converted from Rec 35 (1/24/2025 2:02:35 PM)	-3	Low (1)	

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
3.9	Reverse Flow		Non return valves CK-C13/CK-C14 for both low pressure pumps failure (on the opposite line from the operating one)	3.9.1. Heat ingress due to the recirculation of ammonia	General	4	-2	Moderate (2)	3.9.1. Temperature monitoring in the tank. 3.9.2. Low Pressure L Alarm. **Comment:** PT-C13 & PI-C11 3.9.3. Low-Low Pressure L Alarm and Emergency Shut Down.	-3	Low (1)	35. Classification society to advise on the inclusion of a monitoring sensor.
				3.9.2. Flow to the tank	General	4	-4	Low (0)	3.9.1. Temperature monitoring in the tank. 3.9.2. Low Pressure L Alarm. **Comment:** PT-C13 & PI-C11 3.9.3. Low-Low Pressure L Alarm and Emergency Shut Down.	-3	Low (1)	35. Classification society to advise on the inclusion of a monitoring sensor.

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
3.10	Less Flow		Failure of Low-pressure Pump LP-11	3.10.1. No pressure conditions	General	4	-2	Moderate (2)		-3	Low (1)	36. Temperature monitoring of the low-pressure pump (LP-11, LP-12) is to be also included in the control logic. A holistic monitoring of the pump operation is recommended. 37. High-High Current L Alarm (Control Signal) is to be included in the control logic.
				3.10.2. Temperature Rise of the Pump. Damage to the pump.	Asset	4	-3	Low (1)	3.10.1. Low-Low Pressure L Alarm (PAL) **Comment:** PT-C13 (15barg)	-4	Low (0)	36. Temperature monitoring of the low-pressure pump (LP-11, LP-12) is to be also included in the control logic. A holistic monitoring of the pump operation is recommended. 37. High-High Current L Alarm (Control Signal) is to be included in the control logic.

No.: 3	**Description:** Ammonia transfer system for Ammonia FGSS											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
3.11	Less Flow		Pressure control valve PCV-C15 malfunction	3.11.1. Unable to meet minimum flow requirements for the FGSS LP pump	General	4	-3	Low (1)		-3	Low (1)	38. Further study to be done on the positioning of PCV-C15. 39. Control logic is to include actions for the failure of PCV-C15
3.12	Less Flow		Temperature safety valve TSV-C11 leakage	3.12.1. Heat ingress to the tank system	General	4	-2	Moderate (2)	3.12.1. Temperature monitoring in the tank	-2	Moderate (2)	40. Designer to consider a High Temperature L Alarm (TAL) in the TSV return line. Consideration is to be given on the position of the temperature reading.
3.13	More Flow		Pressure control valve PCV-C15 malfunction.	3.13.1. No concerns were identified.								41. Consider development of appropriate control logic sequence to ensure sufficient ammonia amount is present in the tank.
3.14	Sloshing	Move to node #5	Heavy Weather	3.14.1. Vapour on the suction side of the High-pressure Pumps	General	4	-1	High (3)		-1	High (3)	

No.: 3 | **Description:** Ammonia transfer system for Ammonia FGSS

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
3.15	Maintenance		Valves left open after maintenance	3.15.1. Release of ammonia in the atmosphere	Environmental	4	-2	Moderate (2)		-2	Moderate (2)	

Company: EMSA, YCA, WinGD, Nikkiso, NTUA, ABS		
Title: EMSA NH3		
Description:		
Method: HAZOP	**Type:** Line/Pipe	Ammonia FGSS – Ammonia Supply to M/E
Design Intent:		
Comment:		

No.: 4 — **Description:** Ammonia FGSS – Ammonia Supply to M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
4.1	General			4.1.1. General								46. Automatically operated shutoff valves are to be situated at the bulkhead inside the fuel preparation room 47. Further study to be done on the High-pressure skid following a detailed P&ID submission. 48. Further study is needed to ensure compliance with the engine's tolerance specifications for pressure fluctuations caused by high-pressure pumps. 49. Further study to be done on the overall catch tank philosophy/architecture.

No.: 4 **Description:** Ammonia FGSS – Ammonia Supply to M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
4.2	No Flow		Manual valve MV-F21 closed due to failure or operator's error	4.2.1. Damage to the HP pumps HP-01/02 due to blocked suction	Asset	4	-3	Low (1)	4.2.1. Low-Low Pressure L Alarm (PAL) **Comment:** PT-F21 4.2.2. Install a Low-Low Pressure L Alarm (PALL) for safety and control (ESD) in the discharge of the HP pump skid **Comment:** Converted from Rec 54 (1/24/2025 2:14:32 PM) 4.2.3. High-High Pressure L Alarm (PAHH) and Low-Low Pressure L Alarm (PAL) have been added to PT-F36	-4	Low (0)	107. Pressure pumps are to be equipped with dry running protection
4.3	No Flow		HP pump HP-01/02 failure	4.3.1. No ammonia supply to the main engine.	General	4	-3	Low (1)	4.3.1. High-High Pressure L Alarm (PAHH) **Comment:** PT-F31 (for safety)	-4	Low (0)	61. Addition of an extra pressure transmitter for Emergency Shut Down (ESD) 62. Further study to be done on the control logic part of the high-pressure pump section

No.: 4 **Description:** Ammonia FGSS – Ammonia Supply to M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
									4.3.2. High-High Pressure L Alarm (PAHH) **Comment:** PT-F36 (for control purposes)			
4.4	No Flow		Clogging of filter/strainer ST-F34	4.4.1. Damage to the HP pumps HP-01/02 due to blocked suction 4.4.2. Pressure increase and leak	Asset	4	-3	Low (1)	4.4.1. Install a Low-Low Pressure L Alarm (PALL) for safety and control (ESD) in the discharge of the HP pump skid **Comment:** Converted from Rec 54 (1/24/2025 2:14:32 PM)	-4	Low (0)	50. Consider the installation of a dual filter setup in the position of the single filter ST-F34 107. Pressure pumps are to be equipped with dry running protection
4.5	No Flow		Blocked High-pressure heater HT-01.	4.5.1. Damage to the HP pumps HP-01/02 due to blocked suction	Asset	4	-3	Low (1)	4.5.1. Install a Low-Low Pressure L Alarm (PALL) for safety and control (ESD) in the discharge of the HP pump skid **Comment:** Converted from Rec 54 (1/24/2025 2:14:32 PM)	-4	Low (0)	107. Pressure pumps are to be equipped with dry running protection

No.: 4 **Description:** Ammonia FGSS – Ammonia Supply to M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
				4.5.2. Pressure increases upstream of the High-pressure heater HT-01	Asset	4	-3	Low (1)	4.5.1. Install a Low-Low Pressure L Alarm (PALL) for safety and control (ESD) in the discharge of the HP pump skid **Comment:** Converted from Rec 54 (1/24/2025 2:14:32 PM)	-4	Low (0)	107. Pressure pumps are to be equipped with dry running protection
				4.5.3. Potential leakage of the High-pressure heater HT-01	General	4	-3	Low (1)	4.5.1. Install a Low-Low Pressure L Alarm (PALL) for safety and control (ESD) in the discharge of the HP pump skid **Comment:** Converted from Rec 54 (1/24/2025 2:14:32 PM)	-4	Low (0)	107. Pressure pumps are to be equipped with dry running protection
4.6	No Flow/Less Flow		XV-F81 remains open	4.6.1. Potential loss of pressure and inadequate NH3 fuel supply in M/E, especially in higher loads. NH3 M/E fuel mode fails.	Asset	4	-2	Moderate (2)		-2	Moderate (2)	63. Include a non-return valve 64. Position indicator for valve XV-F81 65. Further study to be done on the inclusion of a Double Block and Bleed Valve (DBBV)

No.: 4 | **Description:** Ammonia FGSS – Ammonia Supply to M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												66. The maintenance procedure for all components of the system must be clearly described.
4.7	No/Less Flow		Failure of CKF54	4.7.1. Control issues, surge in the system	Asset	4	-3	Low (1)	4.7.1. Pressure transmitter **Comment:** PT F36	-4	Low (0)	51. Further study to be done regarding the startup of the HP pump skid 52. Further study to be done on TT F35 or include an additional LL and HH temperature transmitter
4.8	No/Flow/Less Flow		Untagged non-return check valve upstream FVU remains closed due to failure or operator's error.	4.8.1. Loss of pressure of NH3 fuel supply in M/E. NH3 M/E fuel mode fails.	Asset	4	-2	Moderate (2)		-2	Moderate (2)	53. WinGD is to advise whether the untagged non-return check valve upstream of the FVU can be introduced or if it will pose maintenance-related issues. 54. Further study to be done on the necessity of the untagged non-return check valve upstream of the FVU. 108. Consider the possibility of removing the check valve or elaborate further on the purpose of its existence.

No.: 4 | **Description:** Ammonia FGSS – Ammonia Supply to M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
4.9	Low Temperature		HP Heater (HT-01)	4.9.1. Stress in the piping system, pipe rupture, leakages, injury.	Injury	5	-1	High (4)	4.9.1. Low-Low Temperature L Alarm (TALL) and Emergency Shut Down (ESD) **Comment:** TT-E52	-1	High (4)	55. Further study to be done on the heat transfer analysis of the heat exchanger HT-01. Consider a margin allowance for resistance due to particle deposition. 58. Further study to be done on alarm mechanisms for the operation (both safety and control of the glycol system) of the heat exchanger performance. Inclusion of a temperature transmitter after the HP skid and possible addition of another heat exchanger. 109. Consider installation of absorbing/elongation relief devices to mitigate stress in the system. 110. Further study to be done to determine the lowest possible temperature that the piping system can withstand. 111. Further study to be done upon the ventilation air temperature.

No.: 4	**Description:** Ammonia FGSS – Ammonia Supply to M/E											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
4.10	No Flow		Clogged Y-strainer (untagged - after double valve PG-F43/PG-F44)	4.10.1. No ammonia supply to the main engine, resulting to Engine NH3 fuel mode failure.	General	3	-2	Low (1)	4.10.1. High Pressure L Alarm (PAH) **Comment:** PT-F31 4.10.2. High-High Pressure L Alarm (PAHH) **Comment:** PT-F36 4.10.3. Pressure Relief Valve (PRV) **Comment:** PSV-F31 4.10.4. Install a Low-Low Pressure L Alarm (PALL) for safety and control (ESD) in the discharge of the HP pump skid **Comment:** Converted from Rec 54 (1/24/2025 2:14:32 PM) 4.10.5. Switch to diesel fuel	-3	Low (0)	112. Clarification to be given if High-High Pressure L Alarm (PAHH) also has an Emergency Shut Down (ESD) function.

No.: 4	**Description:** Ammonia FGSS – Ammonia Supply to M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
									4.10.6. Switch to diesel fuel			
				4.10.2. No ammonia supply to the main engine. Increase of Carbon Dioxide (CO_2) emissions	Environmental	4	-2	Moderate (2)	4.10.1. High Pressure L Alarm (PAH) **Comment:** PT-F31 4.10.2. High-High Pressure L Alarm (PAHH) **Comment:** PT-F36 4.10.3. Pressure Relief Valve (PRV) **Comment:** PSV-F31 4.10.4. Install a Low-Low Pressure L Alarm (PALL) for safety and control (ESD) in the discharge of the HP pump skid **Comment:** Converted from Rec 54 (1/24/2025 2:14:32 PM) 4.10.5. Switch to diesel fuel	-3	Low (1)	112. Clarification to be given if High-High Pressure L Alarm (PAHH) also has an Emergency Shut Down (ESD) function.

No.: 4	**Description:** Ammonia FGSS – Ammonia Supply to M/E											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									4.10.6. Switch to diesel fuel			
4.11	Less Flow			4.11.1. No concerns were identified.					4.11.1. Low-Low Pressure L Alarm (LALL) **Comment:** PT-F21 4.11.2. Install a Low-Low Pressure L Alarm (PALL) for safety and control (ESD) in the discharge of the HP pump skid **Comment:** Converted from Rec 54 (1/24/2025 2:14:32 PM)			56. Addition of High-High Pressure L Alarm (PAHH) and Emergency Shut Down (ESD)
4.12	More Flow			4.12.1. No concerns were identified.								57. Install a High-High Pressure L Alarm (PAHH) transmitter for safety and control (ESD) in the discharge of the HP pump skid after PT-F31

No.: 4	**Description:** Ammonia FGSS – Ammonia Supply to M/E											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
4.13	Part of Flow			4.13.1. No concerns were identified.								57. Install a High-High Pressure L Alarm (PAHH) transmitter for safety and control (ESD) in the discharge of the HP pump skid after PT-F31
4.14	As well as Flow		Malfunction of non-return valve CK-F54	4.14.1. Minimum flow conditions for the HP-01/02 pumps are not ensured	General	3	-3	Low (0)		-3	Low (0)	113. Further study to be done (simulation of the control logic)
4.15	High Temperature		HP Heater HT-01 malfunction.	4.15.1. Performance of Main Engine, potential Engine NH3 fuel mode failure.	Asset	3	-2	Low (1)	4.15.1. High Temperature L Alarm (TAH) **Comment:** TT-F35	-3	Low (0)	55. Further study to be done on the heat transfer analysis of the heat exchanger HT-01. Consider a margin allowance for resistance due to particle deposition. 58. Further study to be done on alarm mechanisms for the operation (both safety and control of the glycol system) of the heat exchanger performance. Inclusion of a temperature transmitter after the HP skid and possible addition of another heat exchanger. 115. Further study to be done on the control logic

No.: 4 | **Description:** Ammonia FGSS – Ammonia Supply to M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
				4.15.2. Temperature increases in the NH3 from the NH3 FGSS. Potential for M/E NH3 fuel mode failure.	General	4	-2	Moderate (2)	4.15.1. High Temperature L Alarm (TAH) **Comment:** TT-F35	-3	Low (1)	55. Further study to be done on the heat transfer analysis of the heat exchanger HT-01. Consider a margin allowance for resistance due to particle deposition. 58. Further study to be done on alarm mechanisms for the operation (both safety and control of the glycol system) of the heat exchanger performance. Inclusion of a temperature transmitter after the HP skid and possible addition of another heat exchanger. 115. Further study to be done on the control logic
				4.15.3. Pipe rupture, thermal Leakage, human injury	Asset	4	-2	Moderate (2)	4.15.1. High Temperature L Alarm (TAH) **Comment:** TT-F35	-3	Low (1)	55. Further study to be done on the heat transfer analysis of the heat exchanger HT-01. Consider a margin allowance for resistance due to particle deposition.

No.: 4 | **Description:** Ammonia FGSS – Ammonia Supply to M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												58. Further study to be done on alarm mechanisms for the operation (both safety and control of the glycol system) of the heat exchanger performance. Inclusion of a temperature transmitter after the HP skid and possible addition of another heat exchanger. 115. Further study to be done on the control logic
4.16	High Pressure	Details of the HP pump skid (HP-01/02) were not provided.	HP pump HP-01/02 failure	4.16.1. High pressure ammonia feed in the engine, Pipe rupture, Human Injury	Injury	6	-2	High (4)	4.16.1. Pressure Safety Valve. **Comment:** PSV-F31 (90barg) 4.16.2. Pressure Control Valve (Bypass line) **Comment:** PCV-F31	-3	High (3)	57. Install a High-High Pressure L Alarm (PAHH) transmitter for safety and control (ESD) in the discharge of the HP pump skid after PT-F31 58. Further study to be done on alarm mechanisms for the operation (both safety and control of the glycol system) of the heat exchanger performance. Inclusion of a temperature transmitter after the HP skid and possible addition of another heat exchanger.

No.: 4	**Description:** Ammonia FGSS – Ammonia Supply to M/E											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									4.16.3. Addition of a pressure transmitter at the discharge of the high-pressure pump skid after the pressure transmitter PT-F31 **Comment:** Converted from Rec 60 (1/24/2025 4:02:24 PM) 4.16.4. Pressure Relief Valve (PRV) on the engine side			59. Consider adding a Low-Low Pressure L Alarm (PALL) and High-High Pressure L Alarm (PAHH) and Emergency Shut Down (ESD) (include it in the cause and effect diagram) 116. Further study to be done on the design pressure of the HP piping. 117. Further study to be done on the back pressure when the Double Block and Bleed Valve closes. 118. Further study to be done on the reaction time of the pumps
4.17	Pressure Pulse		High pressure in combination with low volume	4.17.1. Potential damage to fuel gas supply systems components.	Asset	6	-2	High (4)		-3	High (3)	48. Further study is needed to ensure compliance with the engine's tolerance specifications for pressure fluctuations caused by high-pressure pumps. 116. Further study to be done on the design pressure of the HP piping.

No.: 4	**Description:** Ammonia FGSS – Ammonia Supply to M/E											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												119. Further study to be done on the installation of accumulator buffers
				4.17.2. Potential damage to fuel gas supply systems components. Injury	Injury	6	-2	High (4)		-3	High (3)	48. Further study is needed to ensure compliance with the engine's tolerance specifications for pressure fluctuations caused by high-pressure pumps. 116. Further study to be done on the design pressure of the HP piping.
4.18	Reverse Flow	Double check with previous deviations	Malfunction of XV-F71	4.18.1. General								67. Further study to be done on the delivery of nitrogen for pressure and ammonia level regulation purposes.

Company: EMSA, YCA, WinGD, Nikkiso, NTUA, ABS		
Title: EMSA NH3		
Description:		
Method: HAZOP	**Type:** Line/Pipe	Ammonia FGSS - Ammonia Return from M/E
Design Intent:		
Comment:		

No.: 5 **Description:** Ammonia FGSS - Ammonia Return from M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
5.1	General			5.1.1. General								68. Further analysis of the node is required once the respective P&ID diagram becomes available. 69. Ammonia FGSS system is to be designed to avoid/limit potential pressure surges and hammering effects.
5.2	No flow		Manual non-return valve CK-F51 closed due to failure or operator's error	5.2.1. Main engine NH3 fuel mode failure/interlock.	Asset	6	-1			-1		45. Further study is to be done on the requirements coming from the engine manufacturer to maintain the pressure of the catch tank (CT-01) at 22 barg for the occasion of receiving ammonia from the engine. 49. Further study to be done on the overall catch tank philosophy/architecture.

No.: 5 | **Description:** Ammonia FGSS - Ammonia Return from M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												70. Addition of a pressure transmitter (safety and control) to trigger an emergency shutdown. 71. Further study to be done on the control logic of the high-pressure pumps HP-01/02 to address the standby operation and purging scenario. 72. Further study to be done on the (re)design of the return line. 73. Further study to be done on the appropriate sizing of valves PCV-F54 and TSV-F03 of the catch tank CT-01
				5.2.2. Pressure increase upstream of valve CK-F51, leading to potential damage of equipment and/or NH3 leakage.	Asset	6	-1			-1		45. Further study is to be done on the requirements coming from the engine manufacturer to maintain the pressure of the catch tank (CT-01) at 22 barg for the occasion of receiving ammonia from the engine. 49. Further study to be done on the overall catch tank philosophy/architecture. 70. Addition of a pressure transmitter (safety and control) to trigger an emergency shutdown.

No.: 5 | **Description:** Ammonia FGSS - Ammonia Return from M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												71. Further study to be done on the control logic of the high-pressure pumps HP-01/02 to address the standby operation and purging scenario. 72. Further study to be done on the (re)design of the return line. 73. Further study to be done on the appropriate sizing of valves PCV-F54 and TSV-F03 of the catch tank CT-01
				5.2.3. Main engine NH3 fuel mode failure/interlock. Pressure increase upstream of valve CK-F51, leading to potential damage of equipment and/or NH3 leakage. Potential of Injury.	Injury	6	-1			-1		45. Further study is to be done on the requirements coming from the engine manufacturer to maintain the pressure of the catch tank (CT-01) at 22 barg for the occasion of receiving ammonia from the engine. 49. Further study to be done on the overall catch tank philosophy/architecture. 70. Addition of a pressure transmitter (safety and control) to trigger an emergency shutdown.

No.: 5 | **Description:** Ammonia FGSS - Ammonia Return from M/E

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												71. Further study to be done on the control logic of the high-pressure pumps HP-01/02 to address the standby operation and purging scenario. 72. Further study to be done on the (re)design of the return line. 73. Further study to be done on the appropriate sizing of valves PCV-F54 and TSV-F03 of the catch tank CT-01
5.3	Other Than Flow		Leak from fresh water side to the fuel side inside the cooler HT-03	5.3.1. General								74. Conduct further analysis once a detailed P&ID of the cooler HT-03 becomes available.
5.4	Other Than Flow		Leakage of water inside the FVU	5.4.1. Water coming in from the water buffer tank and directed to the catch tank CT-01	General	4	-1	High (3)		-1	High (3)	75. Further study to be done on the ammonia injection cooling system and the fuel valve unit once more details become available from the system design.
5.5	Low Level		Emptying of catch tank to the main NH3 fuel supply line.	5.5.1. Loss of pressure in the catch tank and the M/E NH3 fuel return line	Asset	4	-2	Moderate (2)		-2	Moderate (2)	1. Consider the installation of a Tank Connection Space

No.: 5	**Description:** Ammonia FGSS - Ammonia Return from M/E											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
5.6	High Level		Overfilling of catch tank	5.6.1. Vapour creation, overpressure	General	4	-1	High (3)	5.6.1. High-High L Alarm (LAHH) **Comment:** LS-F22 5.6.2. Pressure Safety Valve **Comment:** PSV-C01/C02 5.6.3. Pressure Control Valve (PCV) **Comment:** PCV-15	-1	High (3)	43. Further study to be done on the collection (volume and proper dimensioning) ability of the Vapour collection tank (VCT-01). The dimensions of the catch tank shall accommodate the following: 1. BOG return, 2. engine return, 3. fuel supply. The Vapour Collection Tank should be appropriately sized to ensure compliance with toxicity limits at the vent outlet. 152. Further study to be done on the interface between the WinGD and Nikkiso systems.

Company: EMSA, YCA, WinGD, Nikkiso, NTUA, ABS		
Title: EMSA NH3		
Description:		
Method: HAZOP	**Type:** Other	BOG Handling System
Design Intent:		
Comment:		

No.: 6 | **Description:** BOG Handling System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
6.1	General			6.1.1. General								76. PID diagram of the BOG system is to be supplied

Company: EMSA, YCA, WinGD, Nikkiso, NTUA, ABS		
Title: EMSA NH3		
Description:		
Method: HAZOP	**Type:**	Glycol Water System
Design Intent:		
Comment:		

No.: 7 **Description:** Glycol Water System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
7.1	General			7.1.1. Ammonia in the glycol system	Injury	4	-2	Moderate (2)	7.1.1. Low L Alarm (LAL) **Comment:** @25% 7.1.2. Low-Low L Alarm (LALL) and Emergency Shut Down (ESD).	-2	Moderate (2)	78. Further study to be done on the venting of the glycol water expansion tank TK-11. Consider venting through the dilution tank DT-01 as an alternative to venting directly to the open deck. 88. Install a pH sensor in the glycol water tank TK-11. 120. Further study to be done on the impact of the expansion tank on the system's pressure regulation capability

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				7.1.2. Loss of pressure regulation in the glycol water system Introduction of air in the glycol water system resulting in inadequate heat transfer, overheating, circulation disruption, etc.. Potential for glycol water system and AFSS shutdown.	Asset	4	-1	High (3)	7.1.1. Low L Alarm (LAL) **Comment:** @25% 7.1.2. Low-Low L Alarm (LALL) and Emergency Shut Down (ESD).	-2	Moderate (2)	78. Further study to be done on the venting of the glycol water expansion tank TK-11. Consider venting through the dilution tank DT-01 as an alternative to venting directly to the open deck. 88. Install a pH sensor in the glycol water tank TK-11. 120. Further study to be done on the impact of the expansion tank on the system's pressure regulation capability
7.2	No flow		No glycol water in the Glycol water expansion tank TK-11	7.2.1. Potential to damage glycol water pumps GP-01/02. No glycol water supply leading to the AFSS shutdown.	Asset	3	-2	Low (1)		-2	Low (1)	56. Addition of High-High Pressure L Alarm (PAHH) and Emergency Shut Down (ESD)

No.: 7 **Description:** Glycol Water System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
7.3	No Flow		Manual valve GW-E06 installed at the suction side of the glycol water pumps closed due to failure or operator's error.	7.3.1. Potential to damage glycol water pumps GP-01/02. No glycol water supply leading to the AFSS shutdown.	Asset	3	-1	Moderate (2)	7.3.1. Low L Alarm (LAL) **Comment:** PT-E35 7.3.2. Low-Low L Alarm (LALL) **Comment:** PT-E36 7.3.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown	-2	Low (1)	56. Addition of High-High Pressure L Alarm (PAHH) and Emergency Shut Down (ESD) 121. A list of critical valves must be identified and relevant spare parts to be included in the vessel's inventory.
7.4	No Flow		Either manual valve GW-E01 or GW-E02, installed at the suction side of the glycol water pumps (GP-01 and GP-02, respectively) closed due to failure or operator's error.	7.4.1. Potential to damage glycol water pumps GP-01/02. No glycol water supply leading to the AFSS shutdown.	Asset	3	-1	Moderate (2)	7.4.1. Low L Alarm (LAL). **Comment:** PT-E35 7.4.2. Low-Low L Alarm (LALL). **Comment:** PT-E36 7.4.3. Second glycol water pump in standby mode.	-2	Low (1)	121. A list of critical valves must be identified and relevant spare parts to be included in the vessel's inventory.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.4.4. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between glycol water pumps. 7.4.5. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
7.5	No Flow	On the suction side of the pump	Either strainer ST-E15 or ST-E16, installed at the suction side of the glycol water pumps (GP-01 and GP-02, respectively) clogged.	7.5.1. Potential to damage glycol water pumps GP-01/02. No glycol water supply leading to the AFSS shutdown.	Asset	3	-1	Moderate (2)	7.5.1. Second glycol water pump in standby mode.	-2	Low (1)	32. Procedures are to be developed for the maintenance of the filters and/or strainers.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.5.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between glycol water pumps. 7.5.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
7.6	No Flow		Either flap check valve GW-E11 or GW-E12, installed at the discharge side of the glycol water pumps (GP-01 and GP-02, respectively) closed due to failure	7.6.1. Potential to damage glycol water pumps GP-01/02.	Asset	3	-1	Moderate (2)	7.6.1. Second glycol water pump in standby mode.	-2	Low (1)	123. Further study to be done on the overall (preventive) maintenance plan of the ammonia handling system.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.6.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between glycol water pumps. 7.6.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
				7.6.2. No glycol water supply leading to the AFSS shutdown.	Asset	3	-1	Moderate (2)	7.6.1. Second glycol water pump in standby mode.	-2	Low (1)	123. Further study to be done on the overall (preventive) maintenance plan of the ammonia handling system.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.6.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between glycol water pumps. 7.6.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			

No.: 7 **Description:** Glycol Water System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
7.7	No Flow		Manual valve GW-E03 installed upstream of the GW/JW Heater HT-11 closed due to failure or operator's error	7.7.1. Potential to damage glycol water pumps GP-01/02.	Asset	3	-1	Moderate (2)	7.7.1. Second glycol water pump in standby mode. 7.7.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between glycol water pumps. 7.7.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.	-2	Low (1)	79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				7.7.2. No glycol water supply leading to the AFSS shutdown.	Asset	3	-1	Moderate (2)	7.7.1. Second glycol water pump in standby mode. 7.7.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between glycol water pumps. 7.7.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.	-2	Low (1)	79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
7.8	No Flow		Manual valve GW-E04 installed downstream of the GW/JW heater HT-11 closed due to failure or operator's error	7.8.1. Potential to damage glycol water pumps GP-01/02.	Asset	4	-1	High (3)		-1	High (3)	79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.
				7.8.2. No glycol water supply leading to the AFSS shutdown.	Asset	4	-1	High (3)		-1	High (3)	79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
7.9	No Flow		Manual valve GW-E04 installed downstream of the GW/steam heater HT-12 closed due to failure or operator's error	7.9.1. Potential to damage glycol water pumps GP-01/02.	Asset	4	-1	High (3)	7.9.1. Temperature safety valve TSV-E11 routing glycol water back to the glycol water expansion tank TK-11.	-1	High (3)	79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps. 124. Second valve tagged as GW-E04 in the P&ID is to be renamed.
				7.9.2. No glycol water supply leading to the AFSS shutdown.	Asset	4	-1	High (3)		-1	High (3)	
7.10	No Flow		Either glycol water pump GP-01 and GP-02 failure	7.10.1. No glycol water mixture supply leading to the AFSS shutdown.	General	3	-1	Moderate (2)	7.10.1. Second glycol water pump in standby mode.	-2	Low (1)	122. Further study to be done on the maintenance plan of the pumps.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.10.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between FW/glycol water pumps. 7.10.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
7.11	No Flow		Manual valve GW-F07 installed upstream of the HP heater HT-01 closed due to failure or operator's error	7.11.1. No glycol water supply leading to the AFSS shutdown.	Asset	3	-1	Moderate (2)	7.11.1. Pressure transducer **Comment:** PT-F42	-1	Moderate (2)	79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.

No.: 7 **Description:** Glycol Water System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												80. Install a High-Pressure L Alarm (PAH) transmitter for warning in the upstream of the HP heater HT-01, before the manual valve GW-F07. 127. Further information is to be provided on the pressure data transmitted.
7.12	No Flow		ST-F01 Blocked	7.12.1. No glycol water supply to HP heater HT-01, leading to the AFSS shutdown.	General	3	-1	Moderate (2)	7.12.1. **Comment:** PT-F42	-1	Moderate (2)	32. Procedures are to be developed for the maintenance of the filters and/or strainers. 79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												81. Install a High-Pressure L Alarm (PAH) transmitter in the upstream of the HP heater HT-01, before the manual valve GW-F07. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system. 125. Further information is to be provided on the provision of the high and low pressure readings of PT-F42.
7.13	No Flow	TBC	Strainer ST-F01 installed upstream of the HP heater HT-01 clogged	7.13.1. No glycol water circulation through the HP heater HT-01. Potential to damage to HP heater HT-01.	Asset	4	-1	High (3)		-1	High (3)	79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												81. Install a High-Pressure L Alarm (PAH) transmitter in the upstream of the HP heater HT-01, before the manual valve GW-F07. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system.
7.14	No flow		Manual valve GW-F09 installed upstream of the after cooler HT-02 closed due to failure or operator's error	7.14.1. No glycol water circulation through the HP heater HT-01. Potential to damage to HP heater HT-02.	Asset	3	-1	Moderate (2)	7.14.1. Pressure transducer **Comment:** PT-F42	-1	Moderate (2)	79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												82. Install a High-Pressure L Alarm (PAH) transmitter in the upstream of the after cooler HT-02, prior to the manual valve GW-F09. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system. 127. Further information is to be provided on the pressure data transmitted.
7.15	No Flow		Manual valve GW-F10 installed downstream of the after cooler HT-02 closed due to failure or operator's error	7.15.1. No glycol water circulation through the after cooler HT-02. Potential to damage to after cooler HT-02.	Asset	4	-1	High (3)	7.15.1. Pressure transducer	-1	High (3)	79. Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												82. Install a High-Pressure L Alarm (PAH) transmitter in the upstream of the after cooler HT-02, prior to the manual valve GW-F09. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system. 127. Further information is to be provided on the pressure data transmitted.
				7.15.2. Increase in ammonia temperature downstream of after cooler HT-02 in the line leading to the mixer in the main NH3 fuel supply line.	General	4	-1	High (3)		-1	High (3)	

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
7.16	No Flow		Manual valve GW-E19 (drain of glycol water tank TK-11) left open due to operator's error	7.16.1. Glycol water tank TK-11 depletion. No glycol water supply leading to the AFSS shutdown.	General	3	-2	Low (1)	7.16.1. Level transducer **Comment:** LT-E37	-2	Low (1)	83. Consider installing a physical locking device to secure valve GW-E19 in the closed position, preventing accidental opening due to operator error. 128. Include Low-Low L Alarm (LALL), High-High L Alarm (LAHH) and Emergency Shut Down (ESD) function to the Level Transducer LT-E37. 129. Further study to be done on the drainage of the glycol water expansion tank TK-11. Consider draining from the water expansion tank to the dilution tank DT-01. Further study to be done for the remotely operated valve GW-E19.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												130. Further study to be done on the option of installing the collection tank as a separate system.
7.17	Less Flow		Glycol water pump GP-01/02 malfunction.	7.17.1. Inadequate glycol water supply leading potentially to the AFSS shutdown.	General	3	-1	Moderate (2)	7.17.1. Second glycol water pump in standby mode. 7.17.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between FW/glycol water pumps.	-2	Low (1)	122. Further study to be done on the maintenance plan of the pumps.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.17.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
7.18	Less Flow	TBC	Manual valve GW-E06 installed at the suction side of the glycol water pumps partially closed due to failure or operator's error	7.18.1. Inadequate glycol water supply leading potentially to the AFSS shutdown.	General	3	-1	Moderate (2)	7.18.1. Low L Alarm (LAL) **Comment:** PT-E35 7.18.2. Low-Low L Alarm (LALL) **Comment:** PT-E36 7.18.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown	-2	Low (1)	56. Addition of High-High Pressure L Alarm (PAHH) and Emergency Shut Down (ESD) 121. A list of critical valves must be identified and relevant spare parts to be included in the vessel's inventory.
				7.18.2. Potential image to glycol water pump GP-01/02.	Asset	3	-1	Moderate (2)	7.18.1. Low L Alarm (LAL) **Comment:** PT-E35	-2	Low (1)	56. Addition of High-High Pressure L Alarm (PAHH) and Emergency Shut Down (ESD)

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.18.2. Low-Low L Alarm (LALL) **Comment:** PT-E36 7.18.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown			121. A list of critical valves must be identified and relevant spare parts to be included in the vessel's inventory.
7.19	Less Flow		Manual valve GW-E01/02 partially blocked due to failure or operator's error, or strainer ST-E15/16 partially clogged (both are installed in the suction side of the glycol water pumps GP-01/02)	7.19.1. Inadequate glycol water supply leading potentially to the AFSS shutdown.	General	3	-1	Moderate (2)	7.19.1. Low L Alarm (LAL). **Comment:** PT-E35 7.19.2. Low-Low L Alarm (LALL). **Comment:** PT-E36 7.19.3. Second glycol water pump in standby mode.	-2	Low (1)	121. A list of critical valves must be identified and relevant spare parts to be included in the vessel's inventory.

No.: 7 | **Description:** Glycol Water System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
									7.19.4. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between glycol water pumps. 7.19.5. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
				7.19.2. Potential damage to glycol water pump GP-01/02.	General	3	-1	Moderate (2)	7.19.1. Low L Alarm (LAL). **Comment:** PT-E35 7.19.2. Low-Low L Alarm (LALL). **Comment:** PT-E36 7.19.3. Second glycol water pump in standby mode.	-2	Low (1)	121. A list of critical valves must be identified and relevant spare parts to be included in the vessel's inventory.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.19.4. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between glycol water pumps. 7.19.5. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
7.20	Less Flow		Flap check valve GW-E11/12 at the discharge of glycol water pump GP-01/02 partially blocked due to failure	7.20.1. Inadequate glycol water supply leading potentially to the AFSS shutdown.	General	3	-1	Moderate (2)	7.20.1. Second glycol water pump in standby mode.	-2	Low (1)	84. Check for additional safeguards when P&ID diagram for the glycol water pumps becomes available.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.20.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between FW/glycol pumps. 7.20.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
				7.20.2. Damage to glycol water pump GP-01/02.	Asset	3	-1	Moderate (2)	7.20.1. Second glycol water pump in standby mode.	-2	Low (1)	84. Check for additional safeguards when P&ID diagram for the glycol water pumps becomes available.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.20.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between FW/glycol pumps. 7.20.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
7.21	Less Flow		Manual valve GW-E03 or GW-E04 or GW-EXX or GW-E05 partially blocked due to failure or operator's error	7.21.1. Inadequate glycol water supply leading potentially to the AFSS shutdown.	General	3	-1	Moderate (2)	7.21.1. Second glycol water pump in standby mode.	-2	Low (1)	

No.: 7 | **Description:** Glycol Water System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
									7.21.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between FW/glycol pumps. 7.21.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			
				7.21.2. Damage to glycol water pump GP-01/02.	Asset	3	-1	Moderate (2)	7.21.1. Second glycol water pump in standby mode.	-2	Low (1)	

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									7.21.2. Pressure transmitter PT-E35 (downstream of the glycol water pumps) initiating automatic changeover between FW/glycol pumps. 7.21.3. Pressure transmitter PT-E36 (downstream of the glycol water pumps) initiating AFSS shutdown.			

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
7.22	Less Flow		Manual valve GW-F07 or GW-F08 partially blocked due to failure or operator's error, or strainer ST-F01 partially clogged	7.22.1. Inadequate glycol water supply to HP heater HT-01 leading potentially to the AFSS shutdown.	General	3	-1	Moderate (2)	7.22.1. Pressure transducer **Comment:** PT-F42	-1	Moderate (2)	85. Install a Low-Pressure L Alarm (PAL) transmitter in the upstream of the HP heater HT-01, before the manual valve GW-F07. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system. 127. Further information is to be provided on the pressure data transmitted.
7.23	Less Flow		Manual valve GW-F09 or GW-F10 installed before or after cooler HT-02 partially closed due to failure or operator's error	7.23.1. Inadequate glycol water supply to after cooler HT-02.	General	3	-1	Moderate (2)	7.23.1. Pressure transducer **Comment:** PT-F42	-1	Moderate (2)	86. Install a Low-Pressure L Alarm (PAL) transmitter in the upstream of the after cooler HT-02, prior to the manual valve GW-F09. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												127. Further information is to be provided on the pressure data transmitted.
				7.23.2. Potential shutdown of the BOG compressor skid.	General	3	-1	Moderate (2)	7.23.1. Pressure transducer **Comment:** PT-F42	-1	Moderate (2)	86. Install a Low-Pressure L Alarm (PAL) transmitter in the upstream of the after cooler HT-02, prior to the manual valve GW-F09. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system. 127. Further information is to be provided on the pressure data transmitted.
7.24	Less Flow		Manual valve GW-E21 or manual valve E22 partially closed due to failure or operator's error	7.24.1. Inadequate cooling of glycol water feed from BOG compressor skid.	General	3	-1	Moderate (2)		-1	Moderate (2)	134. Position indicator on manual valve GW-E21

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
7.25	No Flow		HT-12 improper/malfunction (clogging or external/internal leakage)	7.25.1. Lower temperature on the G/W heat exchanger	General	4	-2	Moderate (2)	7.25.1. Pressure Transducers **Comment:** PT-E35, PT-E36 7.25.2. Temperature Transducers **Comment:** TT-E51 7.25.3. Low-Low Pressure Alarm and Emergency Shut Down (ESD) **Comment:** PT-E36	-3	Low (1)	87. Include pressure transmitter and trip function downstream of HT-12 serving the two streams directed to the BOG compressor and the HP heater. Study if the transmitters should be only for safety or should also have a trip function. 103. Critical spare parts, e.g., Thermal Relief Valves, heat exchangers list is to be evaluated and provided/suggested. 135. Further study to be done on the isolation of the heaters (HT-11 and HT-12) and bypass of the (redundancy) heater that an any instance is not operating.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												136. Nikkiso is to provide alternative (including redundancy) methods on the heating modes.
7.26	More Flow		Simultaneous operation of glycol water pumps GP-01/02	7.26.1. Pressure increase downstream of the pumps.	General	3	-1	Moderate (2)	7.26.1. Interlock system to ensure that only one pump can operate at a time.	-2	Low (1)	153. Further study to be done for the installation of a pressure regulating or a pressure relief valve downstream of the glycol water pumps GP-01/02.
				7.26.2. Potential to damage components of the glycol water system, including the heaters and coolers.	Asset	3	-1	Moderate (2)	7.26.1. Interlock system to ensure that only one pump can operate at a time.	-2	Low (1)	153. Further study to be done for the installation of a pressure regulating or a pressure relief valve downstream of the glycol water pumps GP-01/02.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
7.27	Other Than Flow		Leak from the ammonia side to the to the glycol water side inside the HP heater HT-01.	7.27.1. Contamination of glycol water, leading to reduced cooling performance and potential damage or corrosion of equipment.	Asset	5	-1	High (4)		-1	High (4)	78. Further study to be done on the venting of the glycol water expansion tank TK-11. Consider venting through the dilution tank DT-01 as an alternative to venting directly to the open deck. 88. Install a pH sensor in the glycol water tank TK-11.
				7.27.2. Potential environmental impact through the vent of the glycol water expansion tank TK-11.	Environmental	5	-1	High (4)		-1	High (4)	78. Further study to be done on the venting of the glycol water expansion tank TK-11. Consider venting through the dilution tank DT-01 as an alternative to venting directly to the open deck. 88. Install a pH sensor in the glycol water tank TK-11.

No.: 7	**Description:** Glycol Water System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
7.28	Other Than Flow		Leak from fresh water side to the glycol water side inside the GW/JW heater HT-11 or the heat exchanger downstream of the BOG compressor system	7.28.1. Potential for degraded performance of the glycol water system.	Asset	5	-1	High (4)		-1	High (4)	137. Further study to be done to define protection limits for the presence of water in the H/E
7.29	I	The installation of the GW Heater HT-11, supplied with M/E Jacket Water, does not comply with WinGD M/E specifications.	Improper heat exchange in the GW/JW heater HT-11 and GW/steam heater HT-12 Restricted flow of glycol water (due to pump malfunction, clogged strainers, partially opened valves, etc.)	7.29.1. Potential for degraded performance of the glycol water system and off-spec ammonia supply to the main engine.	Asset	6	0		7.29.1. High-High Temperature L Alarm (TAHH) TT-E53 and TT-E52 installed downstream of the GW/JW heater HT-11 and GW/steam heater HT-12 respectively.	0		42. Further study to be done on the interface between the WinGD and the Nikkiso systems.
7.30	Less Temperature	The installation of the GW Heater HT-11, supplied with M/E Jacket Water, does not comply with the WinGD M/E specifications.	Improper heat exchange in the GW/JW heater HT-11, GW/steam heater HT-12, after cooler HT-02, HP heater HT-01, cooler in the upstream of the glycol water expansion tank TK-11	7.30.1. Potential for degraded performance of the glycol water system and off-spec ammonia supply to the main engine.	Asset	6	0		7.30.1. Low Temperature L Alarm (TAL) **Comment:** TT-E51, TT-M41, and TT-F53.	0		42. Further study to be done on the interface between the WinGD and the Nikkiso systems.

No.: 7 **Description:** Glycol Water System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
									7.30.2. Low-Low Temperature L Alarm (TALL) **Comment:** TT-E52, installed downstream of GW/JW heater HT-11, TT-E53 installed downstream of GW/Steam heater HT-12. 7.30.3. Temperature indicators (local). **Comment:** TI-F61, TI-F52.			
7.31	High Level		Operator's error during the filling of operation of the glycol water expansion tank TK-11 Internal leakage in the heaters/coolers	7.31.1. Potential for glycol water flooding on the open deck through the vent Same as deviation "other than flow".	Environmental	5	-1	High (4)		-1	High (4)	138. Further study to be done for the manufacturer to install the appropriate measuring instruments for the control of G/W expansion tank's filling limit.

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Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
7.32	Low Level		Low level of glycol water inside the glycol water expansion tank TK-11	7.32.1. Loss of pressure regulation in the glycol water system.	General	4	-1	High (3)	7.32.1. Low level transmitter. **Comment:** LT-E37	-2	Moderate (2)	139. Information is to be provided on the pressure regulation manner inside the water tank. 140. Further study to be done on the tank vent arrangement to avoid release directly to the environment.
				7.32.2. Introduction of air in the glycol water system resulting in inadequate heat transfer, overheating, circulation disruption, etc.	Asset	4	-1	High (3)	7.32.1. Low level transmitter. **Comment:** LT-E37	-2	Moderate (2)	139. Information is to be provided on the pressure regulation manner inside the water tank. 140. Further study to be done on the tank vent arrangement to avoid release directly to the environment.
				7.32.3. Potential for glycol water system and AFSS shutdown.	General	4	-1	High (3)	7.32.1. Low level transmitter. **Comment:** LT-E37	-1	High (3)	139. Information is to be provided on the pressure regulation manner inside the water tank.

No.: 7 **Description:** Glycol Water System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												140. Further study to be done on the tank vent arrangement to avoid release directly to the environment.

Company: EMSA, YCA, WinGD, Nikkiso, NTUA, ABS		
Title: EMSA NH3		
Description:		
Method: HAZOP	**Type:** Line/Pipe	N2 Supply System
Design Intent:		
Comment:		

No.: 8	**Description:** N2 Supply System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
8.1	General			8.1.1. General.								142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 148. Further study to be done on the purging capacity of the system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
8.2	No flow		Air compressor failure or air intake blockage	8.2.1. No air supply to compressorN2 generator system. No nitrogen generation.	General	4	-1	High (3)	8.2.1. Redundancy via nitrogen cylinders **Comment:** Not accepted	-1	High (3)	89. Further study to be done on the capacity of the nitrogen bottles and whether the stored capacity is sufficient to handle the purging of the system. Nikkiso is to provide the required amounts and the generator capacity of the nitrogen pumps to confirm that the 20 bottles can be refilled once their quantity has been used. 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
				8.2.2. Nitrogen generation inadequacy	General	4	-1	High (3)	8.2.1. Redundancy via nitrogen cylinders **Comment:** Not accepted	-1	High (3)	89. Further study to be done on the capacity of the nitrogen bottles and whether the stored capacity is sufficient to handle the purging of the system. Nikkiso is to provide the required amounts and the generator capacity of the nitrogen pumps to confirm that the 20 bottles can be refilled once their quantity has been used. 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
8.3	No flow		Manual valve MV-X1 (between N2 generator system and N2 booster compressor) closed due to failure or operator's error	8.3.1. Damage of the nitrogen generator system. No nitrogen generation.	Asset	4	-1	High (3)	8.3.1. Redundancy via nitrogen cylinders **Comment:** Not accepted	-1	High (3)	89. Further study to be done on the capacity of the nitrogen bottles and whether the stored capacity is sufficient to handle the purging of the system. Nikkiso is to provide the required amounts and the generator capacity of the nitrogen pumps to confirm that the 20 bottles can be refilled once their quantity has been used. 90. Further study to be done on the installation of a lock open mechanism. 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
8.4	No Flow		Nitrogen booster compression failure	8.4.1. No nitrogen generation.	Asset	5	-1	High (4)	8.4.1. Redundancy via nitrogen cylinders **Comment:** Not accepted	-1	High (4)	89. Further study to be done on the capacity of the nitrogen bottles and whether the stored capacity is sufficient to handle the purging of the system. Nikkiso is to provide the required amounts and the generator capacity of the nitrogen pumps to confirm that the 20 bottles can be refilled once their quantity has been used. 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
8.5	No Flow		Manual valve MV-X2 (between N2 booster compressor and N2 bottles) closed due to failure or operator's error.	8.5.1. Damage of booster compressor, no nitrogen generation.	Asset	5	-1	High (4)	8.5.1. Redundancy via nitrogen cylinders **Comment:** Not accepted	-1	High (4)	89. Further study to be done on the capacity of the nitrogen bottles and whether the stored capacity is sufficient to handle the purging of the system. Nikkiso is to provide the required amounts and the generator capacity of the nitrogen pumps to confirm that the 20 bottles can be refilled once their quantity has been used. 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
8.6	No Flow		Manual valve MV-X3 (downstream of N2 bottles) closed due to failure or operator's error.	8.6.1. Loss of 30 barg nitrogen purging/control capacity	Asset	5	-1	High (4)	8.6.1. Pressure Transmitter **Comment:** PT-H11, PT-H12 & PT-H13	-1	High (4)	91. Upgrade pressure transmitter 92. Install a secondary pressure regulating unit of 30 barg comprised of a manual valve, a pressure regulating valve and a non-return check valve for redundancy. 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
8.7	No Flow		Pressure regulating valve PRV-X1 malfunction due to failure or operator's error.	8.7.1. Loss of 30 barg nitrogen purging/control capacity	Asset	5	-1	High (4)	8.7.1. Pressure Transmitter **Comment:** PT-H11, PT-H12 & PT-H13	-1	High (4)	92. Install a secondary pressure regulating unit of 30 barg comprised of a manual valve, a pressure regulating valve and a non-return check valve for redundancy. 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.
8.8	No flow		Pneumatic valve N2-H01 closed due to failure or operator's error.	8.8.1. Loss of 30 barg nitrogen purging/control capacity.	Asset	5	-1	High (4)		-1	High (4)	93. Connect line of MV-X4 and utilize the parallel line. 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.
8.9	No Flow		Pneumatic valve N2-H03 open due to failure or operator's error	8.9.1. Loss of pressure.	General	4	-1	High (3)		-1	High (3)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested.
8.10	No Flow		Manual valve MV-X5 closed due to failure or operator's error	8.10.1. Lack of nitrogen	Asset	5	-1	High (4)	8.10.1. Pressure transmitters **Comment:** MV-X5	-1	High (4)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
8.11	No Flow		Pressure safety valve PSV-N32 leakage due to failure	8.11.1. Less nitrogen to the system. Potential for AFSS shutdown.	Asset	5	-2	High (3)	8.11.1. Pressure transmitter **Comment:** PT-H12 8.11.2. Low Pressure L Alarm (PAL) **Comment:** 3 barg 8.11.3. High Pressure L Alarm (PAH) **Comment:** 7 barg	-3	Moderate (2)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 144. Further study is to be done on the pressure data transmitted from the pressure valves in correlation to their settings. Definition of the lower and upper limits of the transducers are to be provided.
8.12	No Flow		Pressure regulating valve N2-H13 closed due to failure or operator's error.	8.12.1. Loss of N2 supply for valve control. AFSS shutdown.	Asset	5	-2	High (3)	8.12.1. Pressure transmitter **Comment:** PT-H11 8.12.2. Low Pressure L Alarm (PAL) **Comment:** 4.2 barg	-3	Moderate (2)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
									8.12.3. High Pressure L Alarm (PAH) **Comment:** 4.8 barg			143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 144. Further study is to be done on the pressure data transmitted from the pressure valves in correlation to their settings. Definition of the lower and upper limits of the transducers are to be provided.
8.13	No Flow		MV-X4, or CK-X3 closed due to failure or operator's error.	8.13.1. Loss of N2 supply for valve control. AFSS shutdown.	Asset	5	-2	High (3)		-2	High (3)	94. Pressure indicator is to be included in the line 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												144. Further study is to be done on the pressure data transmitted from the pressure valves in correlation to their settings. Definition of the lower and upper limits of the transducers are to be provided. 145. Further information is to be provided on the "HP PIPE TEST" line.
8.14	More Flow		Pressure regulating valve PRV-X1 malfunction due to failure or operator's error	8.14.1. Loss of pressure.	Asset	5	-1	High (4)	8.14.1. Pressure Safety Valve (PSV) **Comment:** PSV-N31, 32, 33 8.14.2. High L Alarm (LAH) **Comment:** PT-H3	-2	High (3)	95. Add manual valves lock open.
8.15	More Flow		Pressure regulating valve PRV-X3 malfunction due to failure or operator's error	8.15.1. Loss of pressure head for valve control. Potential for AFSS shutdown.	Asset	5	-1	High (4)		-1	High (4)	96. Include a pressure indicator downstream. 142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested.

No.: 8 | **Description:** N2 Supply System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 144. Further study is to be done on the pressure data transmitted from the pressure valves in correlation to their settings. Definition of the lower and upper limits of the transducers are to be provided.
8.16	Part of Flow		N2-H03, PSV-N31, PSV-N32, PSV-N33 leakage.	8.16.1. Unable to isolate the branch due to leakage.	Asset	4	-1	High (3)	8.16.1. Pressure Transmitters **Comment:** Settings for all transducers are to be completed.	-2	Moderate (2)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												144. Further study is to be done on the pressure data transmitted from the pressure valves in correlation to their settings. Definition of the lower and upper limits of the transducers are to be provided.
				8.16.2. Loss of pressure	Asset	4	-1	High (3)	8.16.1. Pressure Transmitters **Comment:** Settings for all transducers are to be completed.	-2	Moderate (2)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 144. Further study is to be done on the pressure data transmitted from the pressure valves in correlation to their settings. Definition of the lower and upper limits of the transducers are to be provided.

No.: 8 | **Description:** N2 Supply System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
				8.16.3. Excessive nitrogen consumption leading to potential system overload.	Asset	4	-1	High (3)	8.16.1. Pressure Transmitters **Comment:** Settings for all transducers are to be completed.	-2	Moderate (2)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 144. Further study is to be done on the pressure data transmitted from the pressure valves in correlation to their settings. Definition of the lower and upper limits of the transducers are to be provided.
8.17	Reverse Flow		N2 booster compressor failure	8.17.1. Nitrogen from cylinder to compressor	Asset	4	-1	High (3)		-1	High (3)	97. Include a non-return valve from the cylinders to the booster compressor in case that cylinder bottles' heads do not prevent return of flow.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 144. Further study is to be done on the pressure data transmitted from the pressure valves in correlation to their settings. Definition of the lower and upper limits of the transducers are to be provided. 146. Further information is to be provided on the 120 barg line.
8.18	High Temperature		Loss of cooling in the air compressors	8.18.1. Loss of system.	Asset	6	-1			-1		147. Further information to be provided on the air compressors system

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
8.19	Contaminated Flow	TBC	High humidity of the air discharge to the nitrogen generator system	8.19.1. Damage to the compressor	Asset	5	-1	High (4)		-1	High (4)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 148. Further study to be done on the purging capacity of the system. 149. Further study to be done on the drying system, if it is to be included in the generator system.
8.20	Contaminated Flow		Rust/oil from the air compressor	8.20.1. Failure, damage of the nitrogen generator	Asset	5	-1	High (4)		-1	High (4)	98. Further study to be done on the filtering capacity of the nitrogen system.

No.: 8 | **Description:** N2 Supply System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
												142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 148. Further study to be done on the purging capacity of the system. 154. Further study to be done on the dehydration system, if it is to be included in the generator system.
8.21	Other than Flow	YCA85 barg is high pressure	Introduction of high-pressure ammonia @ 22 or 85 barg from purging line.	8.21.1. Leakage of ammonia. due to hose rupture leading to potential injury.	Injury	6	-2	High (4)		-2	High (4)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												148. Further study to be done on the purging capacity of the system. 150. Consider including Double Block and Bleed Valves (DBBV) in all purging lines.
				8.21.2. Pressure buildup in the nitrogen pipelines due to ammonia entering at 85 barg.	Environmental	6	-3	High (3)		-3	High (3)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 148. Further study to be done on the purging capacity of the system. 150. Consider including Double Block and Bleed Valves (DBBV) in all purging lines.

No.: 8	**Description:** N2 Supply System

Item	Deviation	Comment	Initiating Event	Consequences	Matrix	Severity	Unmitigated Likelihood	Unmitigated Risk	Existing IPLs (Safeguards)	Mitigated Likelihood	Mitigated Risk	Recommended IPLs (Action Items)
8.22	Loss of Containment		Nitrogen leakage from the system	8.22.1. Dispersion of nitrogen fumes within the compartment.	Injury	6	-2	High (4)		-2	High (4)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested. 143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 148. Further study to be done on the purging capacity of the system. 150. Consider including Double Block and Bleed Valves (DBBV) in all purging lines. 151. Oxygen concentration detectors are to be included in the design.
				8.22.2. Potential loss of system pressure of the system.	Asset	5	-2	High (3)		-2	High (3)	142. Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested.

No.: 8	**Description:** N2 Supply System											
Item	**Deviation**	**Comment**	**Initiating Event**	**Consequences**	**Matrix**	**Severity**	**Unmitigated Likelihood**	**Unmitigated Risk**	**Existing IPLs (Safeguards)**	**Mitigated Likelihood**	**Mitigated Risk**	**Recommended IPLs (Action Items)**
												143. Further study to be done on the redundancy configuration of the nitrogen control/purging system. 148. Further study to be done on the purging capacity of the system. 150. Consider including Double Block and Bleed Valves (DBBV) in all purging lines. 151. Oxygen concentration detectors are to be included in the design.

Appendix C HAZOP Action Items List

Table 10: HAZOP Action Items List

No.	Type	References	Recommendation	Responsibility	Comment
1.	Rec	2.1 General – Fuel Tank Filling 3.14 Sloshing. Heavy Weather – Ammonia Transfer for AFSS 5.5 Low Level. Emptying of catch tank to the main NH3 fuel supply line. – AFSS - Ammonia return from M/E	Consider the installation of an enclosed Tank Connection Space		Advise forthcoming MSC publication (December 2024) CCC 10 WP.6 (to be reviewed when MSC Circ. will be issued)
2.	Rec	2.1 General – Fuel Tank Filling	Further study to be done on the control of temperature in the Tank. Nikkiso is considering of providing thermal insulation to protect from solar radiation. As per the interim guidelines for ammonia as a fuel, the temperature in the tank shall be monitored at all times. In addition, the temperature of the liquefied ammonia in the fuel tanks should be always maintained at a temperature of no more than -30°C, by either reliquefication of vapours, thermal oxidation of vapours, liquefied ammonia fuel cooling (IGF Code, Sec. 6.9.1.1).		Further study to be done on the control of temperature in the Tank. Nikkiso is considering of providing thermal insulation to protect from solar radiation.
3.	Rec	2.1 General – Fuel Tank Filling	Further study to be done on the maximum allowable filling level in the tank ((95% instead of 98% as per the interim guidelines for ammonia as a fuel: 6.8.2)		
4.	Rec	2.1 General – Fuel Tank Filling	Further study to be done on continuous temperature monitoring and control. Update both P&ID and C&ED with temperature transmitters.		

No.	Type	References	Recommendation	Responsibility	Comment
5.	Rec	2.2 No Flow. Remotely controlled valve ESD-M11 closed due to failure or operator's error. – Fuel Tank Filling 2.3 No Flow. Manual valve MV-M13 closed due to failure or operator's error. – Fuel Tank Filling	Clarifications to be provided on the pressure transmitter settings. Emergency shutdown (ESD) must be activated when PT-M30 is triggered		
6.	Rec	2.2 No Flow. Remotely controlled valve ESD-M11 closed due to failure or operator's error. – Fuel Tank Filling 2.3 No Flow. Manual valve MV-M13 closed due to failure or operator's error. – Fuel Tank Filling 2.4 No Flow. Manual valve MV-M14 closed due to failure or operator's error. – Fuel Tank Filling 2.5 No Flow. Remotely controlled valve ESD-M12 closed due to failure or operator's error. – Fuel Tank Filling	Further analysis to be conducted to determine how the reliquefication system will serve as the first line of defence in the event of pressure build up in the bunkering line. Presently, during bunkering process, the only method available to control pressure is through the vapour return line to the supply / bunker ship.	Nikkiso	Venting of fuel vapour for control of the tank pressure is not acceptable except in emergency situations. Ref. MSC.1/Circ. 1687 on Interim Guidelines for the safety of ships using ammonia as fuel.
7.	Rec	2.7 More flow. Running of more than one bunkering pumps – Fuel Tank Filling	Development of appropriate bunkering procedures.	Bunkering Entity, Nikkiso	
8.	Rec	2.9 Part of Flow. Thermal safety valve TSV-M01 stuck open. – Fuel Tank Filling 2.10 Part of Flow. Leakage from the Valve Stem – Fuel Tank Filling	Mechanical Spray Shielding is to be provided around ammonia bunkering flanges (upstream of ST-M11 and ST-M61) if not hot welded (in the case of bolted connections).		
9.	Rec	2.9 Part of Flow. Thermal safety valve TSV-M01 stuck open. – Fuel Tank Filling	Liquid detection at bunkering station. Low temperature leading to Emergency Shut Down (ESD). A study to be made on the sensor calibration for the case of extremely low ambient temperature.		

No.	Type	References	Recommendation	Responsibility	Comment
		2.10 Part of Flow. Leakage from the Valve Stem – Fuel Tank Filling			
10.	Rec	2.9 Part of Flow. Thermal safety valve TSV-M01 stuck open. – Fuel Tank Filling 2.10 Part of Flow. Leakage from the Valve Stem – Fuel Tank Filling	Drip tray to be directed to the dilution tank instead of being discharged overboard.		Drip trays should be provided with means to safely drain or transfer spills that contain ammonia to be contained or treated. Ref. MSC.1/Circ. 1687 on Interim Guidelines for the safety of ships using ammonia as fuel.
11.	Rec	2.13 Misdirected Flow. Remotely controlled valve ESD-C61 open due to failure or operator's error – Fuel Tank Filling	Further identification of all valves that need to be monitored (position) and controlled remotely during bunkering operation.	Nikkiso	
12.	Rec		Considering that classification guidelines do not currently consider a Low-Low Level Alarm (LALL) setting, a study is to be conducted to evaluate the necessity of such a Low setting.		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. Ref. MSC.1/Circ. 1687 on Interim Guidelines for the safety of ships using ammonia as fuel.
13.	Rec	2.16 High Temperature. High ambient temperature during bunkering operations – Fuel Tank Filling	Given that the fuel tank will be uninsulated and the Reliquefication Plant system is disconnected in the current design, further study to be done on heat transfer analysis and monitoring of heat ingress to the tank. This shall be such that the tank is: 1. insulated, 2. have means to control BOG, 3. temperature inside the tank shall be always monitored.		

No.	Type	References	Recommendation	Responsibility	Comment
14.	Rec	2.16 High Temperature. High ambient temperature during bunkering operations – Fuel Tank Filling	Given that the fuel tank will be uninsulated and the Reliquification Plant system is disconnected in the current design, temperature monitoring and Emergency Shut Down (ESD) is to be provided upstream of the tank. This shall be such that the tank is: 1. insulated, 2. have means to control BOG, 3. temperature inside the tank shall be always monitored.		
15.	Rec	2.16 High Temperature. High ambient temperature during bunkering operations – Fuel Tank Filling	Further study to be done on the heat transfer from ammonia returning to the fuel tank from downstream of the HP pump skid, following a triggering of the Pressure Safety Valve PSV-F31.		
16.	Rec	2.17 High Pressure. External fire close to the tank – Fuel Tank Filling	Further study to be done to determine an appropriate safety margin of the Pressure Safety Valves PSV-C51 and PSV-C01 setting, so that its activation pressure will be lower than the maximum design pressure of the tank. Ammonia interim guidelines shall be followed (ref. section 6.7)		
17.	Rec	2.20 Contaminants in the Process Line. Particles from the pipe due to corrosion/erosion – Fuel Tank Filling	Further study to be done on the tolerance of the engine to ammonia contaminants		WinGD: 10-micron filter necessary. Absolute prerequisite.
18.	Rec	2.20 Contaminants in the Process Line. Particles from the pipe due to corrosion/erosion – Fuel Tank Filling	Clarification on the function of the Nikkiso pump filters, i.e. whether they are designed to protect system up to the tank or they also protect the system components downstream of the tank.		
19.	Rec		Further study to be done on the installation of vacuum breakers		
20.	Rec	3.1 General – Ammonia Transfer for AFSS	Consider the re positioning and the type of tank support of the catch tank (CT-01) to limit the effect of sloshing. Capacity of the tank is also to be evaluated.		

No.	Type	References	Recommendation	Responsibility	Comment
21.	Rec	3.1 General – Ammonia Transfer for AFSS	Further study to be done on all return discharges from Pressure Safety Valves (PSV) to the tank to investigate the potential of a high-pressure scenario to the fuel tanks.		
22.	Rec	3.2 No Flow. Failure of Low-pressure pump LP-11. – Ammonia Transfer for AFSS 3.7 Blocked flow. Clogging of Low-pressure pump LP-11 filters. – Ammonia Transfer for AFSS	Evaluate procedures for cleaning low pressure pump filters to ensure as sufficiently maintained to avoid clogging or premature clogging (clogging earlier than it would otherwise occur).		
23.	Rec	3.2 No Flow. Failure of Low-pressure pump LP-11. – Ammonia Transfer for AFSS	Control logic procedure is to be provided/updated for the engagement of the redundancy pump. Secondary pump should start immediately in case of a failure of the first pump.		
24.	Rec	3.2 No Flow. Failure of Low-pressure pump LP-11. – Ammonia Transfer for AFSS 3.4 No flow. Non return valves CK-C13/CK-C14, CK-63/CK-64 inadvertently closed due to failure or operator's error – Ammonia Transfer for AFSS	An additional pressure transducer is to be installed downstream as PCV-C15 does not transmit a signal to the pumps.		
25.	Rec		Adjustment of pressure setting for PT-F21	Nikkiso	
26.	Rec	3.4 No flow. Non return valves CK-C13/CK-C14, CK-63/CK-64 inadvertently closed due to failure or operator's error – Ammonia Transfer for AFSS	Position indicator is to be provided.		
27.	Rec	3.6 No Flow. Clogged Filter ST-F01/ST-F02 – Ammonia Transfer for AFSS	Considering the possibility of a filter rupture further study to done on the type of filters chosen.		WinGD: Duplex type filter is recommended. Absolute filtration grade of 10 micrometres must be selected. Stainless steel wire mesh is recommended.

No.	Type	References	Recommendation	Responsibility	Comment
28.	Rec	3.6 No Flow. Clogged Filter ST-F01/ST-F02 – Ammonia Transfer for AFSS	Consider automatic changeover from one filter to the other		
29.	Rec	3.6 No Flow. Clogged Filter ST-F01/ST-F02 – Ammonia Transfer for AFSS 7.5 No Flow. Either strainer ST-E15 or ST-E16, installed at the suction side of the glycol water pumps (GP-01 and GP-02, respectively) clogged. – Glycol Water System 7.12 No Flow. ST-F01 Blocked – Glycol Water System	Procedures are to be developed for the maintenance of the filters and/or strainers.		
30.	Rec	1.1 General – General	Operational procedures to include the position of valve MV-C18		
31.	Rec		Provide position indicator for Valve MV-C18, MV-C19		
32.	Rec	3.9 Reverse Flow. Non return valves CK-C13/CK-C14 for both low pressure pumps failure (on the opposite line from the operating one) – Ammonia Transfer for AFSS	To be evaluated class requirements on addition of monitoring sensor(s).		
33.	Rec	3.10 Less Flow. Failure of Low-pressure Pump LP-11 – Ammonia Transfer for AFSS	Temperature monitoring of the low-pressure pump (LP-11, LP-12) is to be also included in the control logic. A holistic monitoring of the pump operation is recommended.		
34.	Rec	3.10 Less Flow. Failure of Low-pressure Pump LP-11 – Ammonia Transfer for AFSS	High-High Current L Alarm (Control Signal) is to be included in the control logic.		

No.	Type	References	Recommendation	Responsibility	Comment
35.	Rec	3.11 Less Flow. Pressure control valve PCV-C15 malfunction – Ammonia Transfer for AFSS	Further study to be done on the positioning of PCV-C15. The current positioning does not ensure minimum flow conditions for the LP fuel tank pumps in the event of a PCV-C15 malfunction.		
36.	Rec	3.11 Less Flow. Pressure control valve PCV-C15 malfunction – Ammonia Transfer for AFSS	Control logic is to include actions for the failure of PCV-C15		
37.	Rec	3.12 Less Flow. Temperature safety valve TSV-C11 leakage – Ammonia Transfer for AFSS	Designer to consider a High Temperature L Alarm (TAL) in the TSV return line. Consideration is to be given on the position of the temperature reading.		Candidate location is in the common line VNH-C21-50A-SS316.
38.	Rec	3.13 More Flow. Pressure control valve PCV-C15 malfunction. – Ammonia Transfer for AFSS	Consider development of appropriate control logic sequence to ensure sufficient ammonia amount is present in the tank.		
39.	Rec	7.29 Improper heat exchange in the GW/JW heater HT-11 and GW/steam heater HT-12 Restricted flow of glycol water (due to pump malfunction, clogged strainers, partially opened valves, etc.) – Glycol Water System 7.30 Less Temperature. Improper heat exchange in the GW/JW heater HT-11, GW/steam heater HT-12, after cooler HT-02, HP heater HT-01, cooler in the upstream of the glycol water expansion tank TK-11 – Glycol Water System	Further study to be done on the interface of the WinGD engine system and Nikkiso Fuel Gas Supply System		WinGD: system cannot operate with a 95% filling level. Catch tank should be 2-3 times the system volume.

No.	Type	References	Recommendation	Responsibility	Comment
40.	Rec	5.6 High Level. Overfilling of catch tank – AFSS - Ammonia return from M/E	Further study to be done on the collection (volume and proper dimensioning) ability of the Vapour collection tank (VCT-01). The dimensions of the catch tank shall accommodate the following: 1. BOG return, 2. engine return, 3. fuel supply. The Vapour Collection Tank should be appropriately sized to ensure compliance with toxicity limits at the vent outlet.		
41.	Rec	5.2 No flow. Manual non-return valve CK-F51 closed due to failure or operator's error – AFSS - Ammonia return from M/E	Further study is to be done on the requirements coming from the engine manufacturer to maintain the pressure of the catch tank (CT-01) at 22 bar for the occasion of receiving ammonia from the engine.		
42.	Rec	4.1 General – AFSS - Ammonia Supply to M/E	Automatically operated shutoff valves are to be situated at the bulkhead inside the fuel preparation room		
43.	Rec	4.1 General – AFSS - Ammonia Supply to M/E	HAZOP to be conducted on the high-pressure skid following a detailed PID submission.		
44.	Rec	4.1 General – AFSS - Ammonia Supply to M/E 4.17 Pressure Pulse. High pressure in combination with low volume – AFSS - Ammonia Supply to M/E	Further study is needed to ensure compliance with the engine's tolerance specifications for pressure fluctuations caused by high-pressure pumps.		WinGD: Permissible pressure fluctuation is +- 2 bars --------------------
45.	Rec	4.1 General – AFSS - Ammonia Supply to M/E 5.2 No flow. Manual non-return valve CK-F51 closed due to failure or operator's error – AFSS - Ammonia return from M/E	Further study to be done on the overall catch tank philosophy/architecture.		
46.	Rec	4.4 No Flow. Clogging of filter/strainer ST-F34 – AFSS - Ammonia Supply to M/E	Consider the installation of a dual filter setup in the position of the single filter ST-F34		

No.	Type	References	Recommendation	Responsibility	Comment
47.	Rec	4.7 No/Less Flow. Failure of CKF54 – AFSS - Ammonia Supply to M/E	Further study to be done regarding the startup of the HP pump skid		
48.	Rec	4.7 No/Less Flow. Failure of CKF54 – AFSS - Ammonia Supply to M/E	Further study to be done on TT F35 or include an additional LL and HH temperature transmitter		
49.	Rec	4.8 No/Flow/Less Flow. Untagged non-return check valve upstream FVU remains closed due to failure or operator's error. – AFSS - Ammonia Supply to M/E	WinGD is to advise whether the untagged non-return check valve upstream of the FVU can be introduced or if it will pose maintenance-related issues.		
50.	Rec	4.8 No/Flow/Less Flow. Untagged non-return check valve upstream FVU remains closed due to failure or operator's error. – AFSS - Ammonia Supply to M/E	Further study to be done on the necessity of the untagged non-return check valve upstream of the FVU.		
51.	Rec	4.9 Low Temperature. HP Heater (HT-01) – AFSS - Ammonia Supply to M/E 4.15 High Temperature. HP Heater HT-01 malfunction. – AFSS - Ammonia Supply to M/E	Further study to be done on the heat transfer analysis of the heat exchanger HT-01. Consider a margin allowance for resistance due to particle deposition.		
52.	Rec	4.11 Less Flow – AFSS - Ammonia Supply to M/E 7.2 No flow. No glycol water in the Glycol water expansion tank TK-11 – Glycol Water System 7.3 No Flow. Manual valve GW-E06 installed at the suction side of the glycol water pumps closed due to failure or operator's error. – Glycol Water System 7.18 Less Flow. Manual valve GW-E06 installed at the suction side of the glycol water pumps partially closed due to failure or operator's error – Glycol Water System	Addition of High-High Pressure L Alarm (PAHH) and Emergency Shut Down (ESD), downstream of the HP pump skid.		

No.	Type	References	Recommendation	Responsibility	Comment
53.	Rec	4.12 More Flow – AFSS - Ammonia Supply to M/E 4.13 Part of Flow – AFSS - Ammonia Supply to M/E 4.16 High Pressure. HP pump HP-01/02 failure – AFSS - Ammonia Supply to M/E	Install a High-High Pressure L Alarm (PAHH) transmitter for safety and control (ESD) in the discharge of the HP pump skid after PT-F31		
54.	Rec	4.9 Low Temperature. HP Heater (HT-01) – AFSS - Ammonia Supply to M/E 4.15 High Temperature. HP Heater HT-01 malfunction. – AFSS - Ammonia Supply to M/E 4.16 High Pressure. HP pump HP-01/02 failure – AFSS - Ammonia Supply to M/E	Further study to be done on alarm mechanisms for the operation (both safety and control of the glycol system) of the heat exchanger performance. Inclusion of a temperature transmitter after the HP skid and possible addition of another heat exchanger.		
55.	Rec	4.16 High Pressure. HP pump HP-01/02 failure – AFSS - Ammonia Supply to M/E	Consider adding a Low-Low Pressure L Alarm (PALL) and High-High Pressure L Alarm (PAHH) and Emergency Shut Down (ESD) (include it in the cause and effect diagram)		
56.	Rec		Addition of a pressure transmitter at the discharge of the high-pressure pump skid after the pressure transmitter PT-F31		
57.	Rec	4.3 No Flow. HP pump HP-01/02 failure – AFSS - Ammonia Supply to M/E	Addition of an extra pressure transmitter for Emergency Shut Down (ESD)		
58.	Rec	4.3 No Flow. HP pump HP-01/02 failure – AFSS - Ammonia Supply to M/E	Further study to be done on the control logic part of the high-pressure pump section		
59.	Rec	4.6 No Flow/Less Flow. XV-F81 remains open – AFSS - Ammonia Supply to M/E	Include a non-return valve		

No.	Type	References	Recommendation	Responsibility	Comment
60.	Rec	4.6 No Flow/Less Flow. XV-F81 remains open – AFSS - Ammonia Supply to M/E	Position indicator for valve XV-F81		
61.	Rec	4.6 No Flow/Less Flow. XV-F81 remains open – AFSS - Ammonia Supply to M/E	Further study to be done on the inclusion of a Double Block and Bleed Valve (DBBV)		
62.	Rec	4.6 No Flow/Less Flow. XV-F81 remains open – AFSS - Ammonia Supply to M/E	The maintenance procedure for all components of the system must be clearly described.		
63.	Rec	4.18 Reverse Flow. Malfunction of XV-F71 – AFSS - Ammonia Supply to M/E	Further study to be done on the delivery of nitrogen for pressure and ammonia level regulation purposes.		
64.	Rec	5.1 General – AFSS - Ammonia return from M/E	Further analysis of the node No.5 (ammonia return from M/E) is required once the respective P&ID diagram becomes available.		
65.	Rec	5.1 General – AFSS - Ammonia return from M/E	FGSS system is to be designed to avoid/limit potential pressure surges and hammering effects.		
66.	Rec	5.2 No flow. Manual non-return valve CK-F51 closed due to failure or operator's error – AFSS - Ammonia return from M/E	Addition of a pressure transmitter (safety and control) to trigger an emergency shutdown.		
67.	Rec	5.2 No flow. Manual non-return valve CK-F51 closed due to failure or operator's error – AFSS - Ammonia return from M/E	Further study to be done on the control logic of the high-pressure pumps HP-01/02 to address the standby operation and purging scenario.		
68.	Rec	5.2 No flow. Manual non-return valve CK-F51 closed due to failure or operator's error – AFSS - Ammonia return from M/E	Further study to be done on the (re)design of the return line.		
69.	Rec	5.2 No flow. Manual non-return valve CK-F51 closed due to failure or operator's error – AFSS - Ammonia return from M/E	Further study to be done on the appropriate sizing of valves PCV-F54 and TSV-F03 of the catch tank CT-01		

No.	Type	References	Recommendation	Responsibility	Comment
70.	Rec	5.3 Other Than Flow. Leak from fresh water side to the fuel side inside the cooler HT-03 – AFSS - Ammonia return from M/E	Conduct HAZOP analysis once a detailed P&ID of the cooler HT-03 becomes available.		
71.	Rec	5.4 Other Than Flow. Leakage of water inside the FVU – AFSS - Ammonia return from M/E	Further study to be done on the ammonia injection cooling system and the fuel valve unit once more details become available from the system design.		
72.	Rec	6.1 General – BOG Handling System	PID diagram of the BOG system is to be supplied		
73.	Rec	6.1 General – BOG Handling System	Further study to be done on the purging connection of the BOG and the conformity with the IGF code		
74.	Rec	7.1 General – Glycol Water System 7.27 Other Than Flow. Leak from the ammonia side to the to the glycol water side inside the HP heater HT-01. – Glycol Water System	Further study to be done on the venting of the glycol water expansion tank TK-11. Consider venting through the dilution tank DT-01 as an alternative to venting directly to the open deck.	Ship Designer, Nikkiso	
75.	Rec	7.7 No Flow. Manual valve GW-E03 installed upstream of the GW/JW Heater HT-11 closed due to failure or operator's error – Glycol Water System 7.8 No Flow. Manual valve GW-E04 installed downstream of the GW/JW heater HT-11 closed due to failure or operator's error – Glycol Water System	Install a High-Pressure L Alarm (PAH) transmitter (warning), and a High-High Pressure L Alarm (PAHH) transmitter (safety and control) to initiate AFSS shutdown, downstream of the glycol water pumps.	Nikkiso	

No.	Type	References	Recommendation	Responsibility	Comment
		7.9 No Flow. Manual valve GW-E04 installed downstream of the GW/steam heater HT-12 closed due to failure or operator's error – Glycol Water System 7.11 No Flow. Manual valve GW-F07 installed upstream of the HP heater HT-01 closed due to failure or operator's error – Glycol Water System 7.12 No Flow. ST-F01 Blocked – Glycol Water System 7.13 No Flow. Strainer ST-F01 installed upstream of the HP heater HT-01 clogged – Glycol Water System 7.14 No flow. Manual valve GW-F09 installed upstream of the after cooler HT-02 closed due to failure or operator's error – Glycol Water System 7.15 No Flow. Manual valve GW-F10 installed downstream of the after cooler HT-02 closed due to failure or operator's error – Glycol Water System			
76.	Rec	7.11 No Flow. Manual valve GW-F07 installed upstream of the HP heater HT-01 closed due to failure or operator's error – Glycol Water System	Install a High-Pressure L Alarm (PAH) transmitter for warning in the upstream of the HP heater HT-01, before the manual valve GW-F07.		

No.	Type	References	Recommendation	Responsibility	Comment
77.	Rec	7.12 No Flow. ST-F01 Blocked – Glycol Water System 7.13 No Flow. Strainer ST-F01 installed upstream of the HP heater HT-01 clogged – Glycol Water System	Install a High-Pressure L Alarm (PAH) transmitter in the upstream of the HP heater HT-01, before the manual valve GW-F07. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system.	Nikkiso	
78.	Rec	7.14 No flow. Manual valve GW-F09 installed upstream of the after cooler HT-02 closed due to failure or operator's error – Glycol Water System 7.15 No Flow. Manual valve GW-F10 installed downstream of the after cooler HT-02 closed due to failure or operator's error – Glycol Water System	Install a High-Pressure L Alarm (PAH) transmitter in the upstream of the after cooler HT-02, prior to the manual valve GW-F09. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system.		
79.	Rec	7.16 No Flow. Manual valve GW-E19 (drain of glycol water tank TK-11) left open due to operator's error – Glycol Water System	Consider installing a physical locking device to secure valve GW-E19 in the closed position, preventing accidental opening due to operator error.	Nikkiso	Blank flange (added by Nikkiso) cannot be considered a locking device. WinGD does not accept it as a blank flange
80.	Rec	7.20 Less Flow. Flap check valve GW-E11/12 at the discharge of glycol water pump GP-01/02 partially blocked due to failure – Glycol Water System	Check for additional safeguards when P&ID diagram for the glycol water pumps becomes available.		
81.	Rec	7.22 Less Flow. Manual valve GW-F07 or GW-F08 partially blocked due to failure or operator's error, or strainer ST-F01 partially clogged – Glycol Water System	Install a Low-Pressure L Alarm (PAL) transmitter in the upstream of the HP heater HT-01, before the manual valve GW-F07. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system.		

No.	Type	References	Recommendation	Responsibility	Comment
82.	Rec	7.23 Less Flow. Manual valve GW-F09 or GW-F10 installed before or after cooler HT-02 partially closed due to failure or operator's error – Glycol Water System	Install a Low-Pressure L Alarm (PAL) transmitter in the upstream of the after cooler HT-02, prior to the manual valve GW-F09. Conduct a study to determine whether the transmitter should be used solely for safety or if it should also incorporate a trip function to shut down the system.		
83.	Rec	7.25 No Flow. HT-12 improper/malfunction (clogging or external/internal leakage) – Glycol Water System	Include pressure transmitter and trip function downstream of HT-12 serving the two streams directed to the BOG compressor and the HP heater. Study if the transmitters should be only for safety or should also have a trip function.		
84.	Rec	7.1 General – Glycol Water System 7.27 Other Than Flow. Leak from the ammonia side to the to the glycol water side inside the HP heater HT-01. – Glycol Water System	Install a pH sensor in the glycol water tank TK-11.	Nikkiso	EMSA: to consider is the range of pH that will trigger an alarm. ------------- ABS: the Ammonium water sensor is an Ion Selective Electrode (ISE). It measures charged ammonium ions found in the water. By using a complex calculation, the sensor is also able to measure the ammonia concentration in the water. ---------------------- YCA: conductivity should also be measured.
85.	Rec	8.2 No flow. Air compressor failure or air intake blockage – N2 Supply System 8.3 No flow. Manual valve MV-X1 (between N2 generator system and N2 booster compressor) closed due to failure or operator's error – N2 Supply System 8.4 No Flow. Nitrogen booster compression failure – N2 Supply System	Further study to be done on the capacity of the nitrogen bottles and whether the stored capacity is sufficient to handle the purging of the system. Nikkiso is to provide the required amounts and the generator capacity of the nitrogen pumps to confirm that the 20 bottles can be refilled once their quantity has been used.	Nikkiso	Nikkiso: nitrogen amount is enough to purge the whole system for two shutdowns.

No.	Type	References	Recommendation	Responsibility	Comment
		8.5 No Flow. Manual valve MV-X2 (between N2 booster compressor and N2 bottles) closed due to failure or operator's error. – N2 Supply System			
86.	Rec	8.3 No flow. Manual valve MV-X1 (between N2 generator system and N2 booster compressor) closed due to failure or operator's error – N2 Supply System	Further study to be done on the installation of a lock open mechanism.		
87.	Rec	8.6 No Flow. Manual valve MV-X3 (downstream of N2 bottles) closed due to failure or operator's error. – N2 Supply System	Upgrade pressure transmitter		
88.	Rec	8.6 No Flow. Manual valve MV-X3 (downstream of N2 bottles) closed due to failure or operator's error. – N2 Supply System 8.7 No Flow. Pressure regulating valve PRV-X1 malfunction due to failure or operator's error. – N2 Supply System	Install a secondary pressure regulating unit of 30 barg comprised of a manual valve, a pressure regulating valve and a non-return check valve for redundancy.		
89.	Rec	8.8 No flow. Pneumatic valve N2-H01 closed due to failure or operator's error. – N2 Supply System	Connect line of MV-X4 and utilize the parallel line.		
90.	Rec	8.13 No Flow. MV-X4, or CK-X3 closed due to failure or operator's error. – N2 Supply System	Pressure indicator is to be included in the line		
91.	Rec	8.14 More Flow. Pressure regulating valve PRV-X1 malfunction due to failure or operator's error – N2 Supply System	Add manual valves lock open.		

No.	Type	References	Recommendation	Responsibility	Comment
92.	Rec	8.15 More Flow. Pressure regulating valve PRV-X3 malfunction due to failure or operator's error – N2 Supply System	Include a pressure indicator downstream.		
93.	Rec	8.17 Reverse Flow. N2 booster compressor failure – N2 Supply System	Include a non-return valve from the cylinders to the booster compressor in case that cylinder bottles' heads do not prevent return of flow.		
94.	Rec	8.20 Contaminated Flow. Rust/oil from the air compressor – N2 Supply System	Further study to be done on the filtering capacity of the nitrogen system.		
95.	Rec	8.23 Low Temperature. Control Valves malfunction – N2 Supply System	Further study to be done on the yielding temperature of the nitrogen gas upon reduction of the pressure of the nitrogen gas stream		
96.	Rec		Gas dispersion analysis to be conducted to evaluate efficiency of the gas detection system and the location for gas detectors inside the space.		
97.	Rec	2.7 More flow. Running of more than one bunkering pumps – Fuel Tank Filling	System design is to be developed according to the /IGF codes.	Nikkiso	
98.	Rec	2.9 Part of Flow. Thermal safety valve TSV-M01 stuck open. – Fuel Tank Filling 7.25 No Flow. HT-12 improper/malfunction (clogging or external/internal leakage) – Glycol Water System	Critical spare parts, e.g., Thermal Relief Valves, heat exchangers list is to be evaluated and provided/suggested.		
99.	Rec	2.11 As well as Flow. Nitrogen inside the bunkering line – Fuel Tank Filling	Further study to be done on the nitrogen return line from the BOG.		
100.	Rec	3.3 No Flow. Failure of remotely operated valve ESD-C13. – Ammonia Transfer for AFSS	Further study to be done on the shutoff pressure and the safety pressure limit of the low-pressure pump.		

No.	Type	References	Recommendation	Responsibility	Comment
101.	Rec		Further study to be done on the operational capability of the present design		
102.	Rec	4.2 No Flow. Manual valve MV-F21 closed due to failure or operator's error – AFSS - Ammonia Supply to M/E 4.4 No Flow. Clogging of filter/strainer ST-F34 – AFSS - Ammonia Supply to M/E 4.5 No Flow. Blocked High-pressure heater HT-01. – AFSS - Ammonia Supply to M/E	Pressure pumps are to be equipped with dry running protection		
103.	Rec	4.8 No/Flow/Less Flow. Untagged non-return check valve upstream FVU remains closed due to failure or operator's error. – AFSS - Ammonia Supply to M/E	Consider the possibility of removing the check valve or elaborate further on the purpose of its existence.	Nikkiso	
104.	Rec	4.9 Low Temperature. HP Heater (HT-01) – AFSS - Ammonia Supply to M/E	Consider installation of absorbing/elongation relief devices to mitigate stress in the system.		
105.	Rec	4.9 Low Temperature. HP Heater (HT-01) – AFSS - Ammonia Supply to M/E	Further study to be done to determine the lowest possible temperature that the piping system can withstand.		
106.	Rec	4.9 Low Temperature. HP Heater (HT-01) – AFSS - Ammonia Supply to M/E	Further study to be done upon the ventilation air temperature.		
107.	Rec	4.10 No Flow. Clogged Y-strainer (untagged - after double valve PG-F43/PG-F44) – AFSS - Ammonia Supply to M/E	Clarification to be given if High-High Pressure L Alarm (PAHH) also has an Emergency Shut Down (ESD) function.	Nikkiso	
108.	Rec	4.14 As well as Flow. Malfunction of non-return valve CK-F54 – AFSS - Ammonia Supply to M/E	Further study to be done (simulation of the control logic)	Nikkiso	

No.	Type	References	Recommendation	Responsibility	Comment
109.	Rec		Further study to be done on the outlet pressure	Nikkiso	
110.	Rec	4.15 High Temperature. HP Heater HT-01 malfunction. – AFSS - Ammonia Supply to M/E	Further study to be done on the control logic		
111.	Rec	4.16 High Pressure. HP pump HP-01/02 failure – AFSS - Ammonia Supply to M/E 4.17 Pressure Pulse. High pressure in combination with low volume – AFSS - Ammonia Supply to M/E	Further study to be done on the design pressure of the HP piping.		
112.	Rec	4.16 High Pressure. HP pump HP-01/02 failure – AFSS - Ammonia Supply to M/E	Further study to be done on the back pressure when the Double Block and Bleed Valve closes.		
113.	Rec	4.16 High Pressure. HP pump HP-01/02 failure – AFSS - Ammonia Supply to M/E	Further study to be done on the reaction time of the pumps		
114.	Rec	4.17 Pressure Pulse. High pressure in combination with low volume – AFSS - Ammonia Supply to M/E	Further study to be done on the installation of accumulator buffers		
115.	Rec	7.1 General – Glycol Water System	Further study to be done on the impact of the expansion tank on the system's pressure regulation capability	Nikkiso	
116.	Rec	7.3 No Flow. Manual valve GW-E06 installed at the suction side of the glycol water pumps closed due to failure or operator's error. – Glycol Water System 7.4 No Flow. Either manual valve GW-E01 or GW-E02, installed at the suction side of the glycol water pumps (GP-01 and GP-02, respectively) closed due to failure or operator's error. – Glycol Water System	A list of critical valves must be identified and relevant spare parts to be included in the vessel's inventory.		

No.	Type	References	Recommendation	Responsibility	Comment
		7.18 Less Flow. Manual valve GW-E06 installed at the suction side of the glycol water pumps partially closed due to failure or operator's error – Glycol Water System 7.19 Less Flow. Manual valve GW-E01/02 partially blocked due to failure or operator's error, or strainer ST-E15/16 partially clogged (both are installed in the suction side of the glycol water pumps GP-01/02) – Glycol Water System			
117.	Rec	7.10 No Flow. Either glycol water pump GP-01 and GP-02 failure – Glycol Water System 7.17 Less Flow. Glycol water pump GP-01/02 malfunction. – Glycol Water System	Further study to be done on the maintenance plan of the pumps.		
118.	Rec	7.6 No Flow. Either flap check valve GW-E11 or GW-E12, installed at the discharge side of the glycol water pumps (GP-01 and GP-02, respectively) closed due to failure – Glycol Water System	Further study to be done on the overall (preventive) maintenance plan of the ammonia handling system.		
119.	Rec	7.9 No Flow. Manual valve GW-E04 installed downstream of the GW/steam heater HT-12 closed due to failure or operator's error – Glycol Water System	Second valve tagged as GW-E04 in the P&ID is to be renamed.	Nikkiso	
120.	Rec	7.12 No Flow. ST-F01 Blocked – Glycol Water System	Further information is to be provided on the provision of the high and low pressure readings of PT-F42.	Nikkiso	

No.	Type	References	Recommendation	Responsibility	Comment
121.	Rec	7.11 No Flow. Manual valve GW-F07 installed upstream of the HP heater HT-01 closed due to failure or operator's error – Glycol Water System 7.14 No flow. Manual valve GW-F09 installed upstream of the after cooler HT-02 closed due to failure or operator's error – Glycol Water System 7.15 No Flow. Manual valve GW-F10 installed downstream of the after cooler HT-02 closed due to failure or operator's error – Glycol Water System 7.22 Less Flow. Manual valve GW-F07 or GW-F08 partially blocked due to failure or operator's error, or strainer ST-F01 partially clogged – Glycol Water System 7.23 Less Flow. Manual valve GW-F09 or GW-F10 installed before or after cooler HT-02 partially closed due to failure or operator's error – Glycol Water System	Further information is to be provided on the pressure data transmitted.		
122.	Rec	7.16 No Flow. Manual valve GW-E19 (drain of glycol water tank TK-11) left open due to operator's error – Glycol Water System	Include Low-Low L Alarm (LALL), High-High L Alarm (LAHH) and Emergency Shut Down (ESD) function to the Level Transducer LT-E37.	Nikkiso	
123.	Rec	7.16 No Flow. Manual valve GW-E19 (drain of glycol water tank TK-11) left open due to operator's error – Glycol Water System	Further study to be done on the drainage of the glycol water expansion tank TK-11. Consider draining from the water expansion tank to the dilution tank DT-01. Further study to be done for the remotely operated valve GW-E19.	Nikkiso	

No.	Type	References	Recommendation	Responsibility	Comment
124.	Rec	7.16 No Flow. Manual valve GW-E19 (drain of glycol water tank TK-11) left open due to operator's error – Glycol Water System	Further study to be done on the option of installing the collection tank as a separate system.		
125.	Rec	1.1 General – General	Pressure transmitter PT-F42 is being used in two locations of the P&ID. Update.	Nikkiso	
126.	Rec	1.1 General – General	Tag numbers of P&ID diagram are to be checked and revised.		
127.	Rec	1.1 General – General	All drainage valves are to be blank flanged.		
128.	Rec	7.24 Less Flow. Manual valve GW-E21 or manual valve E22 partially closed due to failure or operator's error – Glycol Water System	Position indicator on manual valve GW-E21		
129.	Rec	1.1 General – General 7.25 No Flow. HT-12 improper/malfunction (clogging or external/internal leakage) – Glycol Water System	Further study to be done on the isolation of the heaters (HT-11 and HT-12) and bypass of the (redundancy) heater that any instance is not operating.		WinGD: The proposed solution is not supported by engine design.
130.	Rec	7.25 No Flow. HT-12 improper/malfunction (clogging or external/internal leakage) – Glycol Water System	Nikkiso is to provide alternative (including redundancy) methods on the heating modes.		WinGD: Can provide guidance on alternative design approach.
131.	Rec	7.28 Other Than Flow. Leak from fresh water side to the glycol water side inside the GW/JW heater HT-11 or the heat exchanger downstream of the BOG compressor system – Glycol Water System	Further study to be done to define protection limits for the presence of water in the H/E	Nikkiso	

No.	Type	References	Recommendation	Responsibility	Comment
132.	Rec	7.31 High Level. Operator's error during the filling of operation of the glycol water expansion tank TK-11 Internal leakage in the heaters/coolers – Glycol Water System	Further study to be done for the operator to install the appropriate instruments for the control of G/W expansion tank.		
133.	Rec	7.32 Low Level. Low level of glycol water inside the glycol water expansion tank TK-11 – Glycol Water System	Information is to be provided on the pressure regulation manner inside the water tank.		
134.	Rec	7.32 Low Level. Low level of glycol water inside the glycol water expansion tank TK-11 – Glycol Water System	Further study to be done on the tank vent arrangement to avoid release directly to the environment.		SPECIAL ATTENTION TO BE GIVEN
135.	Rec	1.1 General – General	Un updated design of the system is to be provided with necessary measuring and protective equipment.		
136.	Rec	8.1 General – N2 Supply System 8.2 No flow. Air compressor failure or air intake blockage – N2 Supply System 8.3 No flow. Manual valve MV-X1 (between N2 generator system and N2 booster compressor) closed due to failure or operator's error – N2 Supply System 8.4 No Flow. Nitrogen booster compression failure – N2 Supply System 8.5 No Flow. Manual valve MV-X2 (between N2 booster compressor and N2 bottles) closed due to failure or operator's error. – N2 Supply System	Critical spare parts list for the Nitrogen generation system is to be evaluated and provided/suggested.	Nikkiso	

No.	Type	References	Recommendation	Responsibility	Comment
		8.6 No Flow. Manual valve MV-X3 (downstream of N2 bottles) closed due to failure or operator's error. – N2 Supply System 8.7 No Flow. Pressure regulating valve PRV-X1 malfunction due to failure or operator's error. – N2 Supply System 8.8 No flow. Pneumatic valve N2-H01 closed due to failure or operator's error. – N2 Supply System 8.9 No Flow. Pneumatic valve N2-H03 open due to failure or operator's error – N2 Supply System 8.10 No Flow. Manual valve MV-X5 closed due to failure or operator's error – N2 Supply System 8.11 No Flow. Pressure safety valve PSV-N32 leakage due to failure – N2 Supply System 8.12 No Flow. Pressure regulating valve N2-H13 closed due to failure or operator's error. – N2 Supply System 8.13 No Flow. MV-X4, or CK-X3 closed due to failure or operator's error. – N2 Supply System 8.14 More Flow. Pressure regulating valve PRV-X1 malfunction due to failure or operator's error – N2 Supply System			

No.	Type	References	Recommendation	Responsibility	Comment
		8.15 More Flow. Pressure regulating valve PRV-X3 malfunction due to failure or operator's error – N2 Supply System 8.16 Part of Flow. N2-H03, PSV-N31, PSV-N32, PSV-N33 leakage. – N2 Supply System 8.17 Reverse Flow. N2 booster compressor failure – N2 Supply System 8.18 High Temperature. Loss of cooling in the air compressors – N2 Supply System 8.19 Contaminated Flow. High humidity of the air discharge to the nitrogen generator system – N2 Supply System 8.20 Contaminated Flow. Rust/oil from the air compressor – N2 Supply System 8.21 Other than Flow. Introduction of high-pressure ammonia @ 22 or 85 barg from purging line. – N2 Supply System 8.22 Loss of Containment. Nitrogen leakage from the system – N2 Supply System 8.23 Low Temperature. Control Valves malfunction – N2 Supply System			
137.	Rec	8.1 General – N2 Supply System 8.2 No flow. Air compressor failure or air intake blockage – N2 Supply System	Further study to be done on the redundancy configuration of the nitrogen control/purging system.	Nikkiso	

No.	Type	References	Recommendation	Responsibility	Comment
		8.3 No flow. Manual valve MV-X1 (between N2 generator system and N2 booster compressor) closed due to failure or operator's error – N2 Supply System 8.4 No Flow. Nitrogen booster compression failure – N2 Supply System 8.5 No Flow. Manual valve MV-X2 (between N2 booster compressor and N2 bottles) closed due to failure or operator's error. – N2 Supply System 8.6 No Flow. Manual valve MV-X3 (downstream of N2 bottles) closed due to failure or operator's error. – N2 Supply System 8.7 No Flow. Pressure regulating valve PRV-X1 malfunction due to failure or operator's error. – N2 Supply System 8.8 No flow. Pneumatic valve N2-H01 closed due to failure or operator's error. – N2 Supply System 8.10 No Flow. Manual valve MV-X5 closed due to failure or operator's error – N2 Supply System 8.11 No Flow. Pressure safety valve PSV-N32 leakage due to failure – N2 Supply System 8.12 No Flow. Pressure regulating valve N2-H13 closed due to failure or operator's error. – N2 Supply System			

No.	Type	References	Recommendation	Responsibility	Comment
		8.13 No Flow. MV-X4, or CK-X3 closed due to failure or operator's error. – N2 Supply System 8.14 More Flow. Pressure regulating valve PRV-X1 malfunction due to failure or operator's error – N2 Supply System 8.15 More Flow. Pressure regulating valve PRV-X3 malfunction due to failure or operator's error – N2 Supply System 8.16 Part of Flow. N2-H03, PSV-N31, PSV-N32, PSV-N33 leakage. – N2 Supply System 8.17 Reverse Flow. N2 booster compressor failure – N2 Supply System 8.18 High Temperature. Loss of cooling in the air compressors – N2 Supply System 8.19 Contaminated Flow. High humidity of the air discharge to the nitrogen generator system – N2 Supply System 8.20 Contaminated Flow. Rust/oil from the air compressor – N2 Supply System 8.21 Other than Flow. Introduction of high-pressure ammonia @ 22 or 85 barg from purging line. – N2 Supply System 8.22 Loss of Containment. Nitrogen leakage from the system – N2 Supply System 8.23 Low Temperature. Control Valves malfunction – N2 Supply System			

No.	Type	References	Recommendation	Responsibility	Comment
138.	Rec	8.11 No Flow. Pressure safety valve PSV-N32 leakage due to failure – N2 Supply System 8.12 No Flow. Pressure regulating valve N2-H13 closed due to failure or operator's error. – N2 Supply System 8.13 No Flow. MV-X4, or CK-X3 closed due to failure or operator's error. – N2 Supply System 8.14 More Flow. Pressure regulating valve PRV-X1 malfunction due to failure or operator's error – N2 Supply System 8.15 More Flow. Pressure regulating valve PRV-X3 malfunction due to failure or operator's error – N2 Supply System 8.16 Part of Flow. N2-H03, PSV-N31, PSV-N32, PSV-N33 leakage. – N2 Supply System 8.17 Reverse Flow. N2 booster compressor failure – N2 Supply System	Further study is to be done on the pressure data transmitted from the pressure valves in correlation to their settings. Definition of the lower and upper limits of the transducers are to be provided.		
139.	Rec	8.13 No Flow. MV-X4, or CK-X3 closed due to failure or operator's error. – N2 Supply System	Further information is to be provided on the "HP PIPE TEST" line.	Nikkiso	
140.	Rec	8.17 Reverse Flow. N2 booster compressor failure – N2 Supply System	Further information is to be provided on the 120 barg line.		
141.	Rec	8.18 High Temperature. Loss of cooling in the air compressors – N2 Supply System	Further information to be provided on the air compressors system		

No.	Type	References	Recommendation	Responsibility	Comment
142.	Rec	8.1 General – N2 Supply System 8.19 Contaminated Flow. High humidity of the air discharge to the nitrogen generator system – N2 Supply System 8.20 Contaminated Flow. Rust/oil from the air compressor – N2 Supply System 8.21 Other than Flow. Introduction of high-pressure ammonia @ 22 or 85 barg from purging line. – N2 Supply System 8.22 Loss of Containment. Nitrogen leakage from the system – N2 Supply System 8.23 Low Temperature. Control Valves malfunction – N2 Supply System	Further study to be done on the purging capacity of the system.	Nikkiso	WinGD: Purging capacity according to their standards is to be able to purge the system at least twice while switching to diesel mode. Changeover period should be around 15 minutes depending on the piping design of the system.
143.	Rec	8.19 Contaminated Flow. High humidity of the air discharge to the nitrogen generator system – N2 Supply System	Further study to be done on the drying system, if it is to be included in the generator system.		
144.	Rec	8.21 Other than Flow. Introduction of high-pressure ammonia @ 22 or 85 barg from purging line. – N2 Supply System 8.22 Loss of Containment. Nitrogen leakage from the system – N2 Supply System 8.23 Low Temperature. Control Valves malfunction – N2 Supply System	Consider including Double Block and Bleed Valves (DBBV) in all purging lines.	Nikkiso	
145.	Rec	8.22 Loss of Containment. Nitrogen leakage from the system – N2 Supply System	Oxygen concentration detectors are to be included in the design.	Nikkiso	

No.	Type	References	Recommendation	Responsibility	Comment
146.	Rec	5.6 High Level. Overfilling of catch tank – AFSS - Ammonia return from M/E	Further study to be done on the interface between the WinGD and Nikkiso systems.		
147.	Rec	7.26 More Flow. Simultaneous operation of glycol water pumps GP-01/02 – Glycol Water System	Further study to be done for the installation of a pressure regulating or a pressure relief valve downstream of the glycol water pumps GP-01/02.		
148.	Rec	8.20 Contaminated Flow. Rust/oil from the air compressor – N2 Supply System	Further study to be done on the dehydration system, if it is to be included in the generator system.		

Appendix D HAZOP Workshop Attendance Sheets

The multi-disciplined HAZOP team from ABS, Fundación Valenciaport, EMSA, WinGD, NIKKISO CEIG, YCA, and NTUA attended the workshop (virtually). NTUA facilitated the workshop, which was scribed by ABS. Table 11 below presents the HAZOP team.

Table 11: HAZOP Team

S/N	Company/Organisation	Main Functions/Affiliations
1	NTUA	Professor
2	NTUA	PhD(c)
3	NTUA	PhD(c)
4	NTUA (Facilitator)	Research Engineer
5	NTUA	Project Manager
6	NTUA	General Manager
7	NTUA	Research Engineer
8	NTUA	Research Engineer
9	ABS (Scribe)	Director of Global Sustainability Centre
10	ABS	Global Sustainability Centre
11	ABS	Global Ships Systems Centre
12	ABS	Global Ships Systems Centre
13	ABS	Global Ships Systems Centre
14	ABS	Global Ships Systems Centre
15	FV	Innovation project Manager
16	WINGD	GM Application Engineering
17	WINGD	Manager, marketing and application
18	WINGD	Application Engineer
19	WINGD	Manager Application Engineering
20	NIKKISO CEIG	Global Business Development, Marine market segment
21	NIKKISO CEIG	Managing Director, Sales & Service
22	NIKKISO CEIG	Marine Project Management

S/N	Company/Organisation	Main Functions/Affiliations
23	NIKKISO CEIG	System Engineering
24	NIKKISO CEIG	System Engineering
25	YCA	HESQ Manager
26	YCA	Bunkering and market development technical manager
27	YCA	HESQ Manager
28	YCA	HESQ Specialist
29	YCA	Project Manager Commercial Development

Appendix E Port Risk Assessment

Hazardous Location	Hazard	Risk	Mitigation
Storage Areas – Ammonia Tanks	Ammonia is stored in large pressurised or cryogenic tanks.	Accidental releases due to equipment failure or over-pressurisation could result in large-scale ammonia spills, leading to toxic exposure.	Continuous monitoring for leaks, reinforced containment systems, and stringent safety protocols are essential.
Loading/Unloading Zones	One of the riskiest operations is the transfer of ammonia between storage tanks and ships via pipelines, hoses, or other transfer systems.	Leaks during transfer, hose failure, or improper connections could cause an ammonia release.	Use specialised equipment for ammonia, regular maintenance, and robust emergency shutdown systems.
Bunkering facilities	Refuelling stations are a critical hazard point.	If there is a system failure or human error, ammonia could escape into the atmosphere, threatening workers and the surrounding environment.	Bunkering areas should have spill containment measures, emergency stop systems, and well-trained personnel following strict operational guidelines.
Piping Systems	Ammonia is transferred through pipelines across the port from storage to the loading area or bunkering stations.	Pipelines can develop leaks due to wear, corrosion, or pressure fluctuations.	Regular inspections, corrosion-resistant materials, and installation of pressure relief valves and leak detection systems are vital.
Ventilation systems in Confined Spaces	Enclosed areas or confined spaces can accumulate toxic fumes if a leak occurs.	Without proper ventilation, any minor leak can lead to the build-up of ammonia concentrations, which can pose serious risks to workers through inhalation or skin contact.	Ensure adequate ventilation, continuous air quality monitoring, and emergency evacuation routes.
Maintenance Areas and Workshops	Liquid, pipeline, and pump maintenance activities present risks due to potential leaks or exposure during repair.	If equipment is not properly decontaminated, isolated, or depressurised, workers can be exposed to harmful ammonia levels during maintenance tasks.	Strict safety protocols during maintenance, personal protective equipment (PPE) use, and ensuring that systems are depressurised and purged before work begins.

Hazardous Location	Hazard	Risk	Mitigation
Emergency Response Zones	Areas designated for handling emergencies, such as spills or leaks of ammonia, are inherently hazardous.	Personnel tasked with responding to an ammonia release face immediate danger from exposure. Poorly equipped or unprepared response zones can escalate an emergency.	To neutralise ammonia, these zones must be equipped with decontamination units, protective gear, and neutralisation agents, such as water or acids.
Ship Engines Rooms for ammonia-fuelled Ships	Engine rooms are particularly hazardous in ships powered by ammonia due to the presence of ammonia fuel lines, tanks, and combustion systems.	A failure in the fuel system could release ammonia gas into the confined space, endangering crew members and potentially causing fires or explosions if the ammonia reaches flammable concentrations.	Install robust safety systems, including gas detection, fire suppression, and emergency shutdowns, and train crew members on ammonia-specific hazards.
Ammonia Production Plants is located in Port.	If ammonia production (from hydrogen) plants are located within the port area, these industrial facilities pose a significant hazard due to the high volumes of ammonia processed.	Large-scale releases or accidents in these plants could have wide-reaching consequences, including toxic gas clouds, explosions, or long-term environmental damage.	Ensure facilities meet the highest safety standards, including containment areas, emergency response plans, and regular audits.

Appendix F Failure Modes, Effects, and Criticality Analysis

Risk assessment and management techniques are used to reduce accidents by providing prevention and protective measures. Hazard Identification (HAZID) studies are an integral part of the risk assessment and a crucial process for the approval of alternative fuels and configurations. Numerous methodologies are available in the literature for conducting HAZID studies. Authors have introduced a range of approaches to address HAZID, such as Failure Mode and Effect Analysis (FMEA) and its expanded counterpart Failure Modes, Effects, and Criticality Analysis (FMECA), Hazard and Operability Study (HAZOP), or hybrid methods that integrate multiple techniques.

FMEA is a systematic method aimed at proactively identifying and addressing potential issues in systems, products, and processes. FMEA is a well-known method for its efficacy in identifying potential system failures and enhancing overall reliability and safety. Originating in the late 1940s with the US military, its application expanded to aerospace and automotive industries and now spans various sectors including maritime industry. It is an exercise where its main purpose is to identify weaknesses and shortcomings in the system, considering all operational modes. Upon determining that an FMEA study is to be performed, the scope of the analysis is approved and an FMEA team is constructed in order carry out the study. The boundaries, which can be referred to as the nodes of the system to be analysed, is defined and agreed upon by the team. This will define the parts of the system that shall be studied and examined. As part of defining the nodes of the system, an exchange of data and information between the team and the stakeholders takes place. This typically includes system schematics such as PI&D and PFD drawings, operational procedures, manuals and systems configurations[11]. The team takes on the task of studying the information provided to identify potential failure modes, their resulting effects and methods to detect the deviations and to list corrective actions to prevent the deviations from occurring or at least to lower the probability of their occurrence. During the process of conducting the study, recommendations are made by experts. The recommendations are also given a rank to highlight their severity of the potential effect. The information gathered is consolidated in a tabular format, shared as a report for the review by the stakeholders.

Further to the FMEA process, FMECA serves as an extension to FMEA in that it offers a supplementary criticality assessment. This highlights the criticality ranking explicitly and draws attention to the critical issues and can be crucial in deciding the corrective actions to be taken. Furthermore, in the development, follow-up and implementation process of corrective actions, criticality assessment assists in allocating the effort, time and resources related to the criticality of deviations or items. The ranking procedure of the critical items can be based on a combination of the severity of the failure as well as the expected likelihood of the occurrence.

Figure 27 depicts the link between the HAZOP and FMEA/FMECA analysis[12]. Here, hazards identified and analysed during the HAZOP analysis are further investigated using the FMEA analysis. Specifically, the failure of components or items and therefore the occurrence of accidents is identified in the FMEA/FMECA analysis, which may be difficult to identify from the HAZOP analysis alone.

Both methods, FMEA and FMECA, focus on component-level failures and their impact on higher-level systems and they should be applied early in the design process to thoroughly analyse potential failure modes. This ensures that critical and catastrophic failures are identified, and appropriate mitigation measures are implemented through design modifications at an early stage. FMEA is a qualitative analysis that employs "what-if?" questions to pinpoint failure modes, while FMECA is a quantitative analysis that quantifies the criticality of each failure. Both tools are employed to facilitate decision-making and implement measures to mitigate risks.

Conventionally, the risk of potential failures has been evaluated using the Risk Priority Number (RPN) method, which is defined as the product of Severity (S), Occurrence (O), and Detectability (D), as shown in the equation below.

$$\text{RPN} = S_i \times O_i \times D_i$$

[11] American Bureau of Shipping (ABS). Failure Mode and Effects Analysis (FMEA) for Classification. ABS, 2015.
[12] Yahao S. et Al. (2023). Preliminary hazard identification for qualitative risk assessment on onboard hydrogen storage and supply systems of hydrogen fuel cell vehicles, Renewable Energy Volume 212, Pages 834-854. https://doi.org/10.1016/j.renene.2023.05.037

where i, denotes each identified potential failure mode. However, this method gives equal weight to S, O, and D and could result in similar RPN values for different combinations.

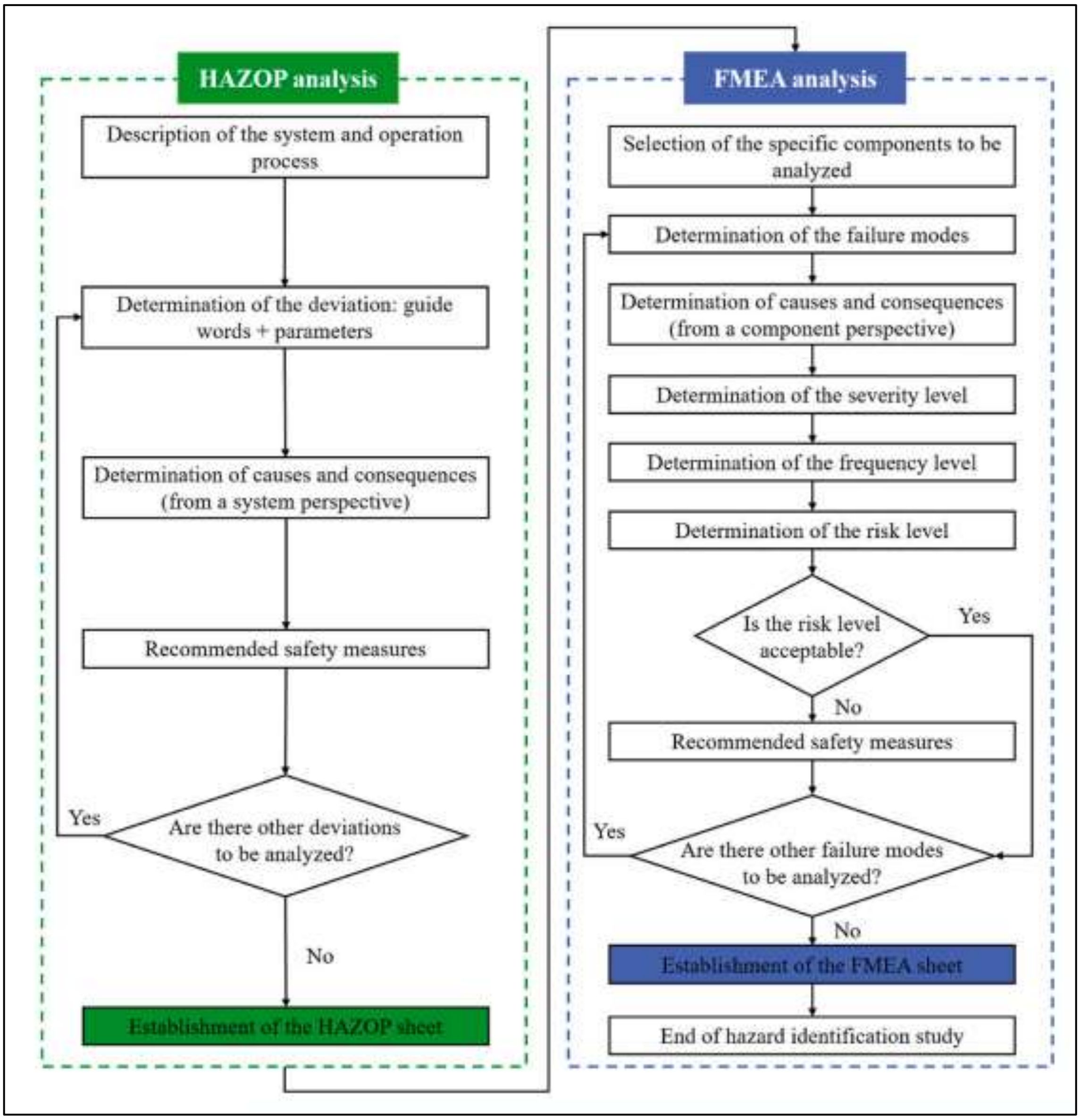

Figure 27: The process for hazard identification assessment.

FMEA and FMECA offer distinct advantages in identifying hazards related to mechanical and electrical equipment failures, including reliability issues. FMECA builds upon FMEA by incorporating an additional step to assess the criticality of each failure mode. In FMECA, after identifying failure modes and their effects, each failure mode is further evaluated to determine its criticality or importance to the system's overall function. Criticality is typically determined by considering factors such as severity, occurrence, and detection, as well as the potential impact on safety, mission success, or system reliability.

Both methods facilitate the identification of both localised and systemic failures, requiring fewer resources in terms of manpower compared to HAZOP studies, and can offer a semi-quantitative assessment of risks. Nonetheless, they have their limitations. They may not adequately identify combinations of failures or risks stemming from the entire process, although proficient teams may detect some combinations. Moreover, FMEA/FMECA primarily focus on equipment failures, potentially overlooking operational errors. Analysts conducting these analyses must possess a profound understanding of equipment functions and failure modes to accurately evaluate their impacts on other system components. Furthermore, the effectiveness of FMEA/FMECA hinges on the quality and relevance of available data[13]. Poor data quality or lack of robustness may diminish the value of the analysis. These uncertainties underscore the importance of comprehensive data collection and analysis to ensure the reliability of FMEA/FMECA results in enhancing system safety and reliability[14]. Despite its thoroughness, FMEA demands significant time for its development, necessitating a knowledgeable team and meticulous analysis of system components and failure modes.

HAZOP is a methodical review of a system, process, or operation carried out by a team with diverse expertise. It involves a thorough examination of the process design, scrutinizing each line or stage for potential deviations using guide words and system parameters. Whenever a hazard or operability issue is pinpointed, the team relies on their collective knowledge to determine whether adjustments or further investigations are necessary. Widely adopted in the chemical and various other industries, HAZOP was developed in the late 1960s and gained widespread acceptance after the publication of the Chemical Industries Association guide in 1977. To conduct a HAZOP analysis, a comprehensive process description and design must be available and finalised, with subsequent modifications made only as directed by the analysis findings or through stringent management procedures. Clearly defined study boundaries specify the equipment and operational modes under scrutiny, outlining the types of potential issues to be addressed.

HAZOP analysis offers several advantages in the process of safety assessment. Firstly, it can identify both operating issues and hazards, providing a comprehensive understanding of potential risks. The structured approach employed in HAZOP increases the likelihood of identifying hazards effectively. Furthermore, HAZOP can assess a wide range of hazards, including chemical, mechanical, electrical, control, and human interactions, making it versatile for various industries. Additionally, HAZOP allows for the investigation of new and innovative processes, fostering continuous improvement in safety protocols. Through HAZOP studies, teams gain profound insights into process operations, enabling the development of enhanced operating procedures. Ultimately, the implementation of HAZOP findings can lead to financial benefits such as faster start-up, reduced operating problems, and increased reliability. However, HAZOP analysis also presents challenges. It demands significant resources in terms of manpower and data, necessitating a multidisciplinary team led by experienced professionals. The study must be conducted within a limited timeframe during the project life, adding to the complexity. Care must also be taken when considering a plant or section as a repeat of a previous study, as true identical systems are rare, leading to potential oversight of unique hazards. Furthermore, uncertainties exist regarding the thoroughness of problem identification, which relies on team skills, technique rigor, and available data. Additionally, the accuracy of the model assumed by the team depends on factors like control over changes, actual process operation, and plant maintenance, with poor management potentially introducing unforeseen hazards.

[13] Miliouris K., et al. Model-Based Safety Analysis and Design Enhancement of a Marine LNG Fuel Feeding System. 2021
[14] Crawley, Frank. (2020). A guide to Hazard Identification Methods. 10.1016/B978-0-12-819543-7.00002-1.

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