AMMONIA BUNKERING OF PASSENGER VESSEL - CONCEPT QUANTITATIVE RISK ASSESSMENT

Green Coastal Shipping Programme (Grønt Skipfartsprogram)

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Objectives:

The objective is to quantitatively assess individual 3rd party risk associated with several concepts for ammonia bunkering of a passenger ship in Port of Oslo. This report documents QRA results, including identified hazards, consequence analyses and risk comparison against established risk acceptance criteria.

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Quantitative risk assessment of 3rd party individual risk related to bunkering operations of ammonia in the Port of Oslo.

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1 EXECUTIVE SUMMARY

DNV is commissioned by 'Grønt Skipfartsprogram' (GSP) to conduct a quantitative risk assessment (QRA) of defined conceptual bunkering operations of liquid ammonia both at pressurized and refrigerated conditions in the Port of Oslo. The passenger ship sailing between Oslo and Kiel is used as representative for the ammonia receiving ship, hereinafter referred to as the passenger ship.

As a part of this assessment, the following bunkering concepts are defined:

- ***Concept 1A***: Transfer of pressurized ammonia from a truck to a pressurized storage tank on the quay and further to the passenger ship.
- ***Concept 1B*:** Transfer of refrigerated ammonia from a bunker ship to a pressurized storage tank on the quay and further to the passenger ship.
- ***Concept 2*:** Transfer of refrigerated ammonia from a bunker ship on the seaside of the passenger ship directly to the passenger ship.

As ammonia is much less flammable than methane, and at the same time very toxic, the main focus of this QRA is on the toxic risk from pressurized, flashing releases and spills of refrigerated ammonia to the sea.

The exposure of 3rd party to the toxic risk is considered and risk contours are presented. Ammonias flammable and explosion hazards are discussed in brief in the report.

Introduction of ammonia as a fuel and risk aspects related to operation of defined bunkering concepts are first identified and recorded in the performed HAZID session. The risk analysis is performed with DNV software SAFETI which is a general QRA software where integral models are applied for the consequence analyses. Each step of the risk assessment is described in dedicated sections, and associated conclusions, discussions and recommendations are provided at the end. Risk Acceptance Criteria (RAC) for 3rd party individual risk established by the Norwegian Directorate for Civil Protection (DSB), /1/, is applied.

This QRA report also includes an Assumptions' Register and HAZID log presented in Appendices A and B, respectively.

Results for Concept 1A and 1B

The risk is assessed as not acceptable for Concept 1A and 1B according to RAC established by DSB. The main reason is related to the permanent storage tank on the quay with pressurized ammonia. A jet spray release of ammonia from the pressurized tank piping connections can generate a large gas cloud. Also, the tank volume of 1,000 m^3 causes a long release duration. In Concept 1A pressurized ammonia is transferred to the shore storage tank, while for Concept 1B the ammonia is transferred in refrigerated condition, then heated-up on quay to the ambient temperature, providing thus warm ammonia to the storage tank. For Concept 1B it is therefore the large releases of warm (pressurized) ammonia that drives the risk picture.

The project team identified several proposals for conceptual changes and design measures that may reduce the size of the risk contours, either by reducing the likelihood or consequences of ammonia release. Further studies of these measures will be needed to determine whether the risk contours can be sufficiently reduced to be within the acceptance criteria established by DSB.

The proposed measures for follow-up studies for Concept 1A and 1B are:

- **Use refrigerated atmospheric storage tank onshore instead of pressurized tank (i.e. refrigerate bunkering concept).** The accidental loss of containment associated with refrigerated ammonia (stored at atmospheric conditions) is assessed to produce smaller toxic gas clouds compared to the release of pressurized ammonia. It is therefore considered to reduce the extent of risk contours. For this particular case with the passenger vessel, it seems not to be a likely option, however it may be considered for the application to other concepts. It should be noted that hazards and associated consequences related to pressurized ammonia will still be relevant if processing equipment to pressurize the ammonia is taken onboard the receiving ship. Nevertheless, the exposure time to the toxic release from the equipment onboard of the receiving vessel will be reduced to time spent by the vessel in the port.
- **Enhanced safety integrity of shore storage tank and external tank connections**. The risk in concept 1A/B is driven by continuous liquid release associated with failed external connections to the pressurized storage tank. Since this is in conceptual stage, no information or details have been provided about the storage tank, and conservative assumptions have therefore been applied for the different leakage scenarios. Design measures such as welded connections, reducing number of external connections, design of tank connections (material, stress analysis) etc. may reduce the leakage probability and hence reduce the risk contours.
- **Double shell/secondary enclosure for piping which should be able to contain any leakages from the primary containment.** This will ensure all leakages are contained in a secondary enclosure. The released ammonia can be stored (if feasible/safe) or be released by Pressure Relief Valves (PRVs) in a dedicated safe location. This may reduce the risk contour sizes.
- **Detailed CFD simulation of accidental releases from the storage tank, representing actual geometry of the location of operations.** It is possible to combine risk contours produced by CFD tool with risk results produced by SAFETI for remaining risk scenarios. Further, potential hazards associated with ammonia release incidents on the receiving ship (while is in the port) should be considered being included to the total risk picture.

Results for Concept 2

The risk is found acceptable for Concept 2 (bunkering ship-to-ship on the seaside). The reason why this gives shorter risk contours is that the ammonia is stored and pumped as refrigerated from the bunkering ship. This gives smaller gas clouds and shorter leak durations.

Some important assumptions are made which are important to implement to obtain these favorable results: Rapid leak detection and ESD isolation times, and reliable ESD and pump shutdown systems. With larger amounts of ammonia, the risk could also increase.

For concept 2, the cloud can be "blocked" by the passenger ship structure, thus limiting the spread of gas in the direction towards the quay. This effect is not reflected by SAFETI model and in the produced risk iso-contours, in this respect the model is conservative. Risk contours produced by SAFETI may underpredict the extent of the contours in the directions in front and aft of the ship slightly since the ship structure is not accounted for. If this effect needs to be accounted for, a 3D CFD model can be used.

This risk results only apply to 3^{rd} party individuals such as neighbours and public that are not associated with the passenger ship. The 2^{nd} party individual risk, i.e. risk to people located on either passenger ship or bunker vessel/truck is not assessed by this QRA. Ingress of gas into the ship, or leaks happening inside the ships are not assessed.

For Concept 2 the risk is found acceptable. However, DSB states that generally risk should be reduced to a level which can reasonably be achieved (ALARP). Thus, several risk reducing measures were proposed (see chapter 8.2). These measures should be implemented unless it can be demonstrated that the cost involved in implementing the measure is grossly disproportionate to the benefit gained.

2 INTRODUCTION

DNV was requested to quantitatively assess 3rd party individual risk related to several concepts for bunkering of an ammonia fueled passenger ship in Port of Oslo.

The company that will operate the ammonia fueled passenger ship targets 40% reduction in CO2-emissions by 2030. That will require a daily consumption of ammonia of approximately 50 tons. The capacity of the ammonia fuel tank on the ship is 200 tons and details on bunkering concepts are presented in Section 4.

2.1 Objective

The objective is to quantitatively assess 3rd party individual risk related to ammonia bunkering operation of defined concepts against the Norwegian Directorate for Civil Protection's (DSB) Risk Acceptance Criteria (RAC).

2.2 Scope of work

The scope for this QRA included definition of bunkering concepts and boundary conditions. The assumptions related to the concepts definition and risk modelling were defined and documented in Appendix A to this report. The established Assumption's Register was continuously updated thought the project execution. The document includes high detail level of applied assumptions for the application to this QRA.

The hazards related to the concepts' operation were systematically identified and recorded. The HAZID Report is attached in Appendix B to this QRA Report. After the HAZID, QRA scenarios subject to quantitative risk evaluation were established. Risk modelling was performed by DNV software package SAFETI v8.23. The 3rd party individual risk results were presented by Location Specific Individual Risk Contours (LSIRCs) and assessed against DSB's RAC, /1/.

Recommendation and risk reducing measures were proposed for concepts assessed to exceed RAC.

2.3 Abbreviations

BLEVE	Boiling Liquid Expanding Vapor Explosion
DSB	Direktoratet for samfunnssikkerhet og beredskap
CRA	Concept risk analysis
ERC	Emergency Release Coupling
ESD	Emergency shutdown
HAZID	Hazard Identification
HCRD	Hydrocarbon Record Database
HSE	Health Safety Environment
IMO	International Maritime Organization
LSIR	Location specific individual risk
NFR	Normal flow rate
P&ID	Piping and Instrumentation Diagram
PFD	Process Flow Diagram
PHAST	Process Hazard analysis Software Tool
PRV	Pressure relief valve

QRA	Quantitative Risk Analysis
RAC	Risk acceptance criteria
RIVM	Rijksinstituut voor Volksgezondheid en Milieu
SAFETI	Scenario Analysis For Effective Technology Integration
STS	Ship to ship
TSL	Temperature of super heat level
TTS	Tank to ship
UDM	Unified dispersion model
WHO	World Health Organization

2.4 Limitations

- QRA is limited to the 3rd party individual risk assessment.
- The 2nd party individual risk assessment is not a part of the scope (i.e. crew and passengers onboard the passenger ship), i.e. no impact risk assessment is carried out for people present on the passenger ship
- Only toxic risk is considered.
- Releases associated with storage tank failures either on the bunker ship or truck are not part of this QRA.
- Releases associated with storage tank and equipment on the passenger ship are not part of this QRA.
- The actual geometry of the area of bunker operations was not considered by this QRA.
- No evaluation for impact on marine life has been included in this QRA.
- The generic frequencies for transfer equipment are based on recorded frequency of accidents for LNG, LPG transfers by ship, and ammonia transfers by road truck. The actual design of transfer equipment to be utilized for future operations was not considered for failure frequency estimates due to the early concept phase.
- The dispersion simulations of toxic gas are performed by Safeti and do not account for actual layout of the port. The gas dispersion and air dilution are considered being impacted by large obstacles in the area and influence toxic gas effect zone.
- The analysis is limited to system definition as presented in Section 4 and analysis assumptions documented in Appendix A, Assumptions' Register.

The concepts design is at its early stage and should be regarded as coarse.

The results of this assessment are only valid within the validity of the assumptions, documented in Appendix A, Assumptions' Register.

3 RISK ACCEPTENCE CRITERIA

DSB's risk acceptance criteria for 3rd party individual risk is applied to this QRA, /1/. These acceptance criteria are briefly described subsequently. Mitigating measures should be considered when the criteria are not satisfied.

DSB's criteria are summarized in Table 3-1 and Figure 3-1.

This risk level is calculated as an average over 24 hours per day for a representative 12-month period.

Table 3-1 Summary of DSB risk tolerance criteria

Consideration zones	Individual Risk up to	Description
Inner zone	1E-05 per year	This is basically the business's own area. In addition, for example, LNF area (Landbruks-, natur- og friluftsområder) can be included in the inner zone. Only short-term passage for third parties.
Middle zone	1E-06 per year	Public road, rail, dock and similar. Permanent industry and office can also be found here. In this zone, there should not be accommodation or housing. Scattered housing can be accepted in some cases.
Outer zone	1E-07 per year	Areas regulated for residential purposes and other uses of the general population can be included in the outer zone, including shops and smaller accommodations.
Outside Outer Zone	Not defined	Schools, kindergarten, nursing homes, hospitals and similar institutions, shopping centres, hotels or large public arenas must normally be placed outside the outer zone.

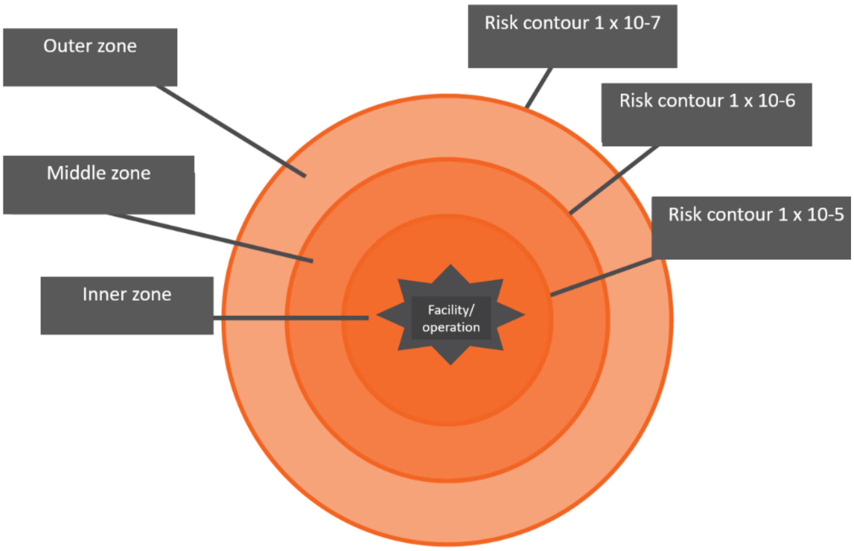


Figure 3-1 DSB criteria for Consideration Zones

DSB defines, in their Guideline for quantitative risk analysis of facilities handling hazardous substances, that: *Plans for land use shall, to the extent necessary, show considerations and restrictions that are relevant to use of the land. This shall be indicated in the plan for land use as consideration zones, with associated guidelines and regulations. The provisions and guidelines that apply, or will apply, to the consideration zones in compliance with the Planning and Building Act, or other acts, shall to the extent necessary be specified. This is important in order to safeguard the consideration indicated by the zone. This means that the consideration zones are stipulated by the planning authority (i.e. the municipality) based on studies, assessments and consultations, etc. as part of their planning process,* /13/.

Note that, in addition to the criteria for upper risk level in each zone, DSB generally requires that risk should be reduced to a level which can reasonably be achieved (As low as reasonably practicable - ALARP) ref. chapter 2 in DSB guidance document for 'Criteria for acceptable risk' /1/.

4 PRESENTATION OF CONCEPTS

The daily consumption of ammonia by the passenger ship is estimated to 50 tons. The capacity of the tank on the ship is 200 tons. The bunkering of the ship every 4th day will be thus executed in the Port of Oslo.

The bunkering will occur either from a pressurized storage tank on the quay in the Port or from a bunker ship on the seaside of the Port.

The pressurized storage tank on quay in the Port of Oslo will receive ammonia either from the bunker ship every 4th day or from two (2) trucks on daily basis.

Two (2) main concepts were defined for this QRA and presented in detail in subsequent sections.

4.1 Concept 1: Bunkering from a pressurized storage tank onshore to a passenger ship

Ammonia stored in pressurized storage tank on the quay will be bunkered to the receiving passenger ship. Ammonia will be transferred from the storage tank to the ship via onshore process pipe and loading arm as depicted in Figure 4-1.

Filling of the pressurized storage tank will occur either from ammonia bunker ships/tankers, as defined in Concept 1B or from trucks, as defined in Concept 1A, by a composite flexible hose. It is acknowledged that a manifold transfer system could be used in Concept 1B, instead of using composite hose, but this configuration is not part of scope for this assessment.

The refrigerated ammonia in concept 1B is delivered by a bunker ship every 4th day and is heated in the Port before it is transferred to the storage tank. Whereas in concept 1A, two (2) trucks deliver pressurized ammonia on daily basis.

Process systems downstream and upstream the pressurized storage tank, i.e. Segments 1A/B, 2A/B, 4, and 5, assumed to be purged with nitrogen prior to/after each bunkering operation to remove remaining ammonia and oxygen. These systems are therefore not considered being pressurized in between bunkering operations.

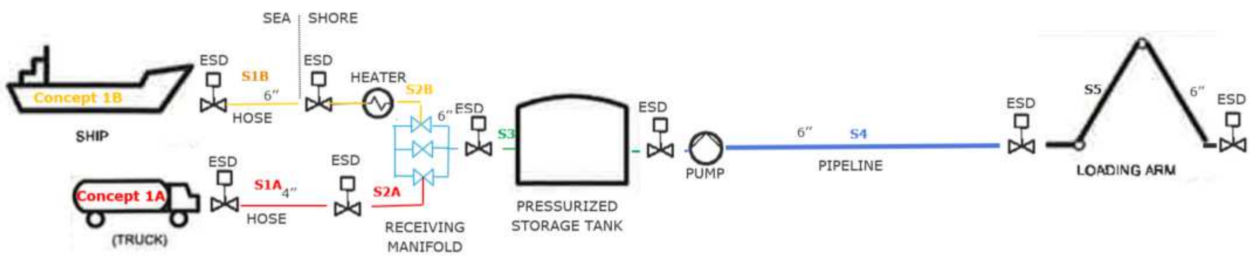


Figure 4-1 Process flow diagram Concept 1A-bunkering of ammonia by trucks; Concept 1B-bunkering of ammonia by ship

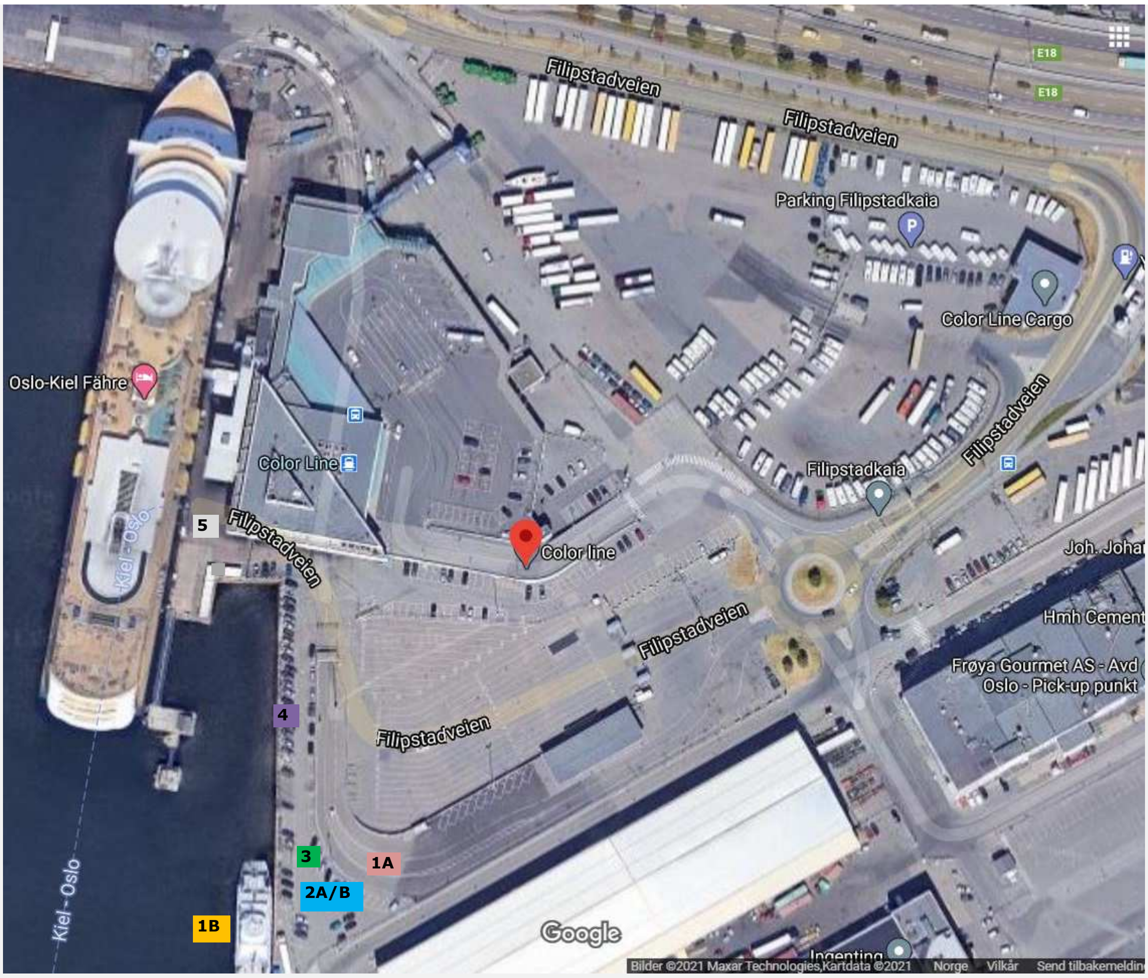
In total five QRA scenarios are defined for this concept and presented in Table 4-1.

Table 4-1 Process conditions for defined segments in Concept 1

Seg. No.	QRA scenario name	Description	Time fraction % per year	Normal operating pressure, barg	Normal temp., deg. C	Density, kg/m^3	Normal operating flow rate, m^3/h	Segment HC static mass, kg
S1A	1A-Truck-Hose	Pressurized ammonia transferred from truck (using hose)	6.6	7.6	15	617	50	100
S1B	1B-Ship-Hose	Refrigerated ammonia transferred from ammonia tanker (using hose)	1.6	4	-33.4	681	200	300
S2A/B	2A/B-Manifold	Ammonia transferred via receiving manifold to the pressurized storage tank in port. Ammonia is heated in the Port for concept 1B	6.6/1.6	7.6	15	617	50/200	563
S3A/B/C/D	3A-Storage-L-Outlet	This scenario includes liquid outlet line from the tank	1	7.6	15	617	-	617,000
	3B-Storage-L-Inlet	This scenario includes liquid inlet line to the tank	1	7.6	15	617	-	617,000
	3C-Storage-G-PRV	Gas leak from the PRV/safety control valves	1	6	15	5.325	-	5,325
	3D-Storage-G-VR	Gas leak from vapor line connection	1	6	15	5.325	-	5,325
S4	4-Process-Pipe	Onshore process pipe delivering ammonia from the storage tank to the loading arm	1.6	15	40	575	200	1,574
S5	5-Loading-Arm-Bunkering	Loading arm transferring ammonia to the vessel's bunkering station	1.6	15	40	575	200	300

It should be noted that storage tank scenario is represented both by liquid and gas scenarios, i.e. 3A, 3B, 3C, and 3D, ref. Table 4-1. Due to the uncertainty related to the tank design and location of external connections to the tank, it was assumed that both inlet (Segment 3B) and outlet (Segment 3A) liquid connections for ammonia transfer will release liquid phase only based on conservative assumptions of tank being filled to maximum allowable limit at all times. Two other scenarios related to failure of PRV (Segment 3C) and associated equipment, and vapor return connection (Segment 3D) are represented by gas phase.

The location of defined QRA scenarios on quay are illustrated in Figure 4-2.



S1A-ammonia transfer from the truck; **S1B**- ammonia transfer from the ship; **S2A/B** – receiving manifold;

S3-Storage tank; **S4**-Process pipe; **S5**-Loading Arm

Figure 4-2 Location of QRA scenarios Concept 1 A/B on quay.

4.2 Concept 2: Bunkering from a bunker ship to a passenger ship

Ammonia is stored in cargo tanks in the bunker vessel (or barge) under refrigerated condition (-33.4°C). The ammonia from the bunker vessel will be bunkered to the passenger ship using a composite flexible hose. The transferred ammonia will possibly be pressurized on board of the passenger ship. The process equipment onboard of the passenger ship is outside of the QRA's scope.

Defined QRA segments with respected process conditions and static mass are presented in Table 4-2, while the location of defined QRA scenarios on quay are illustrated in Figure 4-4.

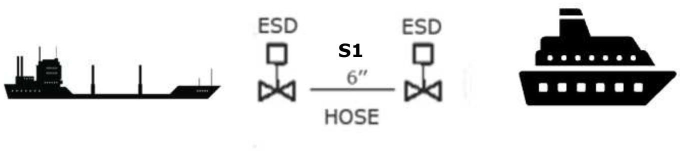


Figure 4-3 Process flow diagram Concept 2.

Table 4-2 Process conditions for defined segments in Concept 2.

Seg. No.	QRA scenario name	Description	Time fraction % per year	Normal operating pressure, barg	Normal Temp., deg. C	Density, kg/m^3	Normal Operating flow rate, m^3/h	Segment hydrocarb on static mass, kg
S1	1-Ship-Hose	Refrigerated ammonia transferred from the bunker ship (using hose)	1.6	4	-33.4	681	200	231

S1-ammonia transfer from the ship

Figure 4-4 Location of QRA scenarios Concept 2

4.3 Safety systems

The safety systems considered for both concepts are in brief discussed in this section.

Each hose and loading arm are protected by ESD valve upstream and downstream, triggered automatically by gas detectors (or manually by operators).

The loading arm is assumed to have a breakaway system consisting of tension monitoring and a powered Emergency Release Coupling (PERC), providing a spill-free disconnection in the event of ship movement outside allowable limits.

The transfer hoses for ammonia bunkering from the ship are assumed to have vessel separation detection and an Emergency Release Coupling (ERC). The ERC failure is considered by transfer leak frequency analysis presented in 6.4.3.

Linked ESD system between the bunkering delivery and receiving unit is assumed.

Automatic ESD system with corresponding detection time of 60 sec and isolation time of 30 sec is assumed following DNV LNG QRA Guideline 16, /2/. The bunker pump is assumed to be stopped 90 sec after release starts. The detection and isolation times define release duration of dynamic inventory. Consequences are sensitive to required time to stop the pump. In case of ESD failure, time to stop the pump of 90 sec is still considered be representative, i.e. pump will be able to shutdown regardless.

Two (2) ESDs are assumed on the bunker side, one ESD valve in the bunkering/manifold station and one tank ESD valve. The dedicated Emergency Shutdown Valves (ESDVs) for the passenger's storage tank and truck tank are as well assumed.

Safety Integrity Level (SIL) requirements to ESD system follow OLF 070, the guideline for implementation of SIL in Norwegian Oil and Gas with a minimum requirement of SIL 2 for the ESD loop with corresponding probability of failure on demand (PFD) of 1%. The PFD impacts final frequency of successfully isolated leaks and frequency of leaks failed to isolate.

4.4 Bund containment of spilled ammonia

The pressurized ammonia will be stored in a liquid state. Typically, the spill would be collected and channeled to an impounding basin, which may be located some distance away from the process equipment. Such a containment system (in particular trenches) would be difficult to model in SAFETI. Ammonia leaks from storage tank will be collected in the bund. For ammonia receiving and process pipe the release will be collected by drain pits. These systems are therefore represented with a bund in SAFETI risk model. This limits the pool size by assumed size of the bund.

Further, all liquid spilled in the bund, is available for vaporizations, i.e. draining of spilled liquid to a safe location is not considered. The leak can potentially hit outside the bund followed by longer rainout distance. The storage tank outlet bottom line is assumed being obstructed by the bund followed by rainout inside the bund. The tank's ammonia inlet line is assumed to be obstructed by equipment and/or wall structure in the vicinity of the release with the rainout assumed to occur inside the bund. The storage tank is considered being protected by the wall to limit external access to the tank. This schematically is depicted on Figure 4-5 below.

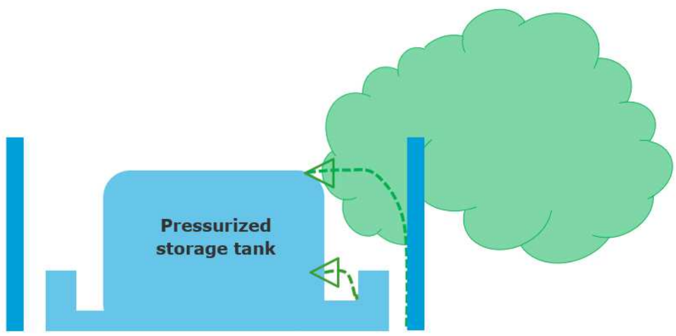


Figure 4-5 Release from the storage tank's inlet and outlet external connections with release being obstructed by the bund and a wall structure followed by rainout inside the bund/wall

Release associated with manifold and process pipe leaks will be collected in the bund, however, ammonia release jet can hit outside the bund. The bund is assumed to be never overfilled on the assumption of spill being routed to the safe place.

For releases from the loading arm, part of the release is assumed to be spilled in water, obstructed thus by the Port's quay and the passenger ship and represented by the bund with overfill property. The remaining release is assumed to occur on the land with no bund modelled.

For STS transfer, the spilled refrigerated ammonia will be bounded by two ship structures, i.e. bunker ship and receiving passenger ship. This effect is therefore represented by a bund with corresponding properties. Two (2) ship structures are assumed to "contain" the spill, defining thus the bund volume by the length of the ships, distance in between two ship structures and minimum (tend to zero) bund height. The bund is modelled to fail if overfilled.

For further details on modelling of bund properties, refer to Assumption A-13 in appendix A.

5 AMMONIA HAZARDS

5.1 Toxic effect on humans

Ammonia is a colourless, toxic gas with a strongly pungent smell already at 5-30 ppm. The gas is lighter than air (vapour density 0.6 compared to air). By pressurizing or cooling, the gas can be converted to liquid. In contact with skin, liquid ammonia can cause irritation and severe burns.

The effect of ammonia fumes on the respiratory organs is usually limited to the upper respiratory tract, since the gas dissolves well in water and also induces strong reflexes that immediately causes a person to hold the breath. At very high concentrations, the ammonia can get into deeper airways. The consequences are then very serious, such as damage to the lungs (pulmonary edema) resulting in possible mortality, /3/.

The release of ammonia in large quantities may create a large ammonia cloud that is toxic when inhaled to great distances from the scenario release location, which is accompanied by a high risk of death. Due to the strong smell of ammonia, which becomes unbearable at concentrations well below fatal concentrations, fatalities will mostly be seen when people are exposed to very high concentrations (next to a major release) or trapped without the ability to escape the toxic gas plume, /4/.

In contact with skin it may cause dehydration as a result ammonia's great attraction for water. Anhydrous ammonia will extract water from body tissue. Once ammonia extracts water from body tissue it forms ammonium hydroxide that can chemically burn tissue. As liquid ammonia vaporizes it pulls heat away from body tissue causing frostbite in an instant.

5.2 Toxic effect on environment

The solubility of ammonia in water is high. Table 5-1 gives the solubility of ammonia as a function of temperature (WHO, 1986), /5/.

Table 5-1 Solubility of ammonia as a function of temperature.

Temperature, °C	Solubility (g/l)
0	895
20	529
40	316
60	168

In addition, the dissolution of ammonia in water is highly exothermic: 2,000 kJ per kilogram of ammonia dissolved in water. As an indication, the dissolution of one kilogram of ammonia releases enough energy to evaporate almost one and a half kilograms, /5/.

For releases of ammonia occurred in sea water, the dissolved ammonia is a serious threat to aquatic organisms killing most in close proximity as lethal concentrations are easily exceeded.

Due to the exothermic reaction with water, ammonia will evaporate at high rates. An ammonia gas cloud will rise up in the atmosphere as ammonia gas is lighter than air. Nevertheless, an ammonia gas cloud is a serious threat to organisms in its surroundings as it could easily expose them to lethal concentrations. It will remain a threat for the time of cloud vaporization and steady mixing with air until completely diluted.

No environmental impact due to the ammonia release to water followed by toxic exposure of aquatic life was considered by this assessment.

5.3 Flammable

Due to the low flammability of ammonia compared to hydrocarbon fuels and chemicals, the ammonia accident statistics does not include fire and combustion events of ammonia, /4/. The ammonia can be lethal to humans at 2,700 ppm when exposed to toxic concentration for a duration of 10 minutes. The lower flammability limit of ammonia is 15% which is equal to 150,000 ppm, /6/. Ammonia requires minimum ignition energy of 8 mJ, which is 30 times more energy than methane needs to ignite, /7/. Ammonia can self-ignite if the temperature is above 651°C, /4/. Therefore, the flammability risks of ammonia are relatively low compared to the toxicity risks.

A cold-boiled ammonia leak does not burn in a self-sustaining way, like most hydrocarbons. This is caused by insufficient heat radiation from the flames entering the pool. When heat is supplied in another way, for example from the ground or with water, enough ammonia can evaporate to maintain the fire.

Ammonia burns with difficulty in open air and will generally need a supporting flame/strong fire source to keep burning.

5.4 Semi-enclosed vapour cloud explosion

A vapour cloud explosion can occur when a large amount of gas ignites in a confined or semi-enclosed space. The risk of fire and explosion exists almost exclusively in poorly ventilated rooms.

Ammonia minimum ignition energy is much higher than for methane as mentioned above. Thus, ammonia release is hard to ignite, however, if accumulated in poorly ventilated area, the explosion may follow.

The ammonia is therefore not highly flammable, but containers of ammonia may explode when exposed to high heat, ref. to self-ignition properties.

5.5 Corrosive

Ammonia when mixed with some water becomes highly corrosive to a range of materials, including zinc, copper and brass. Ammonia that is mixed with water is not corrosive to iron or steel, within the normal operational temperature range of ammonia.

Ammonia corrosion may, however, occur when liquid ammonia that contains impurities are brough in contact with the steel, causing corrosion cracking in steel, a situation that commonly occurs with pressure vessels.

5.6 Other hazards

Due to its high heat of vaporization and strong expansion when boiling *hydraulic shocks* may be of particular concern for ammonia. Hydraulic shock refers to a sudden localized pressure surge in piping or equipment resulting from a rapid change in the velocity of the flowing liquid, with the potential to cause catastrophic failure of piping, valves and other components. It occurs when defrosted system gets in contact with refrigerated flow.

Another hazard associated with ammonia stored at pressurized conditions is flashing and expansion of ammonia when released to the atmosphere. According to /4/, 8-9% of ammonia will flash when leaving the tank. Released as two-phase, will be still flashing when pressure is reduced to ambient. At ambient temperature, ammonia will expand 710 times from storage density as a liquid to vapor at its boiling point and continue to evaporate when raining out. Expelling significant amount of ammonia, ammonia tank rupture at 25°C can be regarded as catastrophic.

Boiling liquid expanding vapor explosion (BLEVE) is a physical explosion due to immediate rapid boiling at loss of pressure of a pressurized liquid stored at temperatures well above its boiling point. For a BLEVE to take place the liquid temperature at a time of pressure loss must be above temperature of superheat level (TSL). For ammonia TSL is 89.8°C, which is much higher than ambient temperatures and storage temperatures. Therefore, BLEVE risk can be assumed limited, /4/.

6 METHODOLOGY

6.1 Analysis approach

With the reference to project scope description presented in Section 2.2, the following approach was adapted and followed as depicted in Figure 6-1. The detailed presentation each of the analysis's steps and associated uncertainties are presented in subsequent sections below.

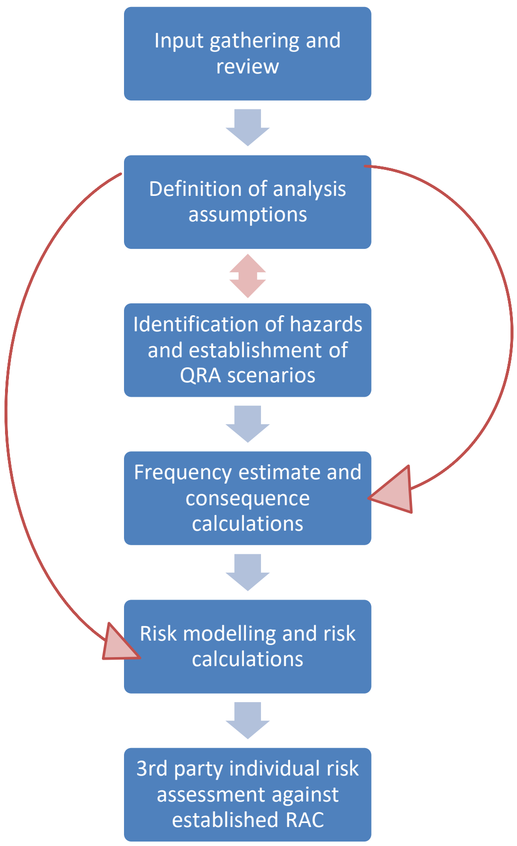


Figure 6-1 Approach defined for application to QRA.

6.2 Quantitative risk analysis

The risk analysis methodology adopted in this QRA is as presented in Figure 6-2.

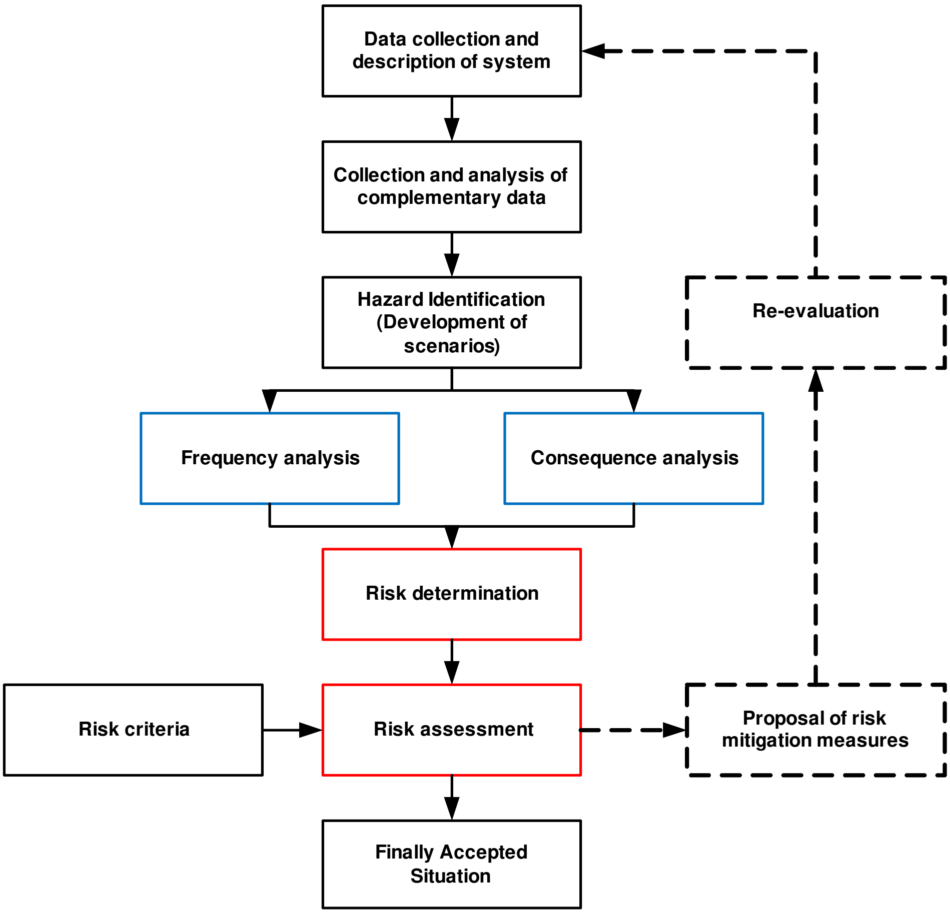


Figure 6-2 QRA Methodology

The risk is calculated by using the DNV standard risk analysis package SAFETI version 8.23. The Safeti software has been the industry standard method for carrying out quantitative risk analysis of onshore process, chemical and petrochemical facilities for more than 30 years. The modelling and simulation of consequences is performed by integrated consequence package – PHAST version 8.23. Event frequency calculations are conducted by DNV Software Leak v.3.3. Further details are presented in subsequent sections below. All modelling assumptions related to the risk modelling are documented in Assumptions' Register, Appendix A.

6.3 HAZID

DNV facilitated a HAZID workshop of ammonia bunkering concepts of a passenger ship in the Port of Oslo on 19th of January 2021. Representatives from Port of Oslo, Wartsila, Yara, passenger ship operator and the Norwegian Maritime Authority (NMA) participated in the workshop. The workshop identified both concept design associated hazards and required safety systems. Up-to-date concepts were established using available technologies and commonly applied safety systems.

The results of the HAZID are documented in HAZID Appendix B. The HAZID session laid a basis for definition of scenarios further considered in the quantitative risk assessment.

6.4 Frequency Analysis

This chapter introduces a basis for leak frequency calculations for process systems located on quay onshore presented in Section 6.4.1 and transfer equipment such as hose and loading arm further presented in Section 6.4.3.

6.4.1 Process leaks

For process equipment, the release frequency is calculated using the DNV internal software LEAK v3.3. This calculates the leak frequency based on data from the Health, Safety and Executive (HSE) Hydrocarbon Release Database (HCRD).

HSE HCRD for 1992-2015 was applied as a basis for leak frequency estimate for process systems located on quay onshore. This database is intended to be applied to process equipment on the topsides of offshore installations and on onshore facilities handling hydrocarbons but are not restricted to releases of hydrocarbons, /8/. The HSE HCRD provides a large, high-quality collection of release experience.

The parts count was executed for Concept 1A/B depicted in Figure 4-1. For evaluation of leak frequency, the frequency analysis was conducted at a "PFD" level for the different process segments. This entails counting only the major equipment items (i.e. from the PFD) and assigning them a detailed parts count of the number of fittings that will apply, i.e. valves, flanges and small-bore fittings based on previously conducted detailed parts count for similar hydrocarbon process systems. The parts count of external leak sources to the ammonia pressurized storage tank was based on typical P&ID for IMO C-type marine tank. Neither leaks nor ruptures of IMO C-type tank were included, where probability for structural failures and leakages through the primary barrier is considered extremely low and can be neglected according to DNV Ship rules, Part 6, Section 2, /9/. The results for parts count are documented in corresponding Assumption A-05 in Appendix A.

A general 1.33 factor is applied to the calculated failure frequencies to account for 25% contribution from recorded process piping leaks in the HCRD, /10/.

6.4.2 Uncertainties in the estimated release frequencies

- Early design phase of the concepts and uncertainties related to the type (for example, type of pump, heat exchanger) and operating conditions of the equipment that greatly impacts the leak frequency output.
- Assumed flowline sizes followed by selection of hole size distribution with representative hole size dimensions per leak size, i.e. small, medium, large and rupture.
- Uncertainty related to the information selection, reporting and inappropriate representation of the release frequency distributions by the fitted correlations in the HCRD 2015, /8/. Although the data in HCRD is considered the best available, the possibility of systematic bias or other errors is recognised.
- Uncertainty related to representative failure causes and mechanisms related to ammonia leaks compared to hydrocarbon systems.

6.4.3 Transfer leaks

A tailor-made leak frequency model for application to this QRA has been established. The model includes transfer leaks related to:

- Ship to ship transfer of refrigerated ammonia by a hose,
- Truck to tank transfer of pressurized ammonia by a hose,
- Tank to ship transfer of pressurized ammonia by a loading arm,

The input for the transfer leaks model is presented in Table 6-1.

Table 6-1 Input to leak model for transfer leaks.

Input data	Bunker vessel to storage tank	Truck to storage tank	Storage tank to ship	Bunker vessel to ship
Transfer type	Cargo loading/ unloading	Cargo loading/ unloading	Bunkering	Bunkering
Transport mode	Marine	Road	Marine	Marine
Flow direction	Delivery	Delivery	Loading	Loading
Fluid type	Ammonia	Ammonia	Ammonia	Ammonia
Tanker type	Ammonia tanker	Liquefied gas road tanker	Ammonia tanker	Ammonia tanker
Transfer equipment	Hose	Hose	Arm	Hose
Hose/arm type	Composite	Composite	Single wall	Composite
No of hoses/arms	1	1	1	1
Flow type	Pumped	Pumped	Pumped	Pumped
Transfer frequency (per year)	91	728	91	91
Quantity transferred (tonnes) per transfer operation	203	27	184	203
Transfer duration (hours)	1.6	0.8	1.6	1.6
Hose /arm diameter (mm)	150	100	150	150
Passing movements (per hour)	1.0	0.0	1.0	1.0
Transfer location	Tidal berth	Customer site	Tidal berth	Tidal berth
ESD	Advanced ESD	Advanced ESD	Advanced ESD	Advanced ESD
ERC	ERC	No ERC	ERC	ERC
Time period	Late 2010s	Late 2010s	Late 2010s	Late 2010s

The analysis uses a model of leaks that was developed by DNV for the Rijksinstituut voor Volksgezondheid en Milieu (RIVM) of the Netherlands government. This model has the capability of estimating frequencies of leaks during transfers of liquefied ammonia involving ships, trucks and bunkering vessels.

In this application, the model uses the following data sources:

- For marine transfer of liquefied ammonia, the model uses data on cargo transfer to/from LNG ships world-wide during 1964-2015, collected by DNV from various public-domain sources.
- For truck transfer of liquefied ammonia, the model uses data on transfer to/from LPG tanker trucks in the USA during 2000-16 from the US Department of Transportation Pipeline and Hazardous Materials Safety Administration incident database.

The RIVM model has the ability to estimate leak frequencies for different scope boundaries, reflecting different leak causes.

The present analysis includes:

- Hose/arm failures
- Hose/arm connection failures
- Leaks from equipment (including ESD valves) on the bunker vessel or truck
- Valve alignment errors

- Disconnection errors
- Leaks due to mooring failure
- Leaks due to the bunker vessel or truck impacting on fixed obstacles while approaching/departing
- Leaks due to striking of the bunker vessel or truck by other ships/vehicles
- Drive-off of the truck while connected

The analysis excludes:

- Leaks from the tanks on the bunker vessel or truck
- Storage tank failures
- Overflow of the storage tank
- Overflow/over-pressurisation of the tank on the passenger ship
- Leaks from equipment (including ESD valves) on the passenger ship

The marine transfer equipment assessed in this evaluation is considered to be equipped with ERC. The ERC is expected to reduce leaks due to mooring failures and strikings. However, it also introduces the possibility of unintended ERC parting without isolation, which is included under connection failures. The marine frequencies are based on LNG ship experience, and it is assumed that all LNG ship transfers already have ERC. Other failure types are dominated by hose failures and valve/disconnection errors.

These sources are used to give the frequency, cause breakdown and size distribution. The model then makes further adjustments related to:

- Frequency of transfer operations and associated duration,
- Type of transfer material and storage conditions, i.e. refrigerated or pressurized ammonia,
- Type of transfer equipment, size and material, including safety systems (as defined in Section 4.3) to represent the required operation.

Estimated leak frequencies are presented in designated Assumption A-05 in Appendix A.

6.4.4 Uncertainties in release frequencies

The RIVM model reports a generic uncertainty range of a factor of 10 higher or lower, applied to the main leak frequency results. The stated range is a 90% confidence range, meaning that 5% probability is judged of more than factor of 10 increase and 5% probability of more than factor of 10 reduction.

6.5 Consequence Analysis

Summaries of the consequence modelling techniques contained within SAFETI, which use the PHAST consequence software platform, are provided in terms of the following key stages:

- Discharge modelling,
- Dispersion modelling,
- Consequence (fire, explosion and toxic impacts).

Key features of the PHAST software, which apply to each of the above stages, are:

- PHAST is a comprehensive hazard analysis software tool which is applicable to all stages of design and operation across a wide range of process industries. It has been adopted by many international companies and governments as a decision support tool in industrial risk and public safety matters.
- The Unified Dispersion Model (UDM) at its heart is respected as one of the world's leading dispersion models for process safety applications. The theory and performance have been independently reviewed as part of the EC funded project SMEDIS, and it has excelled in both areas.
- For liquefied ammonia release under pressure, the UDM has been validated by *Desert Tortoise* (conducted by Lawrence Livermore National Laboratory in the United States in 1983) and *FLADIS* experiments.

In discharge calculations, the modelling uses initial conditions specified by the user and calculates the final conditions. The final conditions are reached when the internal pressure of the released material has fallen to atmospheric pressure. The hole or pipe size, the velocity and the density then determine the mass flow rate. The velocity is the key quantity in determining the rate of entrainment of air in the dispersion modelling. In addition, an estimate of droplet size is made to calculate settling velocities, and hence decide if and when rainout occurs in the dispersion phase.

Once a material has been released into the atmosphere and has expanded so that its internal pressure has fallen to atmospheric pressure, it will travel away from the release point under the influence of its own initial velocity and the ambient wind velocity. The procedure adopted in the consequence module of SAFETI is to calculate the physical parameters of the cloud (dimensions, density, temperature, concentration, liquid fraction) at regular intervals away from the release point. Dispersion continues until the cloud concentration is below the minimum concentration of interest. The end product of dispersion modelling is the calculations of cloud concentrations, dimensions and duration of exposure with increasing distance from the point of interest. In the SAFETI package, horizontal releases are assumed always to be downwind (the worst case).

Finally, dispersion consequences in a form of toxic doses and toxic effect zones used as an input to the risk calculations.

6.5.1 Uncertainty

The SAFETI's UDM dispersion model has been validated against *Desert Tortoise* experiments of liquified ammonia release under pressure. A series of 4 ammonia dispersion tests was conducted to study the dispersion of pressurised liquid ammonia releases in the atmosphere. For the Tortoise Desert tests, the quantities released were between 10,000 and 41,000 kg. In addition, UDM was validated against FLADIS experiments for low rate ammonia release to investigate far field passive effects. It was concluded that performance of the UDM against the aerosol releases of Desert Tortoise and FLADIS, is reasonable.

6.6 **Vulnerability criteria**

For definition of probit function guidance provided in DSB report, /1/, has been followed. Probit function is used in the QRA to estimate the proportion of fatalities following exposure to toxic ammonia release.

The probit function for death due to toxic exposure is specified in dedicated Assumption A-11 in Appendix A. The material constants A, B, and n are based on values estimated by RIVM, 2017, /11/, followed method for derivation of probit functions for acute inhalation toxicity presented in RIVM, 2015, /12/.

According to RIVM, 2015, /12/, probit function is derived based on a range of experiments conducted on animals (mostly rodent data). It is considered taking account of number of uncertainties related to human susceptibility level compared to animal species, complexity of the conducted experiments, potential incompatibility of rodent data with experimental or observational data from humans or primates, etc.

6.7 **Risk estimate and assessment**

Risk modelling and risk calculations are performed by DNV Software package SAFETI v 8.23.

The software incorporates consequence analysis capabilities of PHAST, including UDM. SAFETI analyses complex consequences from accident scenarios and quantifies the risks associated with the release of hazardous chemicals.

Once the consequences have been calculated by the integrated PHAST consequence modelling package, they are combined with the input weather and wind directional probabilities, corresponding failure case frequencies and with the event tree probabilities to calculate the risks. Each failure case is analysed to determine its impact. The probability of death, due to a toxic release, at a point is calculated via the "probit equation" or defined probit function.

The individual risk results in this QRA are presented by location specific individual risk (LSIR) contours or iso-contours. To obtain these, the point risk calculations are repeated at a large number of grid points within the area of interest.

These iso-contours represent a probability that an average unprotected person, permanently present at a certain geographical location, is killed in a period of one year due to an accident resulting from a hazardous activity. It is assumed for individual risk that the population is out of doors and does not shelter or escape.

6.8 SAFETI Limitations

The well-known limitation of SAFETI package is that it does not consider actual layout or physical obstructions associated with the area of release. Software calculates downwind concentrations of a discharge in a free field and is not able to predict downwind concentrations for the case of a discharge impinging an obstacle located few metres away. That should be regarded of particular concern for releases of large amounts of ammonia.

The experiments conducted by INERIS, 2005, /5/, conclude that solid obstacles (wall or ground) located few meters from the discharge point, have a considerable effect on the concentration values measured downwind the obstacle. In tests campaigns conducted, concentrations measured downwind the obstacle were approximately half of those measured for the same discharge into a free field.

Toxic cloud shielding from near-by buildings and cloud channelling effect may affect dispersion behaviour of the cloud leading to potentially overestimate and/or underestimate of consequences.

For definition of safety distances is important to take into account the obstacles in the vicinity of installation.

7 RISK RESULTS

This chapter documents analysis results as an outcome of conducted leak frequency estimate, consequence modelling and evaluation. The 3rd party individual risk calculation results are summarized and presented in the following sections. Main contributors to the risk are defined and explained.

7.1 Frequency results

This section summarizes leak frequency results conducted for application to defined concepts 1A/B and 2. The methodology for frequency estimate is presented in Section 6.4. The equipment parts count results are documented in dedicated Assumption A-05, in Appendix A. The leak size distribution and representative hole size categories are documented in dedicated Assumption A-06.

QRA segments subjected to leak frequency estimate are presented in Table 4-1 and Table 4-2.

The leak frequency results per concept 1A, 1B and 2 are presented in corresponding Table 7-1**,** Table 7-2 and Table 7-3.

As it is seen from Table 7-1 and Table 7-2, ammonia transfer frequencies do not report leaks for medium category. The transfer frequencies are represented by three (3) hole size categories, small, large and rupture, the medium category is not reported. The small leaks associated with ammonia transfer from the truck are excluded based on quantities being transferred per year which are found to have a negligible impact on the 3rd party individual risk.

Table 7-1 Leak frequency results per leak category and % contribution to the total frequency, Concept 1A – truck to tank

QRA Segments	Leak frequency per year					Contribution, %
	Small	Medium	Large	Rupture	Total	
Segment 1A – Truck transfer by hose	-	-	2.9E-04	1.1E-04	4.0E-04	5.8 %
Segment 2A – Loading manifold truck	2.1E-04	3.4E-05	1.1E-06	8.2E-07	2.5E-04	3.6 %
Segment 3 – Pressurized storage tank	2.5E-03	4.0E-04	3.5E-05	3.3E-05	3.0E-03	43.8 %
Segmenr 4 – Process pipe	9.3E-05	1.8E-05	4.5E-06	6.7E-06	1.2E-04	1.8 %
Segment 5 – Loading arm	1.6E-03	-	5.0E-04	9.8E-04	3.1E-03	45 %
Grand Total	**4.4E-03**	**4.5E-04**	**8.3E-04**	**1.1E-03**	**6.8E-03**	**100 %**

Table 7-2 Leak frequency results per leak category and % contribution to the total frequency, Concept 1B – ship to tank

QRA Segments	Leak frequency per year					Contribution, %
	Small	Medium	Large	Rupture	Total	
Segment 1B – Ship transfer by hose	2.9E-03	-	7.7E-04	1.6E-03	5.3E-03	45.5 %
Segment 2B – Loading manifold ship	9.1E-05	1.5E-05	1.5E-06	1.2E-06	1.1E-04	0.9 %

QRA Segments	Leak frequency per year					Contribution, %
	Small	Medium	Large	Rupture	Total	
Segment 3 – Pressurized storage tank	2.5E-03	4.0E-04	3.5E-05	3.3E-05	3.0E-03	25.9 %
Segmenr 4 – Process pipe	9.3E-05	1.8E-05	4.5E-06	6.7E-06	1.2E-04	1.1 %
Segment 5 – Loading arm	1.6E-03	-	5.0E-04	9.8E-04	3.1E-03	26.6 %
Grand Total	**7.2E-03**	**4.3E-04**	**1.3E-03**	**2.6E-03**	**1.2E-02**	**100 %**

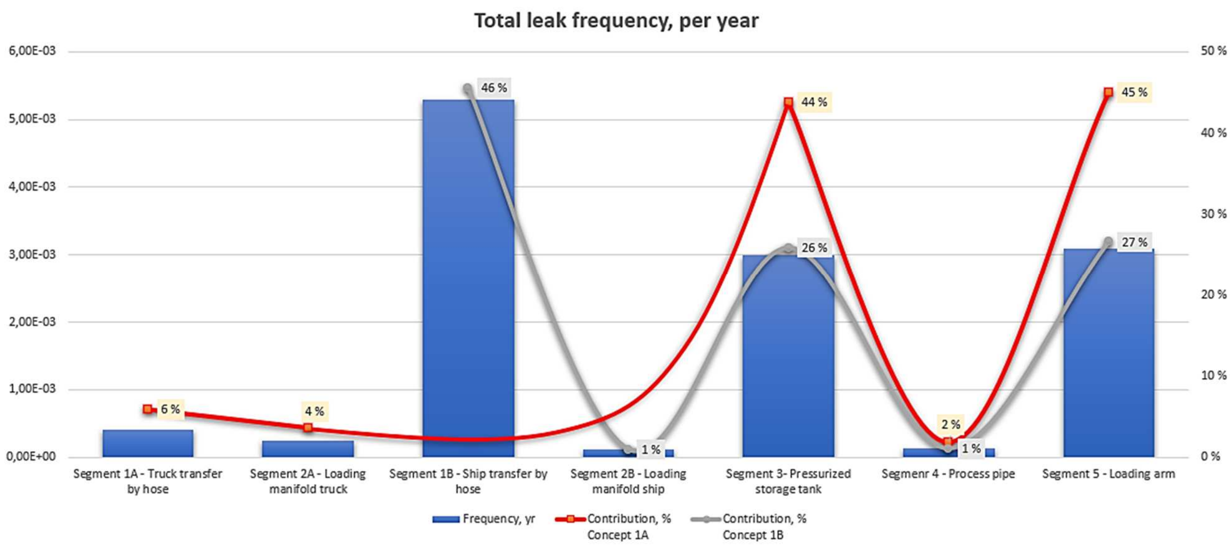


Figure 7-1 Total annual leak frequency and % contribution, Concepts 1A and 1B

The overview of the total leak frequency is depicted in Figure 7-1. As it is seen, the main contributors to the leak frequency in Concept 1A are Segments 3 (storage tank) and Segment 5 (loading arm). Whereas for Concept 1B, the contribution is distributed among 3 segments, i.e. Segment 1B (ship transfer by hose), Segment 3 (storage tank) and Segment 5 (loading arm).

Concept 1B is estimated with higher total leak frequency compared to Concept 1A. The main difference is explained by significantly higher contribution of ship transfer frequency compared to ammonia transfers from truck. Despite higher utilization ratio of transfer hose and loading manifold in Concept 1A, i.e. 6.6% vs 1.6% in Concept 1B, the leak frequency per transfer is much smaller in truck transfers. This difference is much reduced in the frequencies per year, when comparable quantities are transferred, and when small leaks are excluded for truck transfers. Otherwise, small leaks normally contribute by over 50% to the total leak frequency. The remaining difference could result from the use of different data sources, however, may also reflect the benefits of onshore transfer which does not experience any vessel movement.

The Segment 3 (storage tank) is found among top contributors. This contribution is mainly defined by continuously pressurized external connections to the tank. The contribution from other segments onshore, such as receiving manifold and process pipe is low due to the low utilization factor of these systems.

Associated process equipment is assumed to be purged with nitrogen prior to/after each transfer operation, and, thus, pressurized only at times when ammonia transfers occur.

The Concept 2 is represented by a single Segment 1 (ship transfer by hose).

Table 7-3 Leak frequency results per leak category and % contribution to the total frequency, Concept 2 – ship to tank

QRA Segment	Leak frequency per year					Contribution, %
	Small	Medium	Large	Rupture	Total	
Segment 1 – Ship transfer by hose	2.9E-03	-	7.7E-04	1.6E-03	5.3E-03	100 %
Grand Total	**2.9E-03**	**-**	**7.7E-04**	**1.6E-03**	**5.3E-03**	**100 %**

The small leaks contribute mainly to the total leaks, whereas ruptures are estimated with higher leak frequencies compared to large leaks. This could be due to uncertainty in reported leak sizes, but it may also reflect the vulnerability of marine transfer to full-bore rupture due to vessel movement, and possibility of unintended ERC parting without isolation.

7.2 Consequence results

7.2.1 Discharge results

Main discharge parameters for Concept 1 A/B are summarized in Table 7-4.

Table 7-4 Discharge result, Concept 1A and 1B

Segment Name	Leak size	Initial leak rate, kg/s	Liquid fraction after atmospheric expansion	Release duration, s
Segment 1A – Truck transfer by hose	Small	0.02	0.85	3600
	Large	2	0.85	156
	Rupture	11	0.85	100
Segment 2A – Loading manifold truck	Small	0.4	0.85	1642
	Medium	10	0.85	152
	Large	11	0.85	147
	Rupture	11	0.85	147
Segment 1B – Ship transfer by hose	Small	0.03	1	3600
	Large	3	1.00	223
	Rupture	48	1.00	98
Segment 2B – Loading manifold ship	Small	0.4	0.85	1643
	Medium	10	0.85	152
	Large	47	0.85	103
	Rupture	47	0.85	103
Segment 3A – Pressurized storage tank Liquid outlet connection to the tank	Small	0.4	0.85	3600
	Medium	10	0.85	3600

Segment Name	Leak size	Initial leak rate, kg/s	Liquid fraction after atmospheric expansion	Release duration, s
	Large	166	0.85	3600
	Rupture	387	0.85	1701
Segment 3B- Pressurized storage tank Liquid inlet connection to the tank	Small	0.4	0.85	3600
	Medium	10	0.85	3600
	Large	166	0.85	3600
	Rupture	387	0.85	1701
Segment 3C- Pressurized storage tank PRV gas	Small	0.02	0.00	3600
	Medium	1	0.00	3600
	Large	8	0.00	1491
	Rupture	19	0.00	642
Segment 3D- Pressurized storage tank Connection to gas vent pipe	Small	0.02	0.00	3600
	Medium	1	0.00	3600
	Large	8	0.00	1581
	Rupture	19	0.00	732
Segment 4 – Process pipe	Small	1	0.78	3040
	Medium	14	0.78	208
	Large	39	0.78	132
	Rupture	39	0.78	132
Segment 5 – Loading arm	Small	0.1	0.78	3600
	Large	5	0.78	144
	Rupture	39	0.78	97

The initial leak rate for large and rupture cases is often overestimated by SAFETI. In this analysis, the initial rate was capped at 1.25 x NFR for the pump driven segments as documented in corresponding Assumption A-09, following recommendations in DNV LNG QRA Guideline 16, /2/. This applies to Segments 1A/B, 2A/B, 4 and 5. Therefore, initial leak rate for large and rupture scenarios reported in Table 7-4 indicates adjusted values. The release duration for pump driven sections is defined by the time to isolate the leak and static inventory volume. The bunker pump is assumed to be stopped within 90 sec after leak starts. That applies also to ESD failure scenario.

For storage tank events, the initial rate is predicted by SAFETI. No adjustment has been introduced to the modelled leak locations represented by the external connections to the tank. These connections are considered being pressured 100% of the time. The storage tank is 100% filled with liquified ammonia, containing over 600 tons of ammonia at pressurized condition. The initial leak rate is therefore inventory driven, and due to the large tank volume, slow depressurization of the tank is observed followed by slow reduction in mass rate for a duration of SAFETI simulation, i.e. 3600 seconds. In addition, the liquid fraction after atmospheric expansion reduces to 85%, meaning that part of pressurized ammonia flashes when leaving the tank.

Top segments generating high initial rates are illustrated in Figure 7-2. These are Segment 3 (storage tank liquid scenario), Segment 1B (ship transfer by hose) followed by Segment 4 (process pipe), and Segment 5 (loading arm). The remaining segments are considered to generate from moderate to negligible consequence results compared to the main contributors.

Total leak duration is defined by duration of ESD isolation times (ref. Assumption A-07), in addition to duration required to empty the static inventory inside the segment. The maximum release duration is limited by the maximum simulation time of 3600 s applied in this assessment.

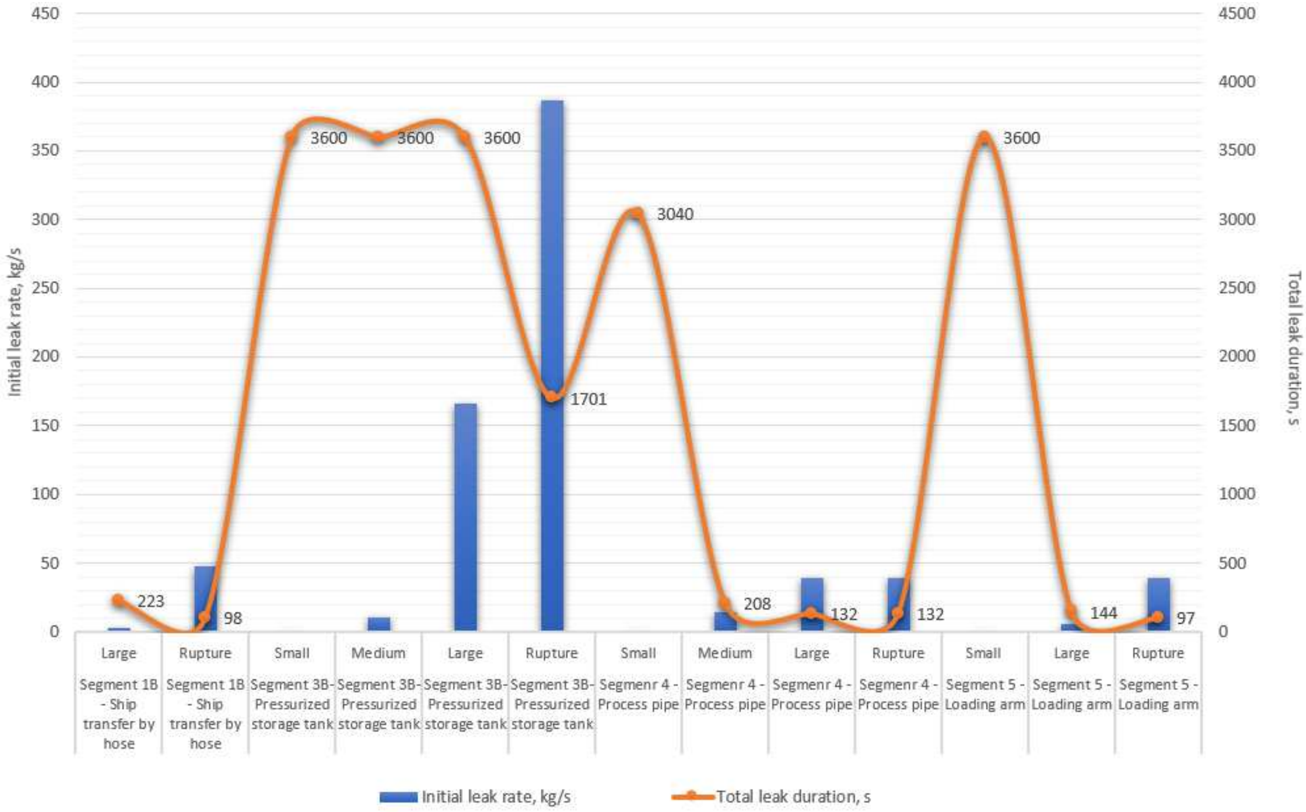


Figure 7-2 Top segments estimated with high initial leak rates

It should be noted that after segment is isolated, the initial leak rate drops as pressure drops in the segment. Therefore, Figure 7-2 represents the initial, i.e. maximum leak rate.

7.2.2 Dispersion results

Dispersion results are represented by top contributors to each of the concepts based on conducted frequency and discharge calculations, reported in 7.1 and 7.2.1, i.e. event failure frequency, initial rate and total release duration.

Once a material has been released into the atmosphere and has expanded so that its internal pressure has fallen to atmospheric pressure, it will travel away from the release point under the influence of its own initial velocity and the ambient wind velocity.

In case of release of pressurized ammonia, it will become diphasic after atmospheric expansion, forming fine aerosol mist flashing when pressure is reduced to ambient followed by vaporization and further dilution with air. When temperature is reduced to ambient, ammonia will expand 700 times from storage density as a liquid to vapor at its boiling point of -33,4°C. Therefore, large quantities of pressurized ammonia released to the atmosphere are assessed to contribute to high vaporization and cloud expansion. Part of the ammonia will rainout and form a pool. The ammonia constituting the pool will evaporate at considerably low rate but will however contribute to the cloud concentration.

Ammonia is hygroscopic (readily absorbs moisture), i.e. in the presence of moisture (such as high relative humidity), the liquefied anhydrous ammonia gas forms vapors that are heavier than air. These vapors spread along the ground. Stable weather conditions and low wind speeds contributes to longer dispersion distances.

Pressurized ammonia releases are assessed to generate worst consequences compared to refrigerated ammonia release. The ammonia spills to water are associated with high vaporization due to the ammonia reactivity with water. Such pressurized releases associated with systems located on the border between shore and the sea (such as Segment 4 and 5) are modelled as spills both on land and in water. Spill of pressurized ammonia to water generates toxic cloud that is fed both by the release vaporization while rainout and vaporization from the pool on the sea surface, which is characterized by higher rate compared to pool vaporization rate if spilled on the land.

When refrigerated ammonia spilled to water, ammonia becomes very reactive and evaporates at high rates. Half of the spilled ammonia will be absorbed by water as discussed in Section 0. The remaining ammonia will evaporate as at the moment of spillage locally insufficient water is available to dissolve all the ammonia resulting in a *gas cloud*. The gas cloud thus exhibits longer dispersion distances at higher wind speeds.

Whereas the land release of cold ammonia is associated with pool formation followed by vaporization when heat from the land gets transferred to the pool. The vaporizations rate is relatively low. Such release is assessed to generate the lowest consequences.

Figure 7-3, Figure 7-4, and Figure 7-5 Illustrate dispersion results for liquid releases of pressurized ammonia, represented by Segments 3 and 5, and refrigerated ammonia, represented by Segment 1B (applies both to Concept 1B and 2). These scenarios are defined as main contributors to the total leak frequency results, ref. Section 7.1 and conducted discharge calculations, ref. Section 7.2.1. It should be noted that these results present dispersion on the land, i.e. with the wind blowing from the sea towards Oslo City Centre.

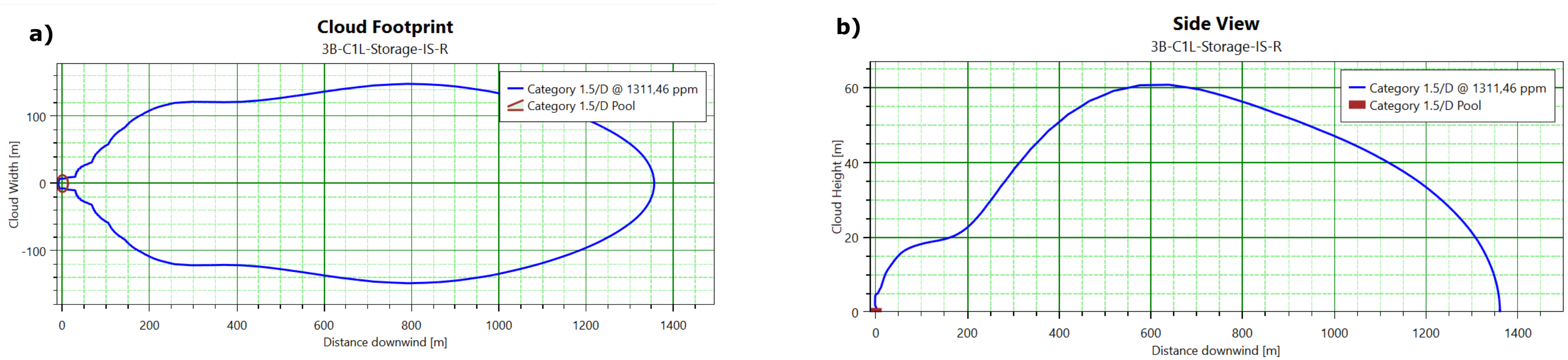


Figure 7-3 Concept 1, Segment 3B – storage tank, liquid release from the tank inlet line connection on land, rupture release scenario. View time is 1650 seconds @ toxic concentration of 1311,46 ppm (0.1% fatality) @ 1.5D wind conditions; (a) toxic cloud footprint (view from above), i.e. cloud width, m vs cloud downwind distance, m, (b) cloud sideview, i.e. cloud height, m vs cloud downwind distance, m.
Dispersion surface – land.

The dispersion results are generated for one (1) representative wind categories, i.e. 1.5m/s which is estimated to produce the worst dispersion distances and generates the biggest toxic clouds. This wind speed has an occurrence of 38% based on 10-year conducted observation (second frequent wind speed category), ref. Assumption A-01. The atmospheric stability class D (neutral – little sun, high wind or overcast/windy night) is applied, ref. Assumptions A-01 and A-02.

The rupture release from the storage tank generates high mass flow rate. As discussed above part of the ammonia will flash when leaving the tank when the pressure drops to ambient followed by vaporization. Remaining liquid ammonia present in the cloud will rainout and form a pool. The pool vaporization rate will not contribute significantly to the cloud concentration compare to the initial flash fraction. For the rupture case on the storage tank liquid inlet, concentration of 1311ppm is reached over 1300m downwind The rupture case forms a high and wide cloud as depicted in Figure 7-3.

The cloud disperses along the ground and behaves as a heavy gas due to the earlier mentioned hygroscopic property of the ammonia.

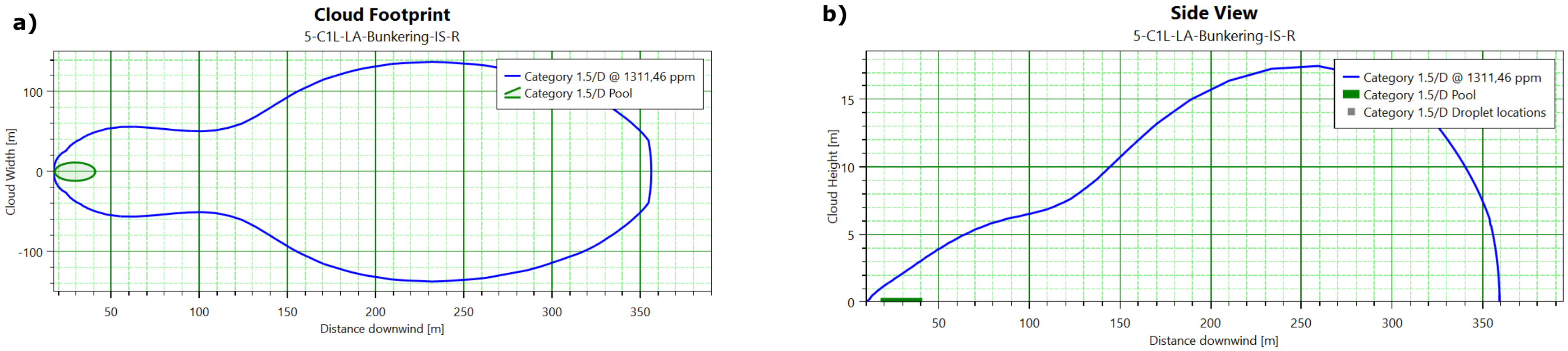
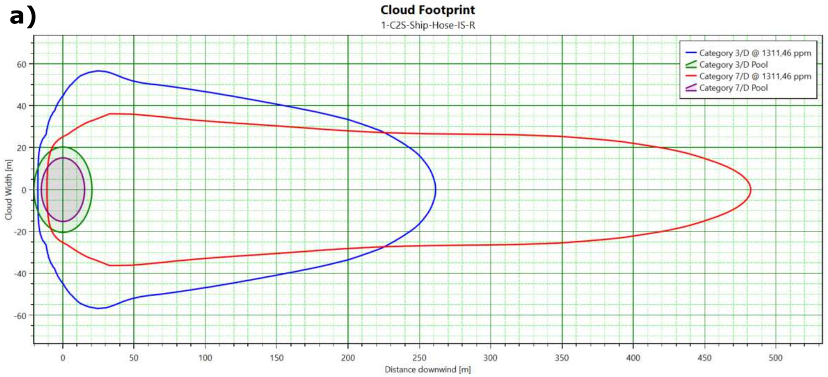


Figure 7-4 Concept 1, Segment 5 – loading arm, pressurized ammonia release on land, rupture release scenario. View time is above 200 seconds @ toxic concentration of 1311,46 ppm (0.1% fatality) @ 1.5D wind conditions; (a) toxic cloud footprint (view from above), i.e. cloud width, m vs cloud downwind distance, m, (b) cloud sideview, i.e. cloud height, m vs cloud downwind distance, m. Dispersion surface – land.

The rupture release associated with failure of loading arm equipment illustrated in Figure 7-4 will be released at higher pressure and temperature compared to the storage tank scenario. That contributes to higher flashing rate when leaving the tank. The scenario exhibits lower dispersion distances defined by significantly lower initial release rate compared to the storage tank scenario.

The cloud disperses along the ground and behaves as a heavy gas due to the earlier mentioned hygroscopic property of the ammonia.

a)



b)

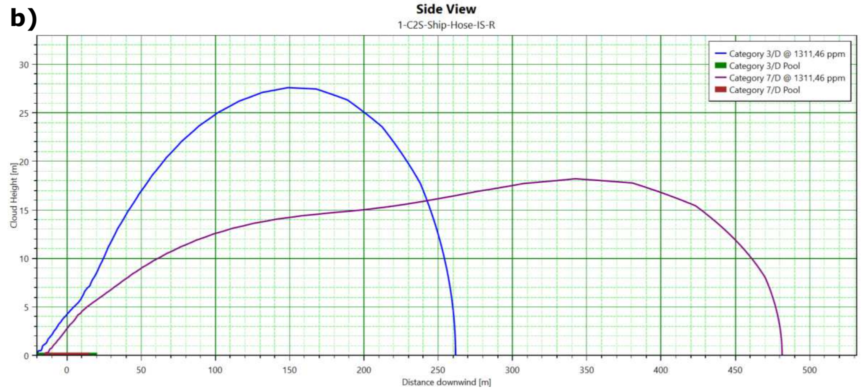


Figure 7-5 Concept 1B/2, Segment 1B/1 – ship transfer by hose, cold ammonia spill to water, rupture release scenario. View time is 190 seconds @ toxic concentration of 1311,46 ppm (0.1% fatality) @ 3D & 7D wind conditions; (a) toxic cloud footprint (view from above), i.e. cloud width, m vs cloud downwind distance, m, (b) cloud sideview, i.e. cloud height, m vs cloud downwind distance, m Dispersion surface – land.

The dispersion results depicted in Figure 7-5 are representative both for Concepts 1B and 2.

When spilled to water, ammonia becomes very reactive and evaporates at high rates. Half of the spilled ammonia will be absorbed by water as discussed in Section 0. The remaining ammonia will evaporate as at the moment of spillage locally insufficient water is available to dissolve all the ammonia resulting in a *gas cloud*. The gas cloud thus exhibits longer dispersion distances at higher wind speeds. Therefore, dispersion results are reported for 3D & 7D wind conditions, comprising 62% of wind occurrence.

The release direction affects the dispersion results. Thus, unobstructed horizontal release will be released at higher momentum compared to release modelled with horizontal impinged direction or down impinged to represent obstacles/obstruction in vicinity of the release. For heavy gas released in free field that implies slower mixing of the toxic cloud with air followed by larger (in volume) clouds. Applied assumptions to the release direction are documented in Assumption A-04.

For releases of pressurized ammonia, the relative height above ground level will contribute to the amount of ammonia being vaporized while rainout and contributing to longer dispersion distances, see Assumption A-03 for details.

In case of rainout hitting outside the bund, much worse consequences are expected for large releases such as storage tank scenario (Segment 3). For this assessment, the jet is assumed being obstructed by the surrounding structure to limit the jet trajectory and rainout distance, see Section 4.4. Whereas, rainout for all other scenarios (Segments 2, 4) with release location on the land, is assumed to hit outside the drainage area represented by the bund in SAFETI.

Depending on the wind direction, the dispersion may as well occur over the sea surface north-east, south, and south-east of the installation. In this case, the dispersion distances will be longer compared to dispersion over ground mainly due to the significantly lower surface roughness represented by the open water (see Assumption A-10). The dispersion results for wind direction from the land towards the sea represented by same scenarios are illustrated in Figure 7-6, Figure 7-7, and Figure 7-8.

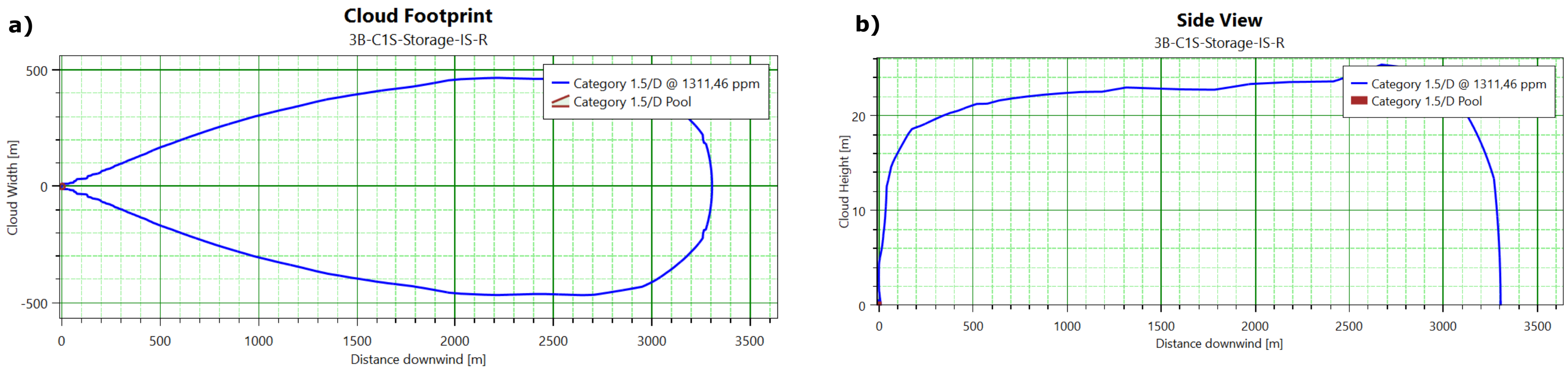
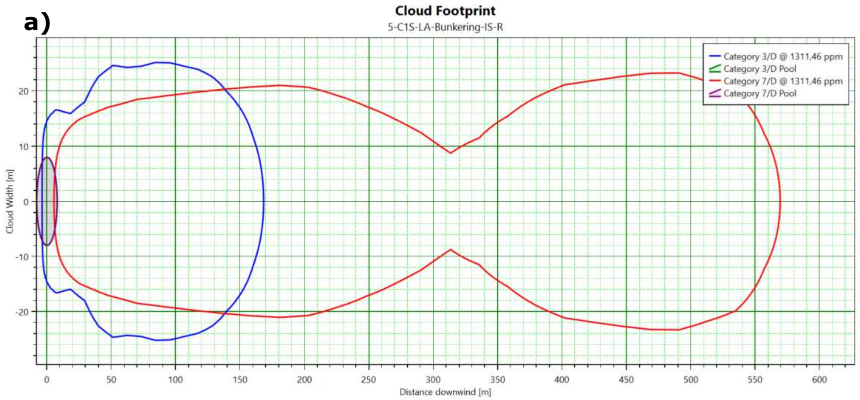


Figure 7-6 Concept 1, Segment 3 – storage tank, liquid release from the tank inlet line on the land, rupture release scenario. View time is 1650 seconds @ toxic concentration of 1311,46 ppm (0.1% fatality) @ 1.5D wind conditions; (a) toxic cloud footprint (view from above), i.e. cloud width, m vs cloud downwind distance, m, (b) cloud sideview, i.e. cloud height, m vs cloud downwind distance, m.
Dispersion surface – open water.

For large release of pressurized ammonia, dispersion of the cloud will occur over longer distance due to a low surface roughness on the see compared to the land see Figure 7-3. The numerous obstacles associated with surface roughness on the land, contribute to reduction in dispersion distances when cloud is being obstructed.

a)



b)

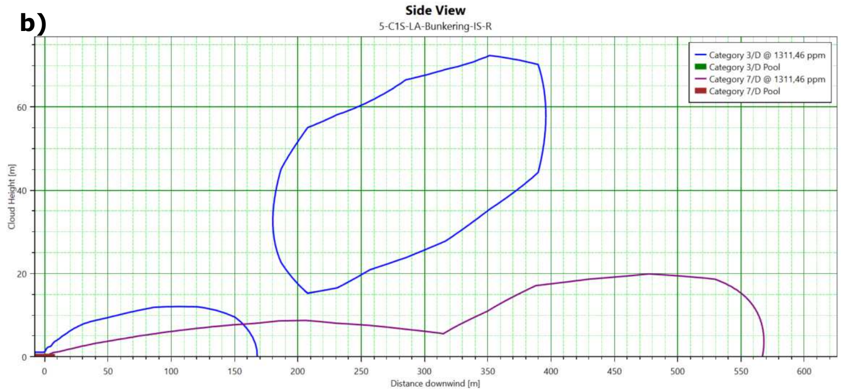


Figure 7-7 Concept 1, Segment 5 – loading arm, pressurized ammonia spill to water, rupture release scenario. View time is above 100 seconds @ toxic concentration of 1311,46 ppm (0.1% fatality) @ 1.5D wind conditions; (a) toxic cloud footprint (view from above), i.e. cloud width, m vs cloud downwind distance, m, (b) cloud sideview, i.e. cloud height, m vs cloud downwind distance, m. Dispersion surface – open water.

The pressurized spill in water, will flash when leaving the tank and vaporize while rainout. The formed pool on the sea surface will continue to vaporize and substitute the gas cloud. The gas cloud is more buoyant thus more affected by higher wind speed categories. Low surface roughness contributes to longer dispersion distances. During first 90 sec after release starts the cloud is mainly fed by dynamic inventory. After 90 sec, the toxic cloud is fed by vaporized pool on the sea surface.

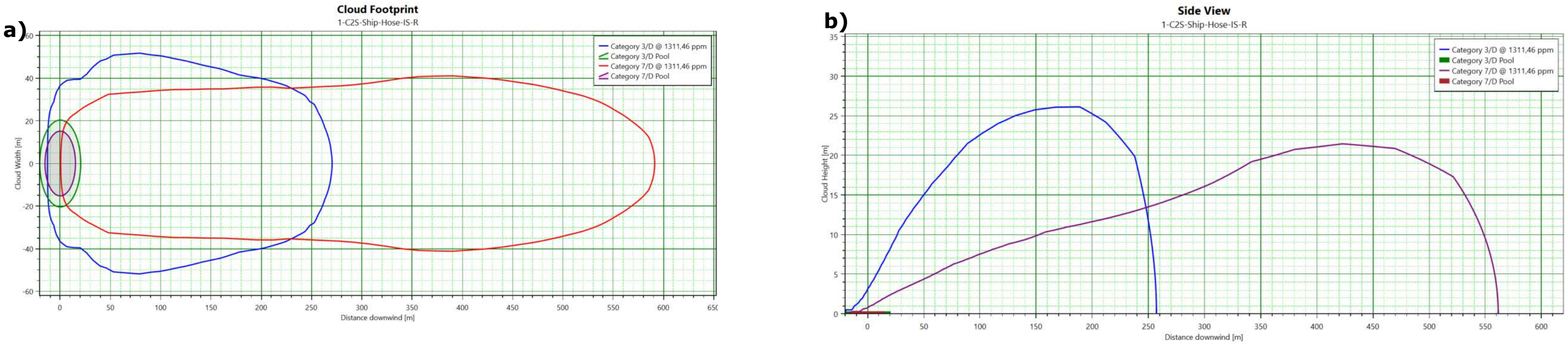


Figure 7-8 Concept 2, Segment 1 – ship transfer by hose, cold ammonia spill to water, rupture release scenario. View time is 190 seconds @ toxic concentration of 1311,46 ppm (0.1% fatality) @ 3D & 7D wind conditions; (a) toxic cloud footprint (view from above), i.e. cloud width, m vs cloud downwind distance, m, (b) cloud sideview, i.e. cloud height, m vs cloud downwind distance, m Dispersion surface – open water.

Compared to the same release with dispersion over the land, the cold ammonia released over the water, experiences much slower drop in toxic concentration which thus is preserved on considerably longer distances.

7.2.3 Toxic outdoor probit footprint

This section reports the outdoor toxic footprint for scenarios presented in Section 7.2.2. Results are presented in Figure 7-9, Figure 7-10 and Figure 7-11.

The following toxic levels are depicted:

Toxic probit	Lethality, %
2	0.1
3	1
4	10
10	99

As discussed in Section 7.2.2, the release over open water is associated with longer dispersion distances due to the little/no obstruction (surface roughness of 0.2 mm is applied, ref. Assumption A-10) contributing thus to longer dispersion distances. Figure 7-9, Figure 7-10 and Figure 7-11 illustrates toxic probit lethality levels for both dispersion of ammonia over the land and over the open water.

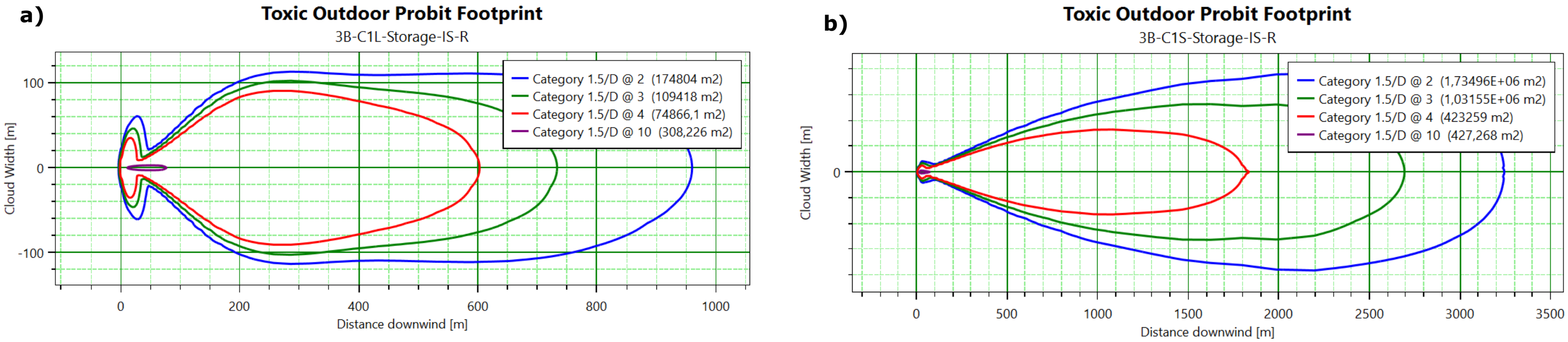


Figure 7-9 Concept 1, Segment 3 – storage tank, liquid release from the tank top, rupture release scenario @ 1.5D wind conditions; (a) dispersion surface – land, (b) dispersion surface – open water.

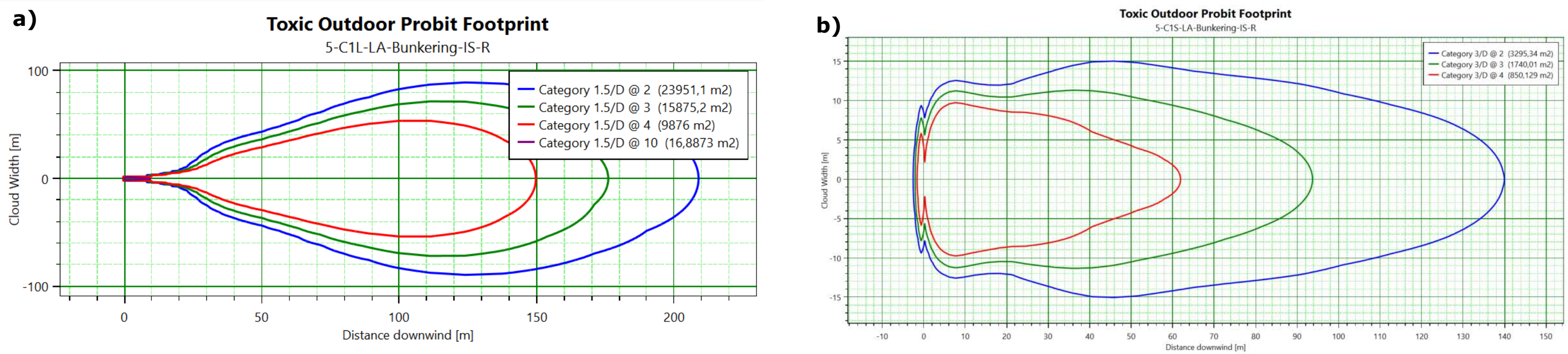


Figure 7-10 Concept 1, Segment 5 – loading arm, rupture release scenario; (a) dispersion surface – land @ 1.5D wind conditions, (b) dispersion surface – open water @ 3D wind conditions.

The results in Figure 7-10 (b) are depicted for the most frequent wind category. Though, wind category 7D will generate worse consequences associated with negligible occurrence compared to two (2) other wind categories. The release does not generate high toxic concentration with fatality rate of 99%. That is the results if the cloud being lighter compared to land release and mixing better with air at higher wind speeds.

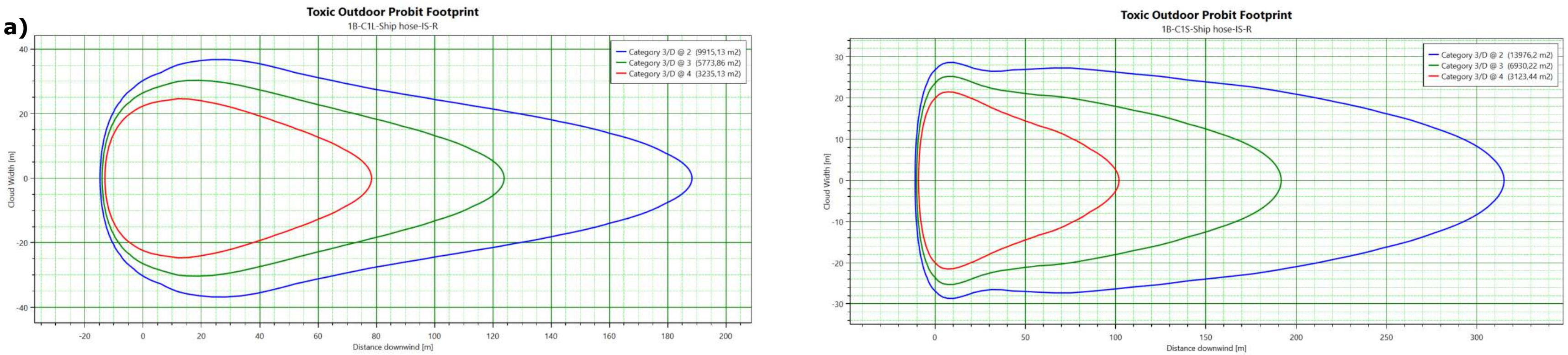


Figure 7-11 Concept 1B/2, Segment 1 – ship transfer by hose, rupture release scenario; (a) dispersion surface – land @ 1.5D wind conditions, (b) dispersion surface – open water @ 3D wind conditions.

The results in Figure 7-11 (b) are depicted for the most frequent wind category. Though, wind category 7D will generate worse consequences associated with negligible occurrence compared to two (2) other wind categories.

7.3 3rd party individual risk results

Based on frequency and consequence analysis and results discussed in Sections 7.1 and 7.2 combined with the input weather and wind directional probabilities, the risk calculations were conducted for Concept 1 A/B and Concept 2. The risk results for 3rd party individual risk are presented in a form of LSIR contours or iso-contours. The risk level is calculated as an average over 24 hours per day for a representative 12-month period. The iso-contours are depicted at 1 m representative height above ground level.

This section documents risk results and assesses risk against defined risk acceptance criteria presented in Section 3.

7.3.1 Concept 1A and 1B

The risk results for Concepts 1 A and B are assessed to exceed defined RAC presented in Figure 7-12 and Figure 7-13, and summarized in Table 7-5.

Figure 7-12 LSIR contours – Concept 1A

Figure 7-13 LSIR contour – Concept 1B

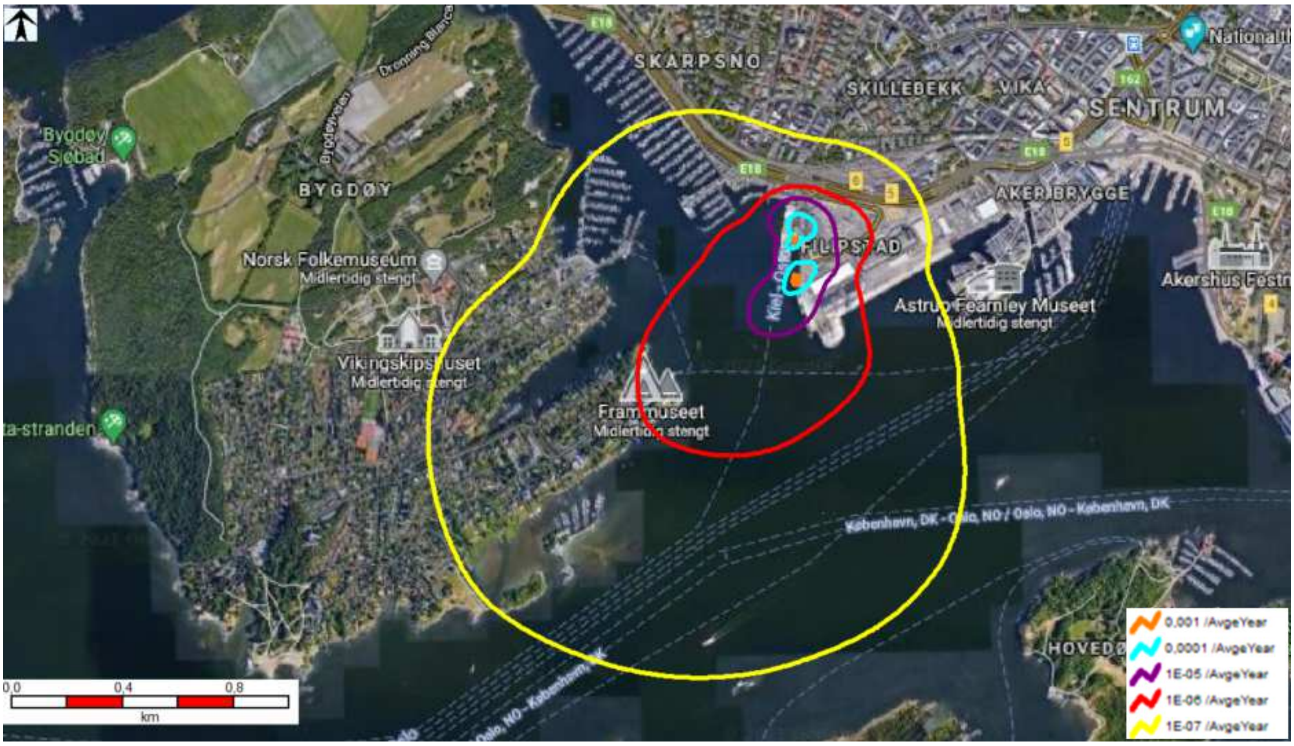


Figure 7-13 LSIR contour – Concept 1B

Table 7-5 Summary of individual risk for Concept 1A and 1B towards RAC

Consideration zones	**Requirement**	**Assessment of Concept 1A and 1B**
Inner zone (up to 1E-05 per year) Purple line	This is basically the business's own area. In addition, for example, LNF area (Landbruks-, natur- og friluftsområder) can be included in the inner zone. Only short-term passage for third parties.	Risk acceptance criteria (RAC) is breached due to 1E-05/yr risk contour covering 3rd party industrial facilities, offices, public local road to the ferry, and parking slots, which should be outside 1E-05/yr risk zone.
Middle zone (up to 1E-06 per year) Red line	Public road, rail, dock and similar. Permanent industry and office can also be found here. In this zone, there should not be accommodation or housing. Scattered housing can be accepted in some cases.	Risk level exceeds RAC. Estimated 1E-06/yr risk contour is assessed to expose permanent/sensitive public areas such as Fram museum south-west of the installation and part of the residential area on Bygdøy
Outer zone (up to 1E-07 per year) Yellow line	Areas regulated for residential purposes and other uses of the general population can be included in the outer zone, including shops and smaller accommodations.	1E-07/yr risk contour covers large areas, including areas regulated for residential purposes and other uses of the general population, including shops and smaller accommodations. Schools, kindergarten, nursing homes, hospitals and similar institutions,

Consideration zones	Requirement	Assessment of Concept 1A and 1B
		shopping centres, hotels or large public arenas must be placed outside 1E-07/yr risk contour, thus assessed not be in accordance with RAC.
Outside Outer Zone Outside yellow line	Schools, kindergarten, nursing homes, hospitals and similar institutions, shopping centres, hotels or large public arenas must normally be placed outside the outer zone.	See description for outer zone.

For Concept 1A, the main contributors to 1E-06/1E-07/yr risk contours are large releases from pressurized storage tank (Segment 3B), including loading arm (Segment 5). For 1E-05/yr risk contour and exposure of the parking slot, the small, medium releases associated with Segment 3B and rupture of loading arm are the main contributors, whereas the risk at passenger ship bunkering area is dominated by large and rupture scenario associated with loading arm (Segment 5). The contribution of truck hose failure and associated equipment is insignificant.

For Concept 1B, the main contributors to 1E-06/1E-07/yr risk contours are large releases from pressurized storage tank (Segment 3B), including loading arm (Segment 5) and STS bunkering scenario (Segment 1B). For 1E-05/yr risk contour and exposure of the parking slot, the ship hose rupture (Segment 1B) is the main contributor, whereas the risk at passenger ship bunkering area is dominated by large and rupture scenario associated with loading arm (Segment 5).

The large contribution of a continuous release from the failed inlet line connection of the pressurized storage tank (Segment 3B) is defined by the large initial release rate followed by large liquid inventory volume combined with relatively high frequency of release. It should be noted that inlet liquid line to the tank was assumed to be represented by 3 m high release location above the ground level. That assumption significantly impacts consequences of the release, contributing to higher vaporization of ammonia while rainout, continuously feeding toxic cloud. Such release is represented by liquid phase only, based on the conservative assumption of tank being filled to maximum allowable limit at all times. Otherwise, if the tank is only filled by liquid 90% or lower, failed connection or associated equipment will first release the gas phase followed by diphasic release of ammonia, decreasing consequence extent.

Further, the release jet from the storage tank is assumed to be obstructed by the surrounding structures, limiting thus the jet trajectory and rainout distance, assuming all rainout to occur inside the bund. The tank is assumed to have a bund and be protected by the wall around to limit the external access and impact. Otherwise, if rainout hits outside the bund, that will imply longer rainout distances associated with longer dispersion distances. That is considered to worsen the risk results.

As it was discussed in the sections above, the pressurized scenarios are assessed to generate worst consequences. That is due to the flashing of pressurized ammonia when liquid becomes gas after released to the atmosphere. The high expansion rate when ammonia reaches its boiling point at ambient temperature generates big toxic clouds. The pool formed as a result of rainout is cold and evaporates at comparatively lower rate.

Whereas release of cold or refrigerated ammonia is assessed with considerably lower consequences. After atmospheric expansion, the temperature of ammonia drops to around – 50°C. Such release forms a pool followed by pool vaporization when heat is being transferred to the spilled cold ammonia. The formed toxic cloud is considerably smaller compared to associated pressurized release of ammonia.

It should be noted that results are influenced by the wind rose and representative wind conditions. For this assessment, wind rose representative for Oslo Centre was utilized. The location specific wind rose may affect the risk contours.

Finally, risk simulated by SAFETI does not take into account the actual geometry of the area of release, including size and shape of the buildings and obstacles around. Thus, based on INERIS experiments, /5/, discussed elsewhere in the report, the toxic concentration of the cloud is documented to drop significantly when obstructed by an obstacle. Such tall and massive obstacles are considered to block parts of the large cloud followed by more effective dilution with air and reduction in toxic concentration. That is considered to impact the risk picture assessed by this QRA.

7.3.2 Concept 2

For Concept 2, risk results are illustrated in Figure 7-14 and summarized in Table 7-6, the risk is assessed acceptable against defined RAC.

The main contribution to the risk is associated with the ship hose transfer of cold ammonia to the passenger ship. Such release in case of transfer equipment failure will occur above water. When spilled to water, ammonia becomes very reactive and evaporates at high rates. Half of the spilled ammonia will be absorbed by water. The toxic *gas cloud* is formed by high vaporization of ammonia spilled in water.

The risk contours for Concept 2 do not account for a release being blocked by the two ship structures. That can further reduce the extent the contours where the passenger ship is. At the same time, it can lead the gas along the ship towards front or aft and lead to more concentrated gas plumes in these locations.

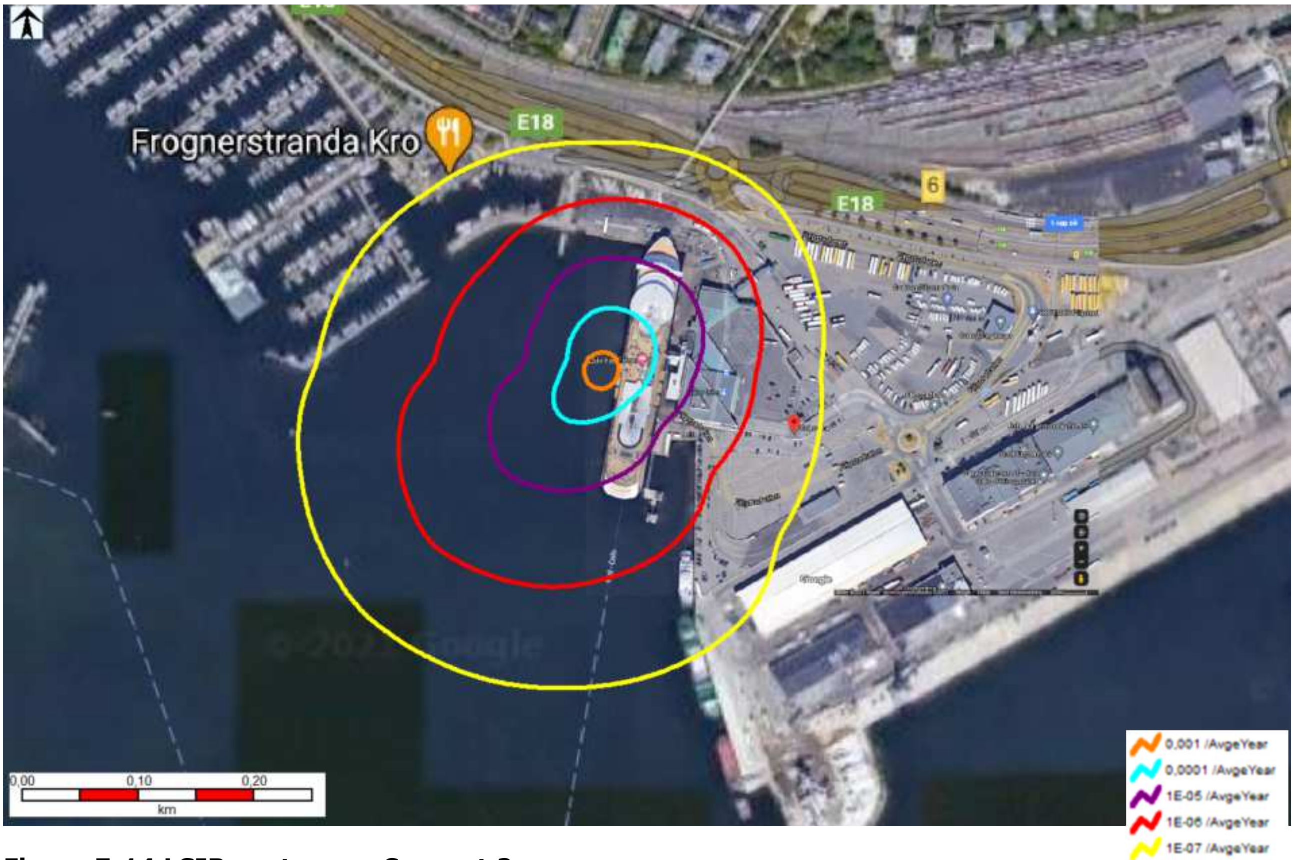


Figure 7-14 LSIR contours – Concept 2

Table 7-6 Summary of individual risk for Concept 2 towards RAC.

Consideration zones	Requirement	Assessment of Concept 2
Inner zone (up to 1E-05 per year) Purple line	This is basically the business's own area. In addition, for example, LNF area (Landbruks-, natur- og friluftsområder) can be included in the inner zone. Only short-term passage for third parties.	The 1E-05 line overlaps part of the terminal with offices. However, the passenger ship will in practice "block" gas from travelling downwind towards the terminal. This is not accounted for in Safeti. Areas in the front or aft can get slightly longer inner zones due to gas moving along the ship.
Middle zone (up to 1E-06 per year) Red line	Public road, rail, dock and similar. Permanent industry and office can also be found here. In this zone, there should not be accommodation or housing. Scattered housing can be accepted in some cases.	Risk level is acceptable

Consideration zones	Requirement	Assessment of Concept 2
Outer zone (up to 1E-07 per year) Yellow line	Areas regulated for residential purposes and other uses of the general population can be included in the outer zone, including shops and smaller accommodations.	Risk level is acceptable
Outside Outer Zone Outside yellow line	Schools, kindergarten, nursing homes, hospitals and similar institutions, shopping centres, hotels or large public arenas must normally be placed outside the outer zone.	Risk level is acceptable

8 CONCLUSION

The general conclusion from the QRA is that the 3rd party individual risk is assessed as not acceptable for Concept 1 A/B, while it is assessed as acceptable for Concept 2 following the DSB's risk acceptance criteria. The main reason for this is that the ammonia is stored as pressurized in concept 1, whereas in concept 2 it is refrigerated. For the pressurized ammonia scenarios in Concept 1 A/B, more severe consequences are predicted compared to Concept 2.

8.1 Discussion

The presented risk results are sensitive to the following system properties applied in the modeling:

Storage tank scenario on the quay:

- ***Ammonia stored at pressurized condition in the storage tank on quay*****:** The high pressure causes a long dispersion length. In case of release of pressurized ammonia, it will become diphasic after atmospheric expansion, forming fine aerosol mist flashing when pressure is reduced to ambient followed by vaporization and further dilution with air. When temperature is reduced to ambient, ammonia will expand 700 times from storage density as a liquid to vapor at its boiling point of -33,4°C. Ammonia is hygroscopic (readily absorbs moisture), i.e. in the presence of moisture (such as high relative humidity), the liquefied anhydrous ammonia gas forms vapors that are heavier than air and travels along the ground on long distances.
- ***Pressurized storage tank being 100% full at all times****:* This implies ammonia being released in liquid state only. In case the inlet connection to the tank is at the tank level below level of stored liquid, the failed connection on the inlet line is considered to release gas followed by two-phase until pressure in the tank is equalized. That will reduce extent of consequences assessed for Segment 3B – top contributor to the risk assessed for Concept 1.
- ***External tank connections failure:*** The risk in concept 1A/B is driven by continuous liquid release associated with failed external connections to the pressurized storage tank. Since this is in conceptual stage, no information or details have been provided about the storage tank, and conservative assumptions have therefore been applied for the different leakage scenarios.
- ***Rainout inside the bund:*** Ammonia leaks from storage tank will be collected in the bund. The leak can potentially hit outside the bund followed by longer rainout distance. The storage tank outlet bottom line is assumed being obstructed by the bund followed by rainout inside the bund. The tank's ammonia inlet line is assumed to be obstructed by equipment/structure in the vicinity of the release with the rainout inside the bund. The storage tank is considered being protected by the wall to limit external access to the tank. Otherwise, much worse consequences are predicted followed by larger risk contours. Longer rainout distances (up to 50 m) will contribute to higher vaporizations level and to more ammonia stay in the cloud, followed by less rainout rate to the pool.

Bunkering:

- ***Number of bunkering operations**:* The full storage tank has been modelled to represent a possibility of ammonia bunkering to more than one passenger ship. This implies higher frequency of bunkering operations and higher contribution of ammonia bunkering scenarios, such as Segment 1, 2, 4, and 5 (Concept 1). That will as well imply more frequent transfer of ammonia to the storage tank. The risk picture presented in this report will no longer be valid if more receiving vessels involved.
- ***Pump isolation time:*** In this assessment, the bunkering pump is assumed to be isolated 90 sec after the leak start regardless of ESD function. In case of longer time required to stop the pump, that will greatly affect amount of ammonia being released during bunkering operations and extent of consequences. That applies both to Concepts 1 A/B and 2.

These assumptions greatly impact risk results and are open for discussion.

8.2 Recommendations

This chapter summarizes proposed recommendations for application to Concepts 1 and 2.

Concept 1A and 1B

The project team identified several proposals for conceptual changes and design measures that may reduce the size of the risk contours, either by reducing the likelihood or consequences of ammonia release. Further studies of these measures will be needed to determine whether the risk contours can be sufficiently reduced to be within the acceptance criteria established by DSB.

The proposed measures for follow-up studies for Concept 1A and 1B are:

- **Use refrigerated atmospheric storage tank onshore instead of pressurized tank (i.e. refrigerate bunkering concept).** The accidental loss of containment associated with refrigerated ammonia (stored at atmospheric conditions) is assessed to produce smaller toxic gas clouds compared to the release of pressurized ammonia. It is therefore considered to reduce the extent of risk contours. For this particular case with the passenger vessel, it seems not to be a likely option, however it may be considered for the application to other concepts. It should be noted that hazards and associated consequences related to pressurized ammonia will still be relevant if processing equipment to pressurize the ammonia is taken onboard the receiving ship. Nevertheless, the exposure time to the toxic release from the equipment onboard of the receiving vessel will be reduced to time spent by the vessel in the port.
- **Enhanced safety integrity of shore storage tank and external tank connections**. The risk in concept 1A/B is driven by continuous liquid release associated with failed external connections to the pressurized storage tank. Since this is in conceptual stage, no information or details have been provided about the storage tank, and conservative assumptions have therefore been applied for the different leakage scenarios. Design measures such as welded connections, reducing number of external connections, design of tank connections (material, stress analysis) etc. may reduce the leakage probability and hence reduce the risk contours.

- **Double shell/secondary enclosure for piping which should be able to contain any leakages from the primary containment.** This will ensure all leakages are contained in a secondary enclosure. The released ammonia can be stored (if feasible/safe) or be released by Pressure Relief Valves (PRVs) in a dedicated safe location. This may reduce the risk contour sizes.
- **Detailed CFD simulation of accidental releases from the storage tank, representing actual geometry of the location of operations.** It is possible to combine risk contours produced by CFD tool with risk results produced by SAFETI for remaining risk scenarios. Further, potential hazards associated with ammonia release incidents on the receiving ship (while is in the port) should be considered being included to the total risk picture.

Other measures only relevant for Concept 1A/B (shore-based operations):

- Designated truck parking and waiting positions in designated areas.
- Performing tank-filling operation during night-time, where traffic level is considered to be limited and limited presence of public in the area.
- Apply best practice regarding corrosion protection of pipelines, incl. supports clams.
- Integrity testing of lines prior to transfer to detect potential leaks (mandatory for maritime applications).
- Designing the piping with sufficient design pressure to account for expansion pressure to avoid the need for Thermal Relief Valves (TRVs). Should TRVs be needed, consider routing lines back to the tank (if I can be done safely).
- Further assess the risk of trapped liquid to decide if this can be accepted.
- Strategies for lowering the concentration of ammonia vapour in air, e.g. by water screens or water curtains set up in the path of a travelling plume. The water screens should be placed between the release point and the threatened area (e.g. terminal).

Concept 2

For Concept 2 the risk is found acceptable. However, DSB states that generally risk should be reduced to a level which can reasonably be achieved (ALARP). Thus, the following risk reducing measures should be implemented unless it can be demonstrated that the cost involved in implementing the measure is grossly disproportionate to the benefit gained:

- Apply best practice on filling procedures from other ammonia loading operations in populated areas (non-industrial sites).
- Procedure Hazard and Operability (HAZOP) study of bunkering checklists.
- Risk mitigation measures for passengers onboard: Areas to be closed, ventilation strategy (normal ventilation, emergency ventilation, stop of ventilation, over/under-pressure strategy etc.), emergency plans and procedures, location of air intakes relative to potential release points, etc.
- Mechanical shielding of leakage points (for crew).

- Placement and type of gas detectors for best possible leakage detection (e.g. by conducting smoke test, dispersion simulations etc.)
- Water curtain system to control and mitigate toxic vapours.
- Designing a solution that prevents any overfilling to be released to the vent mast (e.g. overfilling tank and drain arrangement).
- The results from Safeti are possibly underestimating the extent of the risk contours in the directions in front and aft of the ship since the structure of the ship will lead more gas in those directions than are applied in the Safeti modelling. Therefore, to get a more accurate representation of the risk contours, it is recommended to perform CFD simulations of the gas dispersion where the effect of the geometry is accounted for.

To ensure safe bunkering operation, the following standards and guidelines should be considered in the further concept development. Most of these concern LNG, but many of the safety measures will still be relevant for ammonia:

- DNV - Ammonia as a marine fuel safety handbook
- DNV Recommended Practice G105 - Development and operation of liquefied natural gas bunkering facilities
- EMSA - Guidance on LNG Bunkering to Port Authorities and Administrations.
- ISO 20519 - Specification for bunkering of liquefied natural gas fuelled vessels
- ISO 28460:2010 - Installation and equipment for liquefied natural gas - Ship-to-shore interface and port operations
- IACS – LNG Bunkering Guidelines No. 142.
- IAPH – LNG Bunker Checklists
- SGMF – Gas as a marine fuel (safety guidelines).
- DSB - Guidance on use of dangerous substances (Temaveiledere).

It must be emphasised that this risk assessment results only apply to the 3rd party individual risk. The 2nd party individual risk, i.e. risk to people located on either passenger ship or bunker vessel/truck is not assessed by this QRA.

Finally, this evaluation should be regarded as coarse and presented conclusions rest on the assumptions made for concept definition and risk modelling as well as on failure data applied.

9 REFERENCES

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APPENDIX A
Assumption sheet

Table of contents

1 ASSUMPTIONS OVERVIEW

This document summarizes all the assumptions related to the bunkering operations of ammonia in the port of Oslo.

The assumptions are grouped into three categories:

- Operational assumptions (O) - These are assumptions related directly to the operation of the installation. For example: Number of loading/offloading operations, etc.
- Technical assumptions (T) - These are assumptions pertaining to technical aspects of the design. For example: ESD philosophy, design loads, etc.
- Analytical assumptions (A) - These are assumptions made during the modelling process. During any risk analysis, simplifications have to be made to be able to model complex events.

The assumptions are described in tables containing a description of, and the basis for the assumptions made. In addition to the presentation of the assumptions, a coarse uncertainty assessment is included. Uncertainties are evaluated by using three measures:

- Sensitivity: How changes in assumptions (inputs) affect the computed output of a model.
- Strength of knowledge: The degree to which assumptions/choices are supported by evidence and agreed upon by experts, or the degree to which a phenomenon is understood and can be accurately modelled.
- Belief in deviation: How much we believe the input may deviate from its assumed base value, reflecting the strength of knowledge and the natural variation and randomness.

2 OPERATIONAL ASSUMPTIONS

O-01 Description of concepts

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**O-01**	**Revision: A**
Category:	**OP - Operational**	
Subject:	**Description of concepts**	
Area concerned:	**All**	

Specification:

The following bunkering concepts are assumed for application to this QRA:

1. ***Bunkering of ammonia from a pressurized storage tank,*** permanently installed in the port, to the receiving passenger ship. Ammonia will be transferred from the storage tank to the ship via onshore process piping and loading arm. The ship has two (2) fuel tanks with total capacity of 450 m^3. The required amount of 200 tons @ rate of 200 m^3/hr will be transferred every 4th day.

   Filling of the storage tank will occur either from ammonia tank ships (gas tankers) or from trucks:

   - *Filling from truck*: In average, two (2) trucks filling the storage tank every day are considered. The required amount of 50 ton @ rate of 50 m^3/hr (25 tons per truck) will be transferred every day using a hose. Two (2) trucks will be unloaded, one after another in sequence.
   - *Transfer from ammonia tankers:* In average, a tanker will transfer ammonia every 4th day at the rate of rate of 200 m^3/hr using a hose to deliver required 200 tons. Ammonia is stored in the tanker cargo tanks in refrigerated condition (-33.4 ^{0}C). Ammonia will then be heated up onshore to reach required process conditions when it is delivered to the pressurized storage tank.

The pressurized storage tank in port with the total volume of 1000 m^3 is conservatively assumed to be always 100% filled at all times (up to maximum filling limit).

2. ***Bunkering of ammonia from ship to ship (STS)*** – Ammonia is stored cargo tanks in the bunker vessel (or barge) under refrigerated condition (-33.4 ^{0}C). The ammonia from the bunker vessel will be bunkered using a flexible hose. The required amount of 200 ton @ rate of 200 m^3/hr will be bunkered every 4th day.

A simplified process flow diagrams presenting both concepts are depicted in Figure 2-2 and Figure 2-3 in Assumption O-04.

For QRA application these two concepts will be modelled and assessed separately.

By 'passenger ship' it is meant a cruise ferry with daily sailings between Oslo (Norway) and Kiel (Germany).

Sensitivity High: Risks is directly influenced by the type of operations and hence the results are sensitive to the concept definition.

Strength of knowledge: Moderate The knowledge level is based on similar project performed for bunkering operations and expert judgement.
Belief in deviation: Moderate The project is at a concept phase, and thus deviation from the assumed is expected. Though deviation degree is considered moderate.
Reference: Project kick-off meeting, December 15th, 2020

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

O-02 Location of operations

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**O-02**	**Revision: A**
Category:	**OP - Operational**	
Subject:	**Location of bunkering operations**	
Area concerned:	**All**	

Specification:

The bunkering operation will be conducted while the passenger vessel is moored in Hjortnes terminal, in port of Oslo, Norway.

The ammonia bunkering stations on the passenger vessel are located aft of the aftmost lifeboat, on port and starboard side.

The ammonia bunkering facility, represented by the ammonia storage tank onshore, and the process pipe layout are illustrated in Figure 2-1.

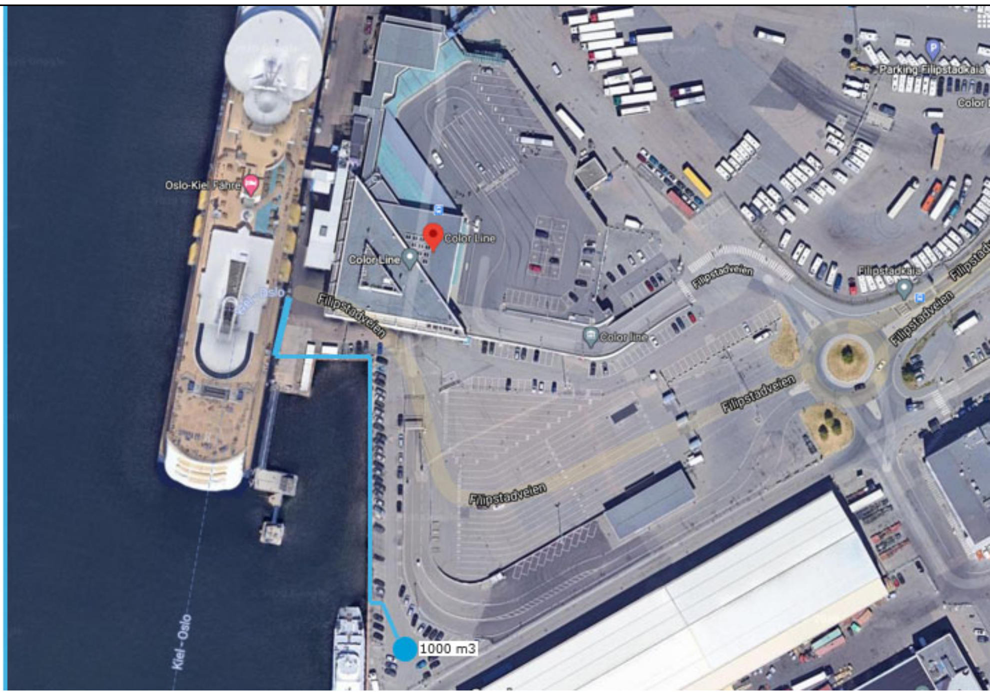

Figure 2-1 Ammonia bunkering facility, from storage tank via process pipe to the passenger ship (shown in blue line).

Sensitivity: Moderate

Risk of the general public is directly influenced by the location of the operations and hence the results are sensitive to the location assumptions.

Strength of knowledge: High

The knowledge level is based on considered location for ammonia bunkering operations in Oslo Port. The location of the ammonia bunker station on the passenger vessel is based on existing bunker station location for fuel oil.

Belief in deviation: Low

The project is at a concept phase, and thus deviation from the assumed is expected. Though deviation degree is considered low.

Reference: Project kick-off meeting, December 15th, 2020

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

O-03 Number of operations

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**O-03**	**Revision: A**
Category:	**OP - Operational**	
Subject:	**Number of bunkering operations and corresponding duration**	
Area concerned:	**All**	

Specification:

Bunkering from the pressurized storage tank: 91 transfers of 1.5 hr each, equals 1.6% of a year.

There,

- *Transferring of ammonia from the truck to the pressurized storage tank ashore:* 728 transfers of 0.8 hr each, equals 6.6% of a year.
- *Transferring of ammonia from the ammonia tanker to the pressurized storage tank ashore:* 91 transfers of 1.5 hr each, equals 1.6% of a year.

Bunkering from the ship (STS): 91 calls of 1.5 hr each, equals 1.6% of a year (every second time the vessel comes to Oslo port).

It is assumed that maximum available time for bunkering is 3.5 hours per entire operation, including required rigging and purging with nitrogen. The leak test is assumed to be performed prior to ammonia transfer operation.

The passenger vessel arrives in Oslo at 10.00 and leaves the same day at 14.00, /1/.

Sensitivity: High

Risk is directly influenced by the number of operations and corresponding duration and hence the results are sensitive to the operational assumptions.

Strength of knowledge: Moderate

The frequency of operations is based on expected required amount of ammonia daily consumed by the passenger ship, assumed transfer rate and corresponding duration for transfer operations. The knowledge level is based on expert judgement.

Belief in deviation: Low/Moderate

The project is at a concept phase, and thus deviation from the assumed is expected. Though deviation degree is considered low/moderate.

Reference:

/1/ https://www.colorline.com/timetable

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

O-04 Segmentation and process conditions

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**O-04**	**Revision: A**
Category:	**OP - Operational**	
Subject:	**Segmentation and process conditions**	
Area concerned:	**All**	

Specification:

The simplified process flow diagrams both for bunkering *Concept 1* and *Concept 2* are presented in Figure 2-2 and Figure 2-3 with location of ESD segregation valves, and major process equipment items. The process conditions for identified process segments are tabulated in Table 2-2 and Table 2-3 below.

The quantity of material available to be released in the event of a leak is specific to each isolatable segment. Key assumptions that apply to the analysis in general are the following:

- The inventory associated to each isolatable segment case is defined as the isolatable mass within each segment under normal operating conditions.

- In case of ESD failure on demand, the inventory volume of the largest neighbouring segment is added.

For inventory volume estimate, the following equipment dimensions were assumed as presented in Table 2-1.

Table 2-1 Physical dimensions for ammonia transfer equipment

Concept No.	Equipment type	Outer diameter (OD), inch	Length, m
1	Onshore process pipe	6	150
1	Truck hose	4	20
1	Ship hose	6	20
1	Loading arm	6	26[1]
1	Receiving manifold piping	6	50
2	Ship hose	6	20

Sensitivity: Moderate

Basis for definition of number of leak sources and consequence modelling for process accidents. If number of either leak sources or process conditions are to change, the risk picture might be impacted. However, slight modifications to the process conditions are not considered to have a large effect on the results. The inventory available for release determines the leak profile and duration. On balance, any specific inventory assumption will have a limited influence on the overall risks, although the inventory is a key parameter with respect to the detailed modelling of each scenario.

Strength of knowledge: Moderate

The number of leak sources are based on defined concept illustrated in Figure 2-2 and Figure 2-3. Definition of process conditions are based on similar operations and typical operating data for liquefied ammonia gas.

[1] Total length based on typical dimensions for 6 inch marine loading arm.

Belief in deviation: Low/Moderate The project is at a concept phase, and thus deviation from the assumed is expected. Though deviation degree is considered low/moderate.		
Reference:		
Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

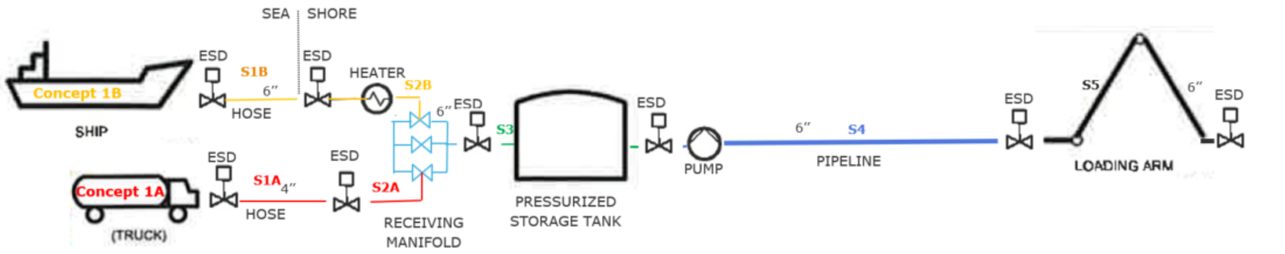

Figure 2-2 Simplified process flow diagram Concept 1

Segments 2A/B and 4 onshore are assumed to be purged (i.e. removing liquid ammonia and oxygen in the pipe with the nitrogen) prior/after conducted transfer operation and thus are pressurized only at times when transfer operation occurs.

The operations of purging piping systems with nitrogen followed by vapor return either to the sending tank, or to the dedicated ammonia scrubber arrangement onshore are not considered for QRA application. That is due to the assumed limited amount of ammonia in the process pipes combined with low, i.e. atmospheric system's pressure, considered to represent a negligible impact on the 3rd party risk compared to other QRA scenarios included in the quantification, ref. Table 2-2.

Defined QRA segments with corresponding process conditions and inventory are presented in Figure 2-2.

Table 2-2 Process conditions for defined segments in Concept 1

Segment No.	QRA scenario name	Description	Time fraction % per year	Normal operating pressure, barg	Normal Temp., deg. C	Density, kg/m3	Liquid mole fraction	Normal Operating flow rate, m3/h	Segment hydrocarbon static mass, kg	Largest neighbouring segment static mass, kg
S1A	1A-Truck-Hose	Ammonia transferred from truck (using hose)	6.6	7.6	15	617	1	50	100	563[2]
S1B	1B-Ship-Hose	Ammonia transferred from ammonia tanker (using hose)	1.6	4	-33.4	681	1	200	300	994[3]
S2A/B	2A/B-Manifold	Ammonia transferred via receiving manifold to the pressurized storage tank in port. Ammonia is heated in the Port for concept 1B	6.6/1.6	7.6	15	617	1	50/200	563	617,000[4]
S3A/B/C /D	3A-Storage-L-Outlet	This scenario includes liquid outlet line bottom of the tank	1	7.6	15	617	1	-	617,000	1,574
	3B-Storage-L-Inlet	This scenario includes liquid inlet line top of the tank	1	7.6	15	617	1	-	617,000	563
	3C-Storage-G-PRV	Leak from the PRV/safety control valves	1	6	15	5.325	1	-	5,325	NA[5]
	3D-Storage-G-VR	Leak from vapor line connection	1	6	15	5.325	1	-	5,325	201[6]
S4	4-Process-Pipe	Onshore process pipe delivering ammonia from the storage tank to the loading arm	1.6[7]	15	40	575	1	200	1,574	617,000
S5	5-Loading-Arm-Bunkering	Loading arm transferring ammonia to the vessel's bunkering station	1.6	15	40	575	1	200	300	1,574

[2] Segment 2 mass inventory
[3] Based on ship piping volume between the tank and bunkering station
[4] Pressurized storage tank inventory mass
[5] No automatic safety systems is assumed, e.g. continuous release with no isolation
[6] Based on the same system volume as for Note 3
[7] Equipment is only in use when transferring of ammonia to the passenger vessel; system is considered to be purged with nitrogen before/prior to each transfer operation

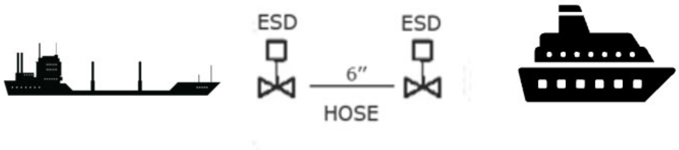

Figure 2-3 Simplified process flow diagram Concept 2 (STS bunkering)

Defined QRA segments with respected process conditions and static mass are presented in Table 2-3.

Table 2-3 Process conditions for defined segments in Concept 2

Segment No.	QRA scenario name	Description	Time fraction % per year	Normal operating pressure, barg	Normal Temp., deg. C	Density, kg/m3	Liquid mole fraction	Normal Operating flow rate, m3/h	Segment hydrocarbon static mass, kg	Neighbouring segment static mass, kg
1	1-Ship-Hose	Ammonia transferred from the bunker ship (using hose)	1.6	4	-33.4	681	1	200	231	994[8]

[8] Based on ship piping volume between the tank and bunkering station

3 TECHNICAL ASSUMPTIONS

T-01 ESD Philosophy

<table>
<tr><td colspan="2">Ammonia bunkering QRA</td><td colspan="2">Date: 2021-01-05</td></tr>
<tr><td>Assumption No.:</td><td>T-01</td><td colspan="2">Revision: A</td></tr>
<tr><td>Category:</td><td colspan="3">T - Technical</td></tr>
<tr><td>Subject:</td><td colspan="3">ESD philosophy</td></tr>
<tr><td>Area concerned:</td><td colspan="3">All</td></tr>
<tr><td colspan="4">Specification:
Concept 1: Bunkering from the pressurized storage tank – linked ESD system between the storage tank and the passenger ship is assumed. In addition to linked ESD system assumed between truck/bunker ship and the pressurized storage tank.
Concept 2: Bunkering from the ship (STS) – linked ESD system between the bunkering delivery and the passenger ship is assumed.
By linked ESD system, it is assumed that ESD initiated in one of the units will be followed by automatic closure of the ESD on the receiving/sending unit.</td></tr>
<tr><td colspan="4">Sensitivity: Moderate
Impacts frequency of QRA scenarios related to ESD success/failure.</td></tr>
<tr><td colspan="4">Strength of knowledge: Moderate/High
Level of knowledge is based on typical ESD philosophy used for trucks/ships.</td></tr>
<tr><td colspan="4">Belief in deviation: Low
Deviation is considered unlikely.</td></tr>
<tr><td colspan="4">Reference:</td></tr>
<tr><td colspan="2">Prepared by:</td><td>Sign: HAJOH/KSEZAK</td><td>Date: 2021-01-05</td></tr>
<tr><td colspan="2">Internal Verification:</td><td>Sign: GOUZY</td><td>Date: 2021-02-10</td></tr>
</table>

4 ANALYTICAL ASSUMPTIONS

A-01 Meteorological data

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-01**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Meteorological data**	
Area concerned:	**All**	

Specification:

Data on wind direction, wind speed and atmospheric stability are combined to form a set of representative weather categories.

The representative wind conditions are tabulated in Table 4-1.

Table 4-1 Wind occurrence % and representative wind conditions

Wind from	**Occurrence (%) of Weather Classes (Pasquill Stability, Wind Speed)**			**Total**
	D	**D**	**D**	
	1.5 m/s	**3 m/s**	**7 m/s**	
N	5.7 %	6.2 %	2.2 %	14 %
NE	10.3 %	17.3 %	3.4 %	31 %
E	2.9 %	1.7 %	0.1 %	5 %
SE	2.5 %	1.6 %	0.1 %	4 %
S	4.3 %	12.1 %	2.3 %	19 %
SW	7.4 %	9.0 %	1.1 %	18 %
W	3.1 %	1.9 %	0.6 %	6 %
NW	2.2 %	1.4 %	0.6 %	4 %
Total	**38%**	**51%**	**10%**	**100 %**

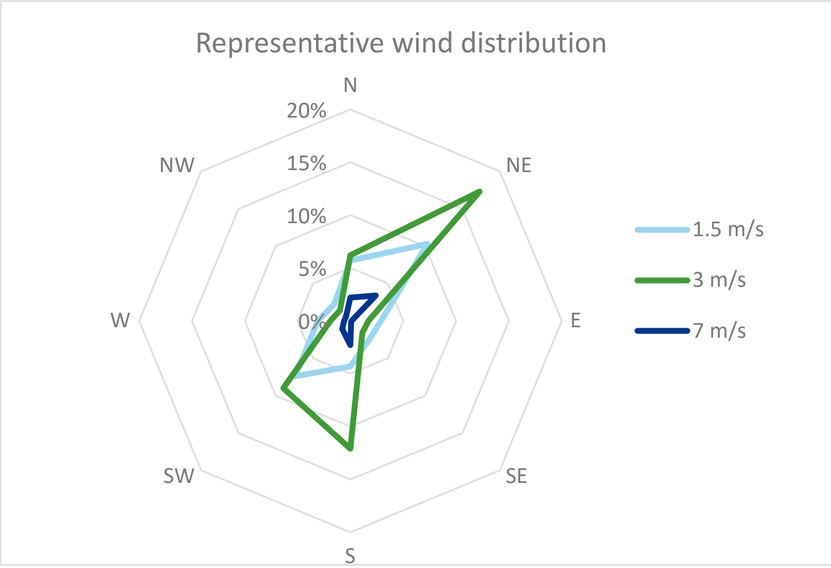

Figure 4-1 All year representative wind rose for Oslo BLINDERN meteorological station

Sensitivity: Moderate/High

The weather conditions have a key influence on gas dispersion, hence the consequences associated with any release.

Strength of knowledge: High

The weather data is obtained based on the periodic meteorological observation from Oslo BLINDERN meteo station and recordings for a period of 10 years obtained from eklima.no (Norwegian Meteorological Institute), /1/.

Belief in deviation: Low

Deviation is considered unlikely.

Reference:

/1/ https://www.met.no/frie-meteorologiske-data/frie-meteorologiske-data

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

A-02 Meteorological parameters

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-02**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Meteorological parameters**	
Area concerned:	**All**	

Specification:

In addition to the weather categories, certain meteorological constants are defined as input to the consequence modelling.

Table 4-2 Meteorological parameters

Parameter	Value	Notes and References
Atmospheric temperature	8 ºC	The overall yearly average is 8ºC
Atmospheric pressure	101,100 N/m^2	Average sea level pressure
Relative humidity	73 %	Average annual relative humidity of the air (Oslo area)
Surface temperature	8 ºC	Taken to be the same as atmospheric temperature.
Solar flux	500 W/m^2	The maximum solar flux (i.e. midday midsummer) is about 1320 W/m^2. However, the solar flux varies diurnally, annually and with cloud amount. Hence the annual mean value will be less than half the maximum. 500 W/m^2 is a representative value.
Wind speed reference height	10 m	Standard for meteorological measurements.

Sensitivity: Low

The meteorological parameters are considered to have influence on dispersion simulation results, though limited impact is considered.

Strength of knowledge: High

The weather data is obtained based on the periodic meteorological observation from Oslo BLINDERN meteo station and recordings for a period of 10 years obtained from eklima.no (Norwegian Meteorological Institute).

Belief in deviation: Low

The meteorological parameters may change on a day to day basis. The applied values are considered representative average for the area of operation.

Reference:

/1/ https://www.met.no/frie-meteorologiske-data/frie-meteorologiske-data

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

A-03 Release location / height

Ammonia bunkering QRA		Date: 2021-01-05
Assumption No.:	**Revision: A**	**Revision: A**
Category:	**A-Analytical**	
Subject:	**Release location / height**	
Area concerned:	**All**	

Specification:

The representative release height is equal to the elevation of flanged connection of the hose, which is statistically considered to be a frequent point of release. The release height will be defined relative to the ground (port) since the primary consideration is the height relative to the potentially exposed population.

Concept 1:

Representative height of 1 m is generally assumed for all process equipment comprising concept 1, except the onshore process pipe, and loading arm bunkering connection.

For process pipe releases, the representative height of 2 m is considered based on actual elevation of the process pipe above the ground level.

For loading arm bunkering connection of 2 m above ground is assumed.

Representative height for releases during ammonia transfer from the truck by the hose is 1 m.

Representative height for releases during ammonia transfer from the bunker vessel is assumed of 2 m above water level.

For storage tank scenarios, the following release is assumed:

Scenario	Height above ground, m
3A-Storage-L-Outlet	1[9]
3B-Storage-L-Inlet	3[10]
3C-Storage-G-PRV	3
3D-Storage-G-VR	3

The release location of modelled QRA scenarios are presented in Figure 4-2.

Concept 2:

Distance from waterline to passenger vessel bunkering flange: 2 m

Distance from waterline to port ground (quay height): 2 m

[9] Tank bottom is assumed to be elevated above ground level and placed on the tank support with corresponding height of 1 m

[10] Based on the assumed tank height of 2 m

Ammonia bunkering QRA		Date: 2021-01-05
Assumption No.:	**Revision: A**	**Revision: A**
Category:	**A-Analytical**	
Subject:	**Release location / height**	
Area concerned:	**All**	
Representative height for releases during ammonia transfer by the hose is thus 2 m above the sea water level. The release location of modelled QRA scenarios are presented in Figure 4-3.		
Sensitivity: Moderate The release height will have some influence on the potential pool / cloud formation and toxic concentration at level of interest.		
Strength of knowledge: High The data is based on actual physical location of the bunkering flange related to waterline/ground level for the existing vessel, in addition to the elevated position of the process pipe. For remaining process equipment, the representative height is considered to give the higher degree of toxic exposure to the public.		
Belief in deviation: Low The deviation is considered unlikely.		
Reference:		
Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

1A - Ammonia transfer from the truck; **1B** - Ammonia transfer from the ship; **2** - Receiving manifold; **3** - Storage tank; **4** - Process pipe; **5** - Loading Arm

Figure 4-2 Concept 1 - Location of defined QRA scenarios

1 - Ammonia transfer from the ship

Figure 4-3 Concept 2 - Location of defined QRA scenarios

A-04 Release direction

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-04**	**Revision: A**
Category:	**A-Analytical**	
Subject:	**Release direction**	
Area concerned:	**All**	

Specification:

A leak can go in any directions. However, the horizontal direction is known to usually give the largest impact zone.

Releases within areas with high congestion are modelled as horizontal impinged (reduced momentum) releases, otherwise the releases are modelled as unobstructed, horizontal releases. For this QRA, impinged release is selected as the outflow is likely to be blocked by e.g. the semi-enclosed bunkering station, ground surface and/or objects in close proximity of the release locations.

Modelled release directions are summarized in Table 4-3 below.

Sensitivity: Moderate/High
Impacts dispersion distance and cloud shape.

Strength of knowledge: Moderate/High
Based on actual planned location for operations and existing obstructions within the area.

Belief in deviation: Low
Deviation is considered unlikely.

Reference:

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

Table 4-3 Modelled release directions

Concept No.	Segment No.	QRA scenario name	Release direction with wind towards Oslo city	Release direction with wind towards Oslo fjord
1	**1A**	1A-Truck-Hose	Horizontal impinged	Horizontal
	1B	1B-Ship-Hose	Down impinged on the ground	Down impinged on the ground
	2A/B	2A/B-Manifold	Horizontal impinged	Horizontal
	3A/B/C/D	3A-Storage-L-Bottom	Horizontal impinged	Horizontal impinged
		3B-Storage-L-Top	Horizontal impinged	Horizontal
		3C-Storage-G-PRV	Horizontal impinged	Horizontal
		3D-Storage-G-VR	Horizontal impinged	Horizontal
	4	4-Process-Pipe	Horizontal impinged	Horizontal
	5	5-Loading-Arm-Bunkering	Horizontal impinged	Down impinged on the ground
2	**1**	1-Ship-Hose	Down impinged on the ground	Down impinged on the ground

A-05 Leak frequency

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-05**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Parts Count and Leak frequency**	
Area concerned:	**All**	

Specifications:

Generic leak frequencies

The generic failure data used as the basis of the frequency analysis through LEAK software (v3.3) is the UK HSE's Hydrocarbon Release Database, or HCRD 2015, ref. /1/.

Parts-count

For evaluation of leak frequency for Concept 1, the frequency analysis is to be conducted at a "PFD" level for the different process segments identified as illustrated in Figure 2-2. This entails counting only the major equipment items (i.e. from the PFDs) and assigning them a detailed parts count of the number of fittings that will apply, i.e. valves, flanges and small-bore fittings based on previously conducted detailed leak frequency estimates for O&G facilities.

The parts count for Concept 1 is based on PFD illustrated in Figure 2-2 are summarized in Table 4-7.

The parts count for Concept 2 includes only the transfer hose with associated generic hose transfer frequencies presented in Table 4-5.

Given the uncertainty of process piping failure frequencies in HCRD, a general 1.33 factor is applied to the calculated failure frequencies to account for process piping failure frequencies. The value of 33 % is applied in order to give a 25 % contribution from piping to the overall estimated leak frequency from the main process. The 25% contribution corresponds to the percentage of recorded leaks from process piping in the HCRD database, ref. /3/.

Leak frequencies for transfer operations

The leak frequency related to the transfer by a hose or by loading arm, from a truck or a ship, is estimated by tailor-made failure frequency model developed for project application and reflects project specific details, such as:

- Type of operations
- Safety measures
- Type of material and density
- Size of transfer equipment
- Duration and frequency of transfer operations.

The failure data is based on:

- For marine transfer of liquefied ammonia, the model uses data on cargo transfer to/from LNG ships world-wide during 1964-2015, collected by DNV GL from various public-domain sources.
- For truck transfer of liquefied ammonia, the model uses data on transfer to/from LPG tanker trucks in the USA during 2000-16 from the US Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) incident database.

Table 4-4 Transfer leak frequencies for ammonia bunkering operation by loading arm

Release Type	Frequency (/per transfer)
Leak	1.6E-03
Large	5.0E-04
Full bore	9.8E-04
Total	**3.1E-03**

Table 4-5 Transfer leak frequencies for ammonia bunkering operation from a bunker vessel by hose

Release Type	Frequency (/per transfer)

Leak	2.9E-03
Large	7.7E-04
Full bore	1.6E-03
Total	**5.3E-03**

The arm is assumed to have a breakaway system consisting of tension monitoring and a powered Emergency Release Coupling (ERC), providing disconnection without significant leakage in the event of ship movement outside allowable limits.

Table 4-6 Ammonia transfer frequency from the truck based on US Road Tanker Transfer Spill Frequencies for Key Materials, 2000-16

Release Type	Frequency (/per transfer)
Leak	0.0E+00[11]
Large	2.9E-04
Full bore	1.1E-04
Total	**4.1E-04**

Transfer of ammonia from a bunker ship is assumed to have vessel separation detection and an ERC.

The composite material of the transfer hose is assumed.

Each hose/arm is protected by ESD valve upstream and downstream, triggered automatically by gas detectors.

Leak frequencies for storage accidents

For Concept 1, ammonia is assumed to be stored in the pressurized storage tank on quay. The storage tank is assumed to be of similar type as IMO Type-C tank. According to DNV GL rules, Part 6 Additional class notations, Chapter 2 Propulsion, power generation and auxiliary systems, /6/, Section 4.2.2.4, no secondary barrier is required for type C independent tanks, where the probability for structural failures and leakages through the primary barrier is extremely low and can be neglected. Thus, leak and rupture scenarios related to the storage tank itself are excluded from the leak frequency estimate. Nevertheless, external leak sources (on outer surface of the storage tank) related to the ESD valves, pressure relief valves, stop valves, flanges, fittings and small piping are included to the leak frequency estimate.

Sensitivity: High

Key influence on the risks (i.e. risk is directly proportional to frequency).

Strength of knowledge: Moderate

[11] Based on the negligible amount of ammonia transferred

Leak frequency data available for application to ammonia bunkering operations and associated incidents is limited. The data applied is based on either related or similar operations performed and is believed to be representative to the extent possible.
Belief in deviation: Moderate Deviation is expected and is mainly defined by safety level related to technical system, operation and its complexity.
Reference: /1/ HSE, 2015. Offshore Hydrocarbon Release Statistics, HSE Offshore Safety Division (OSD), March 2015. /2/ DNV GL Technical Note 14 Process Equipment Failure Frequencies, Rev. 5, dated 2011-03-14. /3/ DNV GL Failure frequency guidance – Process equipment leak frequency data to use in QRA. /4/ DNV GL Report, "Phase 2: Development of Transfer Leak Frequency Model", doc. No. 2019-0438, Rev. 0, dated 2019-02-22 /5/ IOGP Report "Process Release Frequencies", doc. No 434-01, dated September, 2019. /6/ DNV GL rules, Part 6 Additional class notations, Chapter 2 Propulsion, power generation and auxiliary systems, July 2020.

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

Table 4-7 Parts count QRA Segments Concept 1

Segment No.	QRA Scenario Name	Description	Annual usage factor	Piping factor	Type of equipment	Size, inch	Quantity	Annual leak frequency (all leak categories)	Comments
S1A	1A-Truck-Hose	Transfer of ammonia by the flexible hose. The generic leak frequencies obtained for hoses assume to cover possible failures related to the hose itself, hose connections, and ERC parting/disconnection error; ESD valve leaks on the sending tank side are incorporated in the generic failure data.	0.066	-	HOSE	4	1[12]	4.4E-04	Hose frequency is adjusted by the annual usage factor.
S1B	1B-Ship-Hose	Transfer of ammonia by the hose from the ammonia tanker. The generic leak frequencies obtained for hoses assume to cover possible failures related to the hose itself, hose connections, small piping, and ERC parting/disconnection error; ESD valve leaks on the sending tank side are incorporated in the failure data.	0.016	-	HOSE	6	1	5.3E-03	Hose frequency is adjusted by the annual usage factor.
S2A	2A-Manifold	Includes ammonia receiving manifold/flow metering.	0.066	1.33	SMALL_BORE_FIT	0.75	6	2.4E-04	Based on Risavika LNG detailed parts count for secondary master metering station for LNG line, /6/
					SMALL_BORE_FIT	1	6		
					FLANGE	1	2		

[12] Per hose

Segment No.	QRA Scenario Name	Description	Annual usage factor	Piping factor	Type of equipment	Size, inch	Quantity	Annual leak frequency (all leak categories)	Comments
					FLANGE	2	1		
					FLANGE	6	4		
					VALVE_MAN	1	2		
					VALVE_MAN	2	1		
					VALVE_MAN	6	4		
					VALVE_ACT_NON_P/L	6	1		
S2B	2B-Manifold	Includes ammonia receiving manifold/flow metering and heat exchanger for heating up of ammonia transferred at refrigerated condition from the bunker ship.	0.016	1.33	HE_SHELL	6	1	1.1E-04	Based on Risavika LNG detailed parts count for secondary master metering station for LNG line, /6/ Parts count for the shell heat exchanger (HE) is based on detailed parts count for a typical shell heat exchanger unit (oil & gas processing facilities).
					SMALL_BORE_FIT	0.75	6		
					SMALL_BORE_FIT	1	8		
					FLANGE	1	5		
					FLANGE	2	1		
					FLANGE	6	4		
					VALVE_MAN	1	5		
					VALVE_MAN	6	5		
					VALVE_MAN	2	1		
					VALVE_ACT_NON_P/L	6	2		

Segment No.	QRA Scenario Name	Description	Annual usage factor	Piping factor	Type of equipment	Size, inch	Quantity	Annual leak frequency (all leak categories)	Comments
S3 A/B/C/D	3A-Storage-L-Outlet	This scenario includes liquid outlet line bottom of the tank	1[13]	1.33	SMALL_BORE_FIT	1	2	7.3E-04	Parts count is based on typical P&ID for maritime IMO C-type storage tank.
					FLANGE	6	1		
					VALVE_ACT_NON_P/L	6	1		
	3B-Storage-L-Inlet	This scenario includes liquid inlet line top of the tank	1	1.33	SMALL_BORE_FIT	1	2	7.3E-04	
					FLANGE	6	1		
					VALVE_ACT_NON_P/L	6	1		
	3C-Storage-G-PRV	Gas release from PRV/safety control valves	1	1.33	SMALL_BORE_FIT	1	2	1.1E-03	
					FLANGE	6	6		
					VALVE_ACT_NON_P/L	6	2		
					VALVE_MAN	6	2		
	3D-Storage-L-Top	Gas release from the connection to the vapor return line	1	1.33	SMALL_BORE_FIT	1	1	4.6E-04	
					FLANGE	6	1		
					VALVE_ACT_NON_P/L	6	1		

[13] Pressurized at all times

Segment No.	QRA Scenario Name	Description	Annual usage factor	Piping factor	Type of equipment	Size, inch	Quantity	Annual leak frequency (all leak categories)	Comments
S4	4-Process-Pipe	Onshore process piping connecting the storage tank with the loading arm. Parts count include the sending pump, and the ESDV downstream the loading arm.	0.016	1.33	PROCESS_PIPE	6	150[14]	1.2E-04	Quantity is defined by number of meters of the pipe, /1/. The leak frequency in the HCRD is per meter process pipe. No piping factor is applied to this category. Parts count for the pump is based on typical small equipment number for a reciprocating pump used for onshore gas processing facilities.
					PUMP_RECIP	6	1		
					FLANGE	1	12		
					FLANGE	6	4		
					VALVE_MAN	1	5		
					VALVE_MAN	6	2		
					VALVE_ACT_NON_P/L	6	2		
					SMALL_BORE_FIT	1	6		
S5	5-Loading Arm-Bunkering	Transfer of ammonia by the loading arm to the passenger ship. The generic leak frequencies obtained for loading arm consider covering possible failures related to the loading arm itself, connections, in addition to the ESDV on the passenger's vessel tank side.	0.016	-	LOADING_ARM	6	1	3.1E-03	Loading arm frequency is adjusted by the annual usage factor.

[14] Per number of pipe meters

Table 4-8 Parts count QRA Segments Concept 2

Segment No.	QRA Scenario Name	Description	Annual usage factor	Piping factor	Type of equipment	Size, inch	Quantity	Annual leak frequency (all leak categories)	Comments
S1	1-Ship-Ship	Transfer of ammonia by the hose from the ammonia tanker. The generic leak frequencies obtained for hoses assume to cover possible failures related to the hose itself, hose connections, small piping, and ERC parting/disconnection error; ESD valve leaks on the sending tank side are incorporated in the failure data.	0.016	-	HOSE	6	1	5.3E-03	Hose frequency is adjusted by the annual usage factor.

A-06 Representative release sizes

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-06**	**Revision: A**
Category:	**A-Analytical**	
Subject:	**Representative release sizes**	
Area concerned:	**All**	

Specification:

Hazardous release events can vary from small releases to full bore ruptures. To represent the various release events, fours scenario categories are defined. Each release scenario category is represented by a hole size. Selection of hole sizes have a direct bearing on the calculated risks. The selection and distribution of the hole sizes were selected based on the guideline presented in DNV TN14, /3/. The maximum hole size was limited but the biggest line size of the defined process systems subjected quantitative evaluation.

The selected representative hole sizes are presented in Table 4-9:

Table 4-9 Representative hole sizes – process events

Hole size category	Range of hole sizes:	Representative hole size / equivalent diameter:
Small	1 mm – 10 mm	5 mm
Medium	10 mm – 50 mm	25 mm
Large	50 mm – 150 mm	100 mm
Rupture	> 150 mm	152.4 mm

The hose and loading arm transfer frequency is split between leaks and full-bore rupture scenarios and presented in Table 4-9 and Table 4-10.

Table 4-10 Representative hole sizes – ship hose/loading arm transfer events

Leak Size	Representative hole size, mm
Small (1% full diameter)	1,524
Large (10% full diameter)	15,24
Rupture (100% full diameter)	152,4

Table 4-11 Representative hole sizes – truck hose transfer events

Leak Size	Representative hole size, mm
Small (1% full diameter)	1,016
Large (10% full diameter)	10,16
Rupture (100% full diameter)	101,6

Sensitivity: Moderate/High

The release size taken as representative is a key factor in the release parameters and subsequent consequences in each case.

Strength of knowledge: Moderate/High

Determination of hole size distributions refers to data recorded and available in HCRD 2015. It should be noted that, level of uncertainty related to failure data for categories exceeding 100 mm is higher compared to smaller leaks, /2/. The hole size representing rupture scenario is referred as a maximum hole size available within defined QRA segment.
Belief in deviation: Low/Moderate The project is at a concept phase, and thus deviation from the assumed is expected. Though deviation degree is considered low/moderate.
Reference: /1/ Guideline for quantitative risk assessment "Purple Book", CPR 18E; Part one: Establishments /2/ IOGP Report "Process Release Frequencies", doc. No 434-01, dated September, 2019. /3/ DNV GL Technical Note 14 Process Equipment Failure Frequencies, Rev. 5, dated 2011-03-14.

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

A-07 Detection and isolation times

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-07**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Detection and isolation times**	
Area concerned:	**All**	

Specifications:

The times required to detect a release and then to initiate isolation are summarized in the tables below, which give the representative times assumed for events.

For ESD system with execution action, the detection time of 60 sec and isolation time of 30 sec are assumed independently of the leak size following DNV LNG QRA Guideline 16, /1/. This assumption applies to both concepts.

For both concepts it is assumed that bunkering pump is shutdown 90 sec after release start regardless of ESD function.

It is assumed that operations will be continuously be monitored by the personnel/operators, thus small leaks are early detected by operators.

Sensitivity: Moderate

The detection and isolation assumptions are key influences on the release duration and leak profile. However, the influence on the overall risks is moderate.

Strength of knowledge: Moderate

The representative detection times are selected based on recommended values for LNG bunkering operations, /1/, which are considered to be representative for application to this QRA.

Belief in deviation: Low/Moderate

No large deviation to the assumption is considered.

Reference:

/1/ DNV LNG QRA Guideline, rev. 01, dated 2012-08-28

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

A-08 Probability of failure on demand of the ESD system

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-08**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Probability of failure on demand of the ESD system**	
Area concerned:	**All**	

Specification:

SIL requirements: OLF 070, the guideline for implementation of SIL in Norwegian Oil and Gas gives a minimum requirement of SIL 2 for the ESD loop, i.e. including ESD control system and the final element (valve and actuator). NS-EN 1473:2016: "Installation and equipment for liquefied natural gas design of onshore installations", Section 14.3.3.2 requires SIL 3 or better.

Isolation of segments is assumed to be initiated automatically for both concepts. The entire loop is assumed to comply with SIL 2 requirements, with corresponding probability of failure on demand of 1%.

Sensitivity: Moderate

The probability of isolation failure has an influence on the relative frequency of release events that have sufficient duration to lead to escalation. However, it is not expected to have high influence on the personnel risk results.

Strength of knowledge: High

The assumption is based on similar system's design and operation.

Belief in deviation: Low

Deviation is considered unlikely.

Reference:

/1/ DNV LNG QRA Guideline 16, rev. 01, dated 2012-08-28

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

A-09 Release/discharge parameters: Release rate

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-09**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Release / discharge parameters: release rate**	
Area concerned:	**All**	

Specification:

The process segment is assumed pump driven; thus, the maximum release rate will be capped at 125% of the nominal pump flow to account for the sudden pressure loss downstream and the subsequent reaction of (a) centrifugal pump(s) upstream of the rupture, /1/.

For storage tank events, the release rate and velocity are pressure driven. No capping for this scenario is applied.

Sensitivity: Moderate/High

Impacts release rate and, consequently, the extent of consequence results.

Strength of knowledge: Moderate

Based on engineering judgement.

Belief in deviation: Moderate

Actual release may act differently in a released scenario; thus, deviation is expected.

Reference:

/1/ DNV LNG QRA Guideline, rev. 01, dated 2012-08-28

Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

A-10 Dispersion parameters

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-10**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Dispersion parameters and release surface**	
Area concerned:	**All**	

Specification:

Height of interest

In the consequence modeling the height of interest corresponds to the height for which the concentration results are reported. For this analysis, the height of interest is specified at 1 m from the ground. This height is considered representative for toxic exposure of the public. The LSIRCs are thus generated at representative height of 1 m.

***Representative terrain* represented by surface roughness**

The roughness length is (an artificial) linear measurement indicating the influence of the surrounding area on the wind velocity. This may be adjusted based on the distance between obstructions and the height of these obstructions in the vicinity of the operation.

Value: 1 m for land and 0.2 mm for water. Land value appropriate for city center with high- and low-rise buildings; water value is representative for coastal waters.

For *Concept 1*, both terrains will be modelled to represent location of the concept close to sea.

For *Concept 2*, the release is considered to be obstructed by the bunker & passenger vessels. Part of the released ammonia is considered to be absorbed by sea water, thus reducing amount of ammonia available for evaporation. The majority of the release is assumed to be dispersed over the water surface. Both terrains are modelled for concept 2.

The release surface is represented either by land or shallow open water. Thus, systems located on the border between the port and the sea, are represented both by land and shallow open water release surfaces. These systems include: Concept 1 – Segment 4 & Segment 5. The release from Segment 1B is considered to occur only in water. The remaining systems such as receiving manifold Segment 2, and truck transfers Segment 1A, storage tank Segment 3, are modelled to have only land as a release surface.

For Concept 2 STS, the release surface is represented by the shallow open water.

Sensitivity: Moderate/High
Impact the dispersion results and thus, extent of consequences.

Strength of knowledge: Moderate/High

The surface roughness value is considered representative for terrain representing the area of operation.

Belief in deviation: Low

Deviation is considered unlikely.

Reference:		
Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

A-11 Impact criteria to people

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-11**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Impact to people**	
Area concerned:	**All**	

Specifications:

The current analysis focuses on toxic effects following ammonia release in the atmosphere. To assess the exposure and the probability of death associated with ammonia exposure, the analysis uses a probit function approach.

The probit function for death due to toxic exposure is given by:

$$Pr = A + B \ln C^n t$$

Pr – Probit corresponding to the probability of death [-];

C – gas concentration [ppm, volume based];

t - duration of exposure [sec];

A, B, and n are material constants and are based on values estimated by RIVM [RIVM, 2017], /1/, following recommendation given in DSB Guidelines for quantitative risk analysis of facilities handling hazardous substances, /2/.

Parameter	Value
A	-16.5
B	0.99
n	2.02

As the gas concentration varies over time, SAFETI will calculate Pr for a number of times, based on the average time equals exposure time. For each release the program will calculate the exposure time at different locations, and will calculate the toxic effects at each location using the exposure time calculated for that location, and then integrate over time, corresponding to the duration of the event (up to one hour).

The function calculates the probability of fatality at a given geographical point. At each point, the gas concentration from scenario a, Ca with duration will occur with a certain frequency fa. The probability of fatality is then given by the probit function Pr (Ca, ta). For each point, the contributions are then summed from individual scenarios that could have an effect on the given point. This can be expressed as follows: P (fatality) $=1-\Pi(1-[fa\times \Pr(Cata)])$. Probability of fatality is thus calculated for each grid in a fine-meshed grid (squares of 0.1 x 0.1 m) over the relevant area and is then plotted as risk contours on a map.

The presented iso-risk contours give the frequencies that a person who stays outdoors at a given point, and who does not try to escape the unwanted events included in the analysis, dies. Therefore, the averaging toxic time applied in software equals to the simulated (full) exposure time of the geographical location by the toxic cloud.

Below is guiding levels of toxic effects following acute exposure to ammonia by inhalation. These values are not used directly in SAFETI (probit function is used). It is listed here as reference values for the generic public, for information only.

Concentration	**Effect**
10-20 mg/m^3 (15-30 ppm)	Smell of ammonia is noticeable
70 mg/m^3 (100 ppm)	Irritates the nose and can give burning feeling in the eyes
200-350 mg/m^3 (280-400 ppm)	Tolerable up to 0.5-1 hour
1,200 mg/m^3 (1700 ppm)	Coughing causing and can result in severe damage by exposure less than 30 minutes
2,500-4,500 mg/m^3 (3,500-6,400 ppm)	Exposures at concentrations of can be dangerous to life at 0.5-1 hours of exposure.
3,500-7,000 mg/m^3 (5,000-10,000 ppm)	Concentrations on are fatal at short exposure time (10-15 minutes).

Sensitivity: Moderate

The probability of death is sensitive to the selected probit values.

Strength of knowledge: Moderate/High

Based on recommended values in /2/.

Belief in deviation: Low

Deviation is considered unlikely.

Reference: /1/ RIVM, 2017, 20170606-ammonia-interim, 6 June, 2017, http://www.rivm.nl/ /2/ DSB -Guidelines for quantitative risk analysis of facilities handling hazardous substances, Report no: 106535/R1 Rev: Final report, Rev A (English). Date: 6 May 2019		
Prepared by:	Sign: HAJOH/KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

A-12 Surroundings and obstructions

Ammonia bunkering QRA		**Date: 2021-01-05**
Assumption No.:	**A-12**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Surroundings and obstructions**	
Area concerned:	**All**	

Specification:

The DSB guidelines require that if one is to analyse a facility where one of the following characteristics applies, computational fluid dynamics (CFD) tools should be used to model dispersion:

- Terrain
- Large buildings
- Complex or large diffuse releases
- Release in congested areas
- Special scenarios

Alternatively, if empirical tools are used, one must describe uncertainties related to assumptions about conditions as mentioned above, and possibly how one has sought to compensate for such conditions.

The passenger vessel and the terminal acts as a physical barrier for potential hazards that might arise during bunkering. Also, a physical obstruction as big as a passenger vessel has an influence on the incoming wind, generating more turbulence etc. The risk modelling in SAFETI do not take this effect into account. All hazards and associated risks are calculated in a free field without any physical obstructions potentially hindering a gas dispersion.

In SAFETI, the height and density of the obstructions in the surroundings is partly accounted for by modifying the surface roughness length (see assumption A-10) and reducing release momentum by modelling impinged releases (see assumption A-04).

For this risk assessment of the conceptual bunkering operation, use of SAFETI is considered sufficient for the first screening of the concept. However, a large released amount of ammonia may disperse over a longer distance given the obstruction (due to the slower dilution of ammonia with air) compare to SAFETI dispersion results. Thus, for large/rupture cases, the consequences might be underestimated. For small/medium releases, the consequences generated by SAFETI are considered representative.

Sensitivity: Moderate

SAFETI assumes a free path for the dispersion, without any obstructions, which is regarded as conservative, apart from rupture scenarios and release of large inventories, which when obstructed are expected to preserve toxic concentration on longer distance. Possible vortexes or recirculation of the gas dispersion in between the vessels (for STS) or between ship and terminal (for TTS) are also not considered. It is expected this would result in more dilution if taken into account, resulting in smaller toxic effect distances.

For improved understanding of the gas behavior at the specific location, CFD analysis is recommended. It may also be required for final design assessment and permitting towards authorities. A 3D model of the surroundings can be developed in a CFD tool. For the STS and TTS bunkering operations, the characteristic dimensions of obstacles in the surroundings (e.g. the passenger vessel, the terminal and the bunker vessel) are as such that a vortex, recirculation or preferential direction for gas dispersion may occur. The CFD analyses could take such obstacle effects into account.
Strength of knowledge:
Belief in deviation: Moderate Potential underestimate of consequences related to dispersion simulation of large/rupture scenarios should be expected.
Reference:

Prepared by:	Sign: HAJOH	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

A-13 Bund properties

Ammonia bunkering QRA		Date: 2021-01-05
Assumption No.:	**A-13**	**Revision: A**
Category:	**A - Analytical**	
Subject:	**Bund properties**	
Area concerned:	**All**	

Specification:

The following bund specification is assumed for QRA application.

1. Bund around *pressurized storage tank* – bund design volume is assumed to be never overfilled. Rainout to occur inside the bund.

2. Elevated drain pits system along the *process pipe* connecting the storage tank with the loading arm – assume to limit the pool size by the size of the drainage system. The system is represented by the bund in Safeti and is assumed to be never overfilled. Rainout outside the bund is possible.

3. Drainage system *receiving manifold area* - assume to limit the pool size by the size of the drainage system. The system is represented by the bund in Safeti and is assumed to be never overfilled. Rainout outside the bund is possible.

4. The leak from the loading arm connection to the bunkering station on the passenger ship is considered to occur to water. The spill is therefore assumed being obstructed by the quay's and ship's structures. Bund overfill is possible. The rainout from the cloud is assumed to occur inside the bund on the assumption of jet being obstructed by the passenger ship's structure.

5. For the application to Concept 2, the release will be obstructed by the structure of bunker and passenger vessels. Thus, the pool on the sea will be limited to the opening between these two ships on the east and west and represented by the corresponding bund. Bund overfill is possible. The rainout from the cloud is assumed to occur inside the bund on the assumption of jet being obstructed by two (2) ship structures.

The bund physical size assumed for different area are summarized in Table 4-12.

Table 4-12 Bund dimensions defined in Safeti

Bund area	Height, m	Bund area, m2
Pressurized storage tank	2	500
Process pipe	0.1	300
Loading arm[15]	0.1	200
Receiving manifold	0.1	10

[15] Applied for spills to water from the loading arm bunkering leaks obstructed by the quay's structure and a passenger ship

Bund on the sea	0.01	3000

Sensitivity: Moderate

Limits size of the pool from the spilled ammonia.

Strength of knowledge: Moderate

Applied assumptions is based on general industry practice.

Belief in deviation: Low/Moderate

Considered unlikely.

Reference:

Prepared by:	Sign: KSEZAK	Date: 2021-01-05
Internal Verification:	Sign: GOUZY	Date: 2021-02-10

APPENDIX B
HAZID Log

Minutes of Meeting (MoM)

To:		**Doc No:**	10INAGHT-1 **FINAL**
Workshop participants		**From:**	Hans Jørgen Johnsrud
		Date:	2021-04-27
Copied to:		**Prep. By:**	Christine Krugerud
-		**Verified by:**	Hans Jørgen Johnsrud

HAZID OF AMMONIA BUNKERING CONCEPT OF PASSENGER SHIP IN PORT OF OSLO

Reading guidance to the HAZID Log

ID: A reference ID for the hazardous event.

Node: System or operation/process breakdown into manageable parts.

Guideword: Guidewords used to trigger discussions.

Hazardous event: Occurrence or change of a particular set of circumstances

Potential cause: The cause(s) of the event, i.e. hazards and triggering events that can lead to the hazardous event. If several causes relate to the same consequence, they are normally not listed in separate rows.

Potential consequence: The effect of the hazardous event.

Assumed safety measures: Safety measures assumed for the operation of the considered concept.

Possible additional risk reducing measures: Risk measures that should be considered, pending on the outcome of the QRA.

Assumptions and Limitations

- The performed HAZID, defined hazardous events and associated consequences are limited to the level of details available at this stage of the project. For definition of ammonia bunkering concept and assumed design parameters, the QRA Assumptions' Register should be referred to. For potential future updates in the concept definition, the performed HAZID analysis should be revisited.
- No risk rating has been performed since the major accident events will be quantified and assessed in the QRA.
- No responsibility or priority/criticality is assigned to the proposed additional safety measures. That is due to the early concept development phase of the project Additional safety measures should be considered based on QRA's outcomes.
- Assumed safety measures are based on experts' best industry knowledge. Due to the early concept phase of the project, the assumed safety measures may be revisited and updated at later project phase.
- This HAZID Log lies a basis for definition of QRA scenarios.

Notes:

- Passenger ship: Cruise ferry operating between Oslo and Kiel

HAZID date: 2021-01-26

Location: Online

Participants:

Simen Diserud Mildal (Sjøfartsdirektoratet)

Carl Jørgen Rummelhoff (Wartsila)

Gunhild Elin Bækken (Wartsila)

Roar Tverberg (passenger ship operator)

Karl Wisløff (passenger ship operator)

Heidi Neilson (Oslo Havn)

Carl Johan Hatteland (Oslo Havn)

Rob Stevens (Yara)

Ksenia Zakariyya (DNV)

Hans Jørgen Johnsrud (DNV)

Christine Krugerud (DNV)

Erlend Nervold Hanssen (DNV)

Linda Sigrid Hammer (DNV)

HAZID workshop log – Concept 1: Tank-to-ship bunkering

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
Node 1: Ammonia transport in port by truck (trailer, semi-trailer etc.)							
1.1	Impact	Truck collision with other port vehicles or fixed objects leading to loss of containment	- Port high activity level /high traffic density (cars, trailers, lift trucks, etc.) - Vehicle on the wrong course	Instantaneous high-momentum release of ammonia. Part of the ammonia will: - Rapidly flash - Create fine aerosol mist of the remaining liquid, which will remain airborne - Form a pool (also from rainout), parts of this will also evaporate.	- Dedicated traffic lanes with road marking - Speed restriction/traffic regulation - Truck requirements (e.g. impact loads) according to European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) - International Ship and Port Facility Security Code (ISPS) port regulations, incl. port entrance restrictions	- Consider performing the tank-filling operation during night-time, where traffic level is considered to be limited and limited presence of public in the area	- Pressurized tank transport assumed - Location: Hjortnes terminal - Loss of containment would require high impact energy (mass and speed)
1.2	Pressure	Overpressure, leading to lifting of Pressure Safety Valves (PSV) on truck tank	Pressure-build up in tank due to heat ingress, insulation failure etc.	- Limited duration of gas release from PSV	- Pressurized tank with sufficient 'holding time' - Monitoring of tank pressure and temperature in tank by truck personnel - ADR requirements (design pressure, tank insulation, pressure monitoring etc.)	- Consider specify truck parking and waiting positions in designated areas.	'- Opening of PSV only in emergency
Node 2: Truck-tank-connection and filling operation							

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
2.1	External leakage	Leaks in truck piping (in loading station/ manifold)	- Piping degradation internal or external (stress, material corrosion, fatigue, defects, etc.)	High-momentum release of ammonia. Part of the ammonia will: - Rapidly flash - Create fine aerosol mist of the remaining liquid, which will remain airborne - Form a pool (also from rainout), parts of this may also evaporate.	- Safety zone and ISPS - Gas detection (on truck and tank manifold) - Operational procedures - Visual monitoring - ADR requirements - Regular inspection and maintenance to detect material degradation - Fixed permanent lighting - Emergency shutdown (ESD) - Informing other operators and activities in port	- Apply best practice on filling procedures from other ammonia loading operations in populated areas (non-industrial sites). - Port and operator emergency preparedness plans to be updated for ammonia operations (inc. communication, evacuation, managing.	- There is also a safety risk if the filling operation procedures deviate too much from other operations in other places. Associated hazards should be considered. - Ammonia gas concentrations between 20 and 50 ppm are detectable by most people. This provides an adequate warning of its presence well below the hazardous concentration levels.
2.2	External leakage	Leak in flexible hose or coupling	- Wear and tear - Fabrication error - Incorrect coupling connection (technical or human error)	See consequence description above	See safety measures above, in addition: - Quick Connect Disconnect Coupling (QCDC) - Hose certification - Hose inspection prior to use		
2.3	Breakaway	Truck breakaway	- Inclined ground - Truck brakes failure	See consequence description above	- Truck hand brakes shall be kept applied and the wheels at both ends of the truck shall be blocked. - No inclined parking in port		

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
2.4	External leakage	Leak in tank manifold station piping	- Piping degradation internal or external (stress, material corrosion, fatigue, defects, etc.)	See consequence description above	- Safety zone around filling operation and ISPS - Gas detection - Hazardous zone and EX equipment -Regular inspection and maintenance to detect material degradation -Water curtain wall		
2.5	Overfilling	Overfilling of storage tank	Technical and/or human failure	See consequence description above	- High and high-high tank level alarms - ESD automatically activated on high-high level	- Responsibilities during the filling operation to be clarified (use best practice from other similar operations), incl. monitoring of tank level and pressure.	
Node 3: Specific risks if filling shore tank from ship instead of truck							
2.6	External leakage	Loss of containment	Technical and/or human failure	See consequence description above	Assumed safety measures similar to ship-to-ship transfer /bunkering concept 2	- For input to further concept development, consider how similar operations are carried out on other locations.	Assumed pressurized liquified ammonia will be delivered from the bunkering vessel @ operating pressure of 5 barg.
2.7	Temperature	Transfer of cold ammonia to warm tank	Transfer of ammonia from refrigerated state to pressurized tank	Tank exposure to cold ammonia. Possible hydraulic shock effect.	Handling of cold ammonia according to best practice	- Consider storage tank to be designed for applicable ammonia temperatures (incl. refrigerated ammonia, not only pressurized)	Additional systems will be required for heating up ammonia before entering the pressurized storage tank onshore
Node 4. Ammonia storage in tank on land							
3.1	External leakage	Tank leak or rupture	- Internal degradation: Ammonia Stress Corrosion Cracking (SCC), cracks being formed in carbon steel in contact	High-momentum release of ammonia. Part of the ammonia will: - Rapidly flash - Create fine aerosol mist of the remaining liquid, which will remain airborne - Form a pool (also from	- Tank "leak before rupture" analysis - Gas detection - Nitrogen (N2) purging to prevent air getting into the ammonia system - The European Pressure Equipment Directive	Ongoing port developments plans should consider bunkering of alternative fuels for ferries to Denmark and Germany, as well as cruise ships. These operations may contain low flashpoint fuels and toxic	- Placement of tank need to be in accordance with Quantitative Risk Analysis (QRA) of actual design and operation, as required by DSB.

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
			with ammonia due to presence of oxygen (air) and residual stress - External degradation: External corrosion	rainout), parts of this may also evaporate.	- Regulation to prevent major accidents in activities involving dangerous substances ("Storulykkeforskriften") - Coated/painted on outside surface to protect against external corrosion - Assume C-type pressure tank, which is designed not to leak (strict design and stress analysis requirements)	materials. Valid for tank-to-ship, truck-to-ship and ship-to-ship operations. - Bund to collect spill	- Risk contours from tank will define what type of buildings that can be built in the area (in relation to distance to tank) - Ongoing port developments plans for ferry terminals and developments for the Filipstad area ('long term')
3.2	Pressure	Overpressure, leading to opening of safety valves on tank	Failure of insulation, tank heat ingress	See consequence description above	- Pressure Relief Valve - Pressurized tank, can handle a certain pressure rise		- Operating pressure in line up to 15 bar for tank to ship bunkering.
3.3	Fire/ explosion	Fire/explosion in other areas in port affecting the ammonia storage tank	Combustible materials	In case of strong fire source exposing the pressurized storage tank, followed by gas expansion and lifting of tank pressure valves.	Tank Design Temperature: - 40 °C / + 50 °C	- Investigate design pressure and temperature on land storage tank compared to maritime requirements, to ensure operation from tank to ship is able to handle all foreseen pressures and temperatures.	
3.4	Impact	Tank rammed by other vehicles	Port traffic	See consequence description above	- Fenced off to make it inaccessible to the public and other transport (Safety zone, ISPS) - Physical 'crash barrier'		
3.5	Terror	Terror and sabotage	Deliberate action	See consequence description above	ISPS		
3.6	Blackout	Blackout in area/terminal	Electrical failure	- Given pressurized C type tank with design pressure of 18 bar; good holding time (can passively keep the pressure) and no immediate safety consequences.	C type tank	- If atmospheric tank or a tank that depends on systems and equipment required to actively ensure required temperature or sufficient pressure, redundancy in power input will be needed. - Burning boil-off gas	- For information: refrigerated and atmospheric tank, can potentially have risks related to lack of refrigeration

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
Node 5. Above-ground supply piping and supporting structure from tank to ship (during bunkering), piping from tank to loading arm, including pump							
4.1	External leakage	Pipeline leaks	- Leak from connections -Oxygen ingress External piping degradation: - External corrosion on piping - External corrosion under pipe clamps and at welded joints - Corrosion under insulation Internal degradation: - Stress corrosion cracking (SCC) - Pressure waves	High-momentum release of ammonia. Part of the ammonia will: - Rapidly flash - Create fine aerosol mist of the remaining liquid, which will remain airborne - Form a pool (also from rainout), parts of this may also evaporate.	- Carbon / low temp carbon steel pipelines are normally painted on the outside surface to protect against corrosion - Regular visual inspection of pipelines, incl. welded joints, clamps, isolation valves, TRVs, etc. - Regular wall thickness measurements - All elements in the pipeline (valves, flanges and gaskets) will be suitable for the maximum allowable operating pressure - Gas detection at loading arm, on tank / tank manifold and in bunker station - ESD linked to gas detection, and shutting down the bunkering operation - Pressure testing after commissioning - The European Pressure Equipment Directive requirements - Regulation to prevent major accidents in activities involving dangerous substances ("Storulykkeforskriften") - Pipeline pressure monitoring - Flow monitoring - Samtykkepliktig operasjon (DSB)	- Consider best practice regarding; corrosion protection of pipeline, supports clams etc. - Consider regular pressure testing of pipeline - Consider type of ammonia sensors for optimal leakage detection, also considering low concentrations relevant for the protection of people - Consider material quality suitable for marine environment - Consider optic fiber based on temperature variations - Consider to purge by nitrogen after bunkering operation. - Consider emergency handling / leak handling (e.g. water curtain and placement according to credible leak points) - Consider to carry out a leak/integrity testing of the bunkering system/line prior to initiating bunkering in order to detect potential leaks. - Investigate guidelines and procedures from other locations where similar operations are carried out. - Consider carrying out 'Procedure HAZOP' of the proposed loading and bunkering operation checklist/procedure.	There are basically three commonly used types of ammonia sensors: - The electrochemical type - The solid-state type - The infrared type Use carbon steel with low or no nickel, no copper Piping and manifold exposed to marine environment Welded connections along the pipe to be confirmed. For QRA application, flanged connection is conservatively assumed.

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
4.2	Impact	Rammed by other vehicles in the port	Technical or human error	Loss of containment is expected if vehicle large enough to directly expose the pipeline and/or weight and mass of the vehicle can generate a collision energy impact sufficient to damage the pipeline support structure followed by the loss of support and pipeline's integrity.	Pipeline marking/labelling at regular intervals and warning signs w/ emergency telephone number - Road marking, designated traffic lanes and parking area in port - Pipeline is assumed elevated 2 m above ground	- Consider elevating the pipeline certain meters above ground and consider the dimensioning of supporting structure to account for energy impact, to account for potential vehicle impact.	- Port development currently ongoing. - Potential collision impact from cars is expected to damage the pipeline support structure. The extent of consequences is a function of vehicle size and weight combined with vehicle travel speed.
4.3	Impact	Rammed by ships or ship equipment/ operations (mooring line snap etc.)	Technical or human error	As per scenario 4.1	Ship-port/terminal compatibility assessment		
4.4	Stability	Ground/jetty movement (instability)	Landslide, flooding	Loss of structural integrity followed by loss of containment	Port regulations and risk assessments		
4.5	Stability	Structural failure of piping support	Material degradation (corrosion, cracks)	- Piping/equipment damage - Most likely no loss of containment	- Remaining support strength when one support fails - Regular inspection and maintenance		
4.6	Dropped object	Dropped object on piping	- Construction activity in area - Objects falling from the ship	Loss of containment (See above)	- Piping clearly marked - Lifting restrictions in port over ammonia-containing equipment	- Consider prohibiting all lifting operations on the ship above the bunkering area, and/or consider mechanical dropped-object protection	

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
4.7	Trapped liquid	Ammonia trapped in an isolated section of a line/segment, e.g. between two closed valves.	- ESD activation - Closing valves	Ammonia, like most liquids, expands when heated.	Design pressure of pipeline	- Investigate if it is possible to design the piping with sufficient design pressure (accounting for expansion pressure) to avoid the need for Thermal Relief Valve (TRV). - If TRV needed to protect against over pressurization due to thermal expansion of pipeline, consider to route back to the tank. - Investigate of any trapped liquid should be accepted.	- Guidelines developed by major EU producers show that thermal relief valves are to be provided to sections of a pipeline that can be blocked in with more than 50-100 liters of liquid ammonia
Node 6. Loading arm (during bunkering) and piping in bunkering station (during bunkering)							
5.1	External leakage	Leaks	Technical or human failure	High-momentum release of ammonia. Part of the ammonia will: - Rapidly flash - Create fine aerosol mist of the remaining liquid, which will remain airborne - Form a pool (also from rainout), parts of this may also evaporate. Gas may be trapped in confined or semi-confined space, may lead to ignition and explosion (e.g. if trapped in road tunnel under passenger terminal, or trapped in/under vehicles)	- Provision of a cable connection between ship and shore to enable the closure of ESD valves remotely from the land as well as from the ship - Manual activation of ESD, or ESD based on gas detection - Breakaway system - Bunkering procedures - PPE - Process monitoring - Drip tray in bunker station	Consider strategies for lowering the concentration of ammonia gas/vapour in air, e.g. by water screens or water curtains set up in the path of a travelling plume. The water screens should be placed between the release point and the threatened area (e.g. terminal). - Consider bund for spill containment in loading arm area -Drain pits for spilled ammonia	- Similar concepts as other locations with LNG, e.g. Halhjem (5-6 ferries) - can utilize experiences from these operations. Check relevant risk analyses, guidelines and procedures
5.2	Icing	Environmental conditions rendering loading arm non-functioning	- Weather conditions - Potential icing	Blacked control air, freezing of equipment etc.	All safety systems should fail to "safe state"		

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
5.3	Impact	Vehicles/trucks ramming loading arm or dropped objects	- Other activities at the terminal	- Damage to loading arm - Ammonia leaks	Crash barrier		
5.4	Breakaway	Ship drifting	- Mooring line failure - Extreme weather conditions	- Excessive forces on loading arm - Damage to loading arm - Ammonia leaks	- Tension monitoring and activation of Emergency Release Coupling (ERC), with 'dry disconnection'. - ESD prior to activation of ERC - Tension monitoring on shore power connection and gangway (smaller margins compared to loading arm) - SIMOP analysis requirement (water, passenger handling, car loading/offloading, proviant loading, shore power connection, etc.)	- Ensure overpressure and ventilation, to avoid ammonia gas entering the passenger ship (similar to current procedures in cold conditions to prevent cold entering the ship) - Ensure to close off passenger deck (on the bunkering side) during bunkering - Establish weather restrictions for carrying out bunkering operations.	- Gangway is weather protected, but open to deck. Not mechanically ventilated.
5.5	External leakage	Leaks in bunkering station	As per scenario 5.4	As per scenario 5.4			
5.6	SIMOP	Shore power connection, may be source of ignition	Need for shore power	Ignition of flammable gas	- SIMOP analysis requirement (drinking water, passenger handling, car loading/offloading, proviant loading, shore power connection)		
5.7	Damage	Hydraulic shock		Pipeline damage and gas release		Further investigate risk related to hydraulic shock (water hammering and/or rapid evaporation)	
Node 7. Fuel tank on passenger ship (during bunkering)							
6.1	Overfilling	Overfilling	Technical and/or human error	Ammonia spill from vent mast (worst case)	- In principle similar safety barriers as for LNG/LPG operations (according to applicable regulations) - Filling curves - ESD	- Consider designing a solution that prevents any overfilling to be released to and from the vent mast (e.g. overfilling tank and drain arrangement). To be considered in ship's risk	

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
						assessment. - Alternative Design process and approval for ship, according to IGF Code, incl. risk analysis.	
6.2	Venting	Venting of an ammonia and nitrogen mix during normal operations	- Start and stop of the engines - Purging	Release of ammonia via vent mast		- Venting of ammonia during normal operations should be avoided. Concept to be developed.	Closed loop scrubbers for cleaning the ammonia gas (e.g. using citric acid) commercially available.
6.3	External leakage	Tank leakage	- Tank defects	Continuous ammonia release	C-type tank, designed not to leak		
6.4	Temperature	Tank temperature increase	Exposed to heat	Pressure increase, lifting of safety valves	- Tank location, stable temperature and atmosphere, insulation, passive fire protection		Systems should be in place to ensure low temperature in the tank
6.5	Pressure	Overpressure in tank	Exposed to heat	Pressure increase, lifting of safety valves	- As opposed to LPG and LNG, it will be required to have ~infinite holding time for NH_3. Tank to be designed for maximum ambient temperature (45°C). This means that the tank should have a design pressure of 18 barg.	- System to be designed to avoid lifting of PSVs during bunkering, considering temperatures, pump pressure etc.	
6.6	Impact	External impact damaging the tank	- Mechanical impact (RoRo activities) - Dropped objects - Ship collision	Continuous ammonia release	- Location of tank		
6.7	Roll-over	Roll-over	- Warm ammonia (temperature difference)	- Rapid release of large amount of vapor leading to potential over pressurization of the tank	- Continuous use during operation		- Not very relevant for fuel tank

HAZID workshop log – Concept 2: Ship-to-ship (STS) bunkering

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
Node 1: Cargo tank on Bunker Vessel (during bunkering)							
1.1	External leakage	Tank leak or rupture	- Internal degradation: Ammonia Stress Corrosion Cracking (SCC), cracks being formed in carbon steel in contact with ammonia due to presence of oxygen (air) and residual stress - External degradation: External corrosion	- For spills with refrigerated ammonia the release is at its boiling point and when released there will be no immediate evaporation of ammonia. Ammonia will fall to ground generate a pool at -33.4°C which will spread and gradually evaporate by heat transfer from ground. - No pressurization of the tank, thus when a release happens the ammonia is forced out by gravity only.	- Tank leak before break/ rupture analysis - Gas detection - Nitrogen (N2) purging to prevent air getting into the ammonia system - Coated/painted on outside surface to protect against external corrosion - C type tanks designed not to leak - A or B tanks have secondary barriers		A or B type tanks can in theory leak, but should have a full or partial secondary barrier, respectively. - STS bunkering location: Hjortnes terminal
1.2	Fire/ explosion	Fire/explosion due to other non-ammonia related fire incidents onboard (compressor room, technical rooms, switchboard room etc.)	Emergency situation onboard one of the vessels, e.g. Fire/explosion in engine room, accommodation or other parts of the vessels	Heating of cargo tank leading to increased pressure Tank rupture	- Active and passive fire safety system onboard - Separation distances		
Node 2: Bunkering system on Bunker Vessel (during bunkering), including bunker hose							
2.1	External leakage	Leaking connections or parts of bunker system	Technical malfunction of equipment or human error (fabrication error, wear and tear of flanges, couplings, reducers, etc.)	- Release of refrigerated ammonia on the sea water surface - Ammonia is highly soluble in water, but there will be some evaporation.	- Gas detection in bunker station - Operational procedures - Hazardous zone and EX equipment - Emergency Shutdown (ESD) system - Drip tray (designed for cold temp)		- Pressure in bunker line can vary from atmospheric up to 5 bar.

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
2.2	External leakage	Leaking transfer hose or coupling	- Fabrication error, wear and tear - Hose bending radius out of allowable limits	- Release of ammonia.	See above - Hose certification - Hose inspection prior to use - Emergency Shutdown (ESD) system		
2.3	Relative motions	Vessel breakaway or large movements of the vessels alongside due to excessive relative motions	- Wind, waves, vessel ballasting, tide, current, surge from passing vessels, etc. - Weather suddenly deteriorates (weather and/or sea conditions exceed the limitations) - Inadequate mooring, mishandling of mooring lines - Loss of stability / buoyancy (excessive list / trim, ballast failure)	Activation of ERC should ensure no release	- Mooring analysis and arrangement - ESD and ERC - Vessel Separation Detection (VSD) system, with predefined limits.		
2.4	Impact	External vessel colliding with the bunker vessel and/or bunkering hose	Navigational error	Activation of ERC should ensure no release	- Safety/exclusion/security zone around bunkering operation, restricting traffic - Speed limits - Watchkeeping and manual activation of ESD - Limited traffic in area, mostly pleasure crafts		In case the operation will be carried out in a different location, with a higher density of traffic ships, a separate navigational risk assessment should be carried out.
2.7	Dropped object	Dropped objects	Technical malfunction or human error	- Release of ammonia.	- Gas detection in bunker station - Operational procedures - Hazardous zone and EX equipment - Emergency Shutdown (ESD) system - No lifting operations above bunkering area		

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
2.8	Venting	Venting of an ammonia and nitrogen mix during normal operations	- Start and stop of the engines - Purging	Release of ammonia via vent mast		- Venting of ammonia during normal operations should be avoided. Concept to be developed. - Burning of gas (burner)	Closed loop scrubbers for cleaning the ammonia gas (e.g. using citric acid) commercially available.
Node 3: Bunker Station on passenger ship (during bunkering), including bunker line							
3.1	External leakage	Leaks in bunker station / loading manifold piping	- Piping degradation internal or external (stress, corrosion, material defects, etc.)	- Release of ammonia	- Gas detection in bunker station - Operational procedures - Hazardous zone and EX equipment - Emergency Shutdown (ESD) system - Line cool-down before transfer operation		
3.2	External leakage	Leak in hose coupling (QCDC)	- Wear and tear - Fabrication error - Incorrection coupling connection (technical or human error)	- Release of ammonia	As per scenario 3.1		
3.3	Stress	Thermal stress		Cracks	Tank and piping cooled down slowly in order to minimize thermal stress		
3.4	Damage	Hydraulic shock (in bunker line)	-	- Liquid hammering (rapid condensation and pressure drop)		Further investigate risk related to hydraulic shock (water hammering and/or rapid evaporation)	
3.5	Trapped liquid	Ammonia trapped in bunker line, e.g. between two closed valves.	- ESD activation - Closing valves	Ammonia, like most liquids, expands when heated. - Corrosion if in contact with water			
3.6	Other	In case of heating of the ammonia to ambient (in – hull)	Technical failure	Thermal shock due to rapid collapse of the fuel tank vapour pressure. A liquid column will move fast from the bunker vessel to the			Outside scope of QRA (due to failure downstream ESD bunkering valve) but included as it is a relevant for scenario to be considered during

ID	Guideword	Hazardous event	Potential causes	Potential consequences	Assumed safety measures	Possible additional risk reducing measures	Comments
		temperatures onboard: Failure of heating medium supply or failure in activating the supply		receiving vessel if this happens.			bunkering.
Node 4. Ammonia fuel tank on passenger ship							
Hazards are similar to node 7 on Tank-to-Ship concept							Assumed C-type tank, design pressure 18bar, may also be used for containment of cooled ammonia

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